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A ZigBee Position Technique for Indoor Localization based on Proximity Learning

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***Abstract* - In this paper, a new method of position along with node teaching and placement is proposed. Different from the traditional triangulation position, the proposed method employs a faster computation technique with special proximity learning and placement, which leads to reduced computational time. In position computation, the received signal strength indication (RSSI) values from ZigBee CC2431 modules (by Texas Instruments) were processed. The simple and efficiency position technique can be extended to many applications; for example, the handover mechanism for reference node, position using WSN protocols like Wi-Fi and Bluetooth, and basic indoor navigation.**

Index Terms - Wireless Sensor Network (WSM), ZigBee, Indoor Localization, Reference Node (RN), Blind Node (BN), Positioning Algorithm (PA).

I. INTRODUCTION

Wireless Sensor Network (WSN) is used of distributed autonomous operation nodes, through the network to monitor changes in physical or environmental factors, such as temperature, sound, humidity, vibration, pressure, movement and pollution. Recently, it has been widely used in many applications. For example, in the application of biological information, the sensor can be set in the habitat, the habitat of plants, long-term collection of animal or plant information for scientists or government units to analyze, research and monitoring of biological health and the environment variety. In the disaster relief application, the sensor can be deployed in the disaster area, real-time and dynamic detection of environmental changes and disaster relief personnel trends, and the sensor can be used as a relay point control equipment relay point [1]. Recently, this WSN technology has also been widely used in industrial and consumer products, such as the monitoring and control of industrial manufacturing processes, the normal operation of the machine detection. Therefore, the application of WSN, in our daily life gradually becomes more and more important [2-4].

This article is to explore the spatial positioning technology; the GPS technology is most commonly usage of positioning technology. We adopted the GPS to combine the Wi-Fi which used the search near the entire MAC Address signal, to get enough information to calculate the exact location. However, GPS technology has large power consumption, large volume, and unsuitable for the indoor environments. In addition, the Wi-Fi is also large power consumption for the communication mechanism. For this reason, we chose the 802.15.4 / ZigBee technology, it was low cost, low power consumption, small size, and easy to deploy, etc., it is very suitable for short-range wireless transmission system [5].

In this design, the WSN is composed of many sensor nodes with wireless communication function, they also combine with a convergence node of integrated information packets, together constitute the network system. The main function is to collect the necessary information for the sensor within the acceptable range of the network, and sends the data to the confluent node through wireless transmission, and then connects the sink node to the server. The host computer can analyze the data, and then gives an immediate monitoring message.

In order to save the transmission energy between network nodes, the structure will try to shorten the transmission distance. According to the characteristics of the system design requirements, the transmission distance between the nodes is about several meters to tens of meters, when the sensor distance from the sink node is too far, may not be able to directly transfer data, this time the transmission can pass through the closer nodes, the message is sent for the multi-hop way. Because the node cost is very low, so they can deploy a large number of to achieve a wide range of detection and transmission purposes.

II. THE ZIGBEE'S WSN

A. The ZigBee

For short-range wireless control, monitoring, data transmission technology requirements, available technologies are 802.11, Bluetooth, Home RF, and etc., these technologies have their own advantages, but there are still such as power consumption, poor organizational network capacity and other disadvantages.

In order to obtain better wireless transmission techniques, Honeywell ZigBee Alliance [6], they developed ZigBee technology since 1998, and the Institute of Electrical and

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Electronics Engineers (IEEE) Associations proposed into the IEEE 802.15.4 standard specification in 2001. Since then, ZigBee technology has become one of the common low-speed short-range wireless communication technologies [7].

ZigBee contains two different specifications, one is ZigBee, and the other is the IEEE 802.15.4 standard, which is developed by the IEEE Association [8]. ZigBee is defined by the ZigBee Alliance, which defines the profile of the network layer, the security service provider layer, the application layer and various application products. The IEEE 802.15.4 standard defines the PH3 layer and the MAC Layer, Fig. 1.

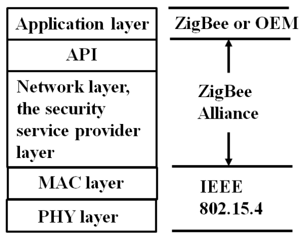

Fig. 1: ZigBee wireless communication protocol stack.

The IEEE 802.15.4 standard specifies two physical and direct sequence spread spectrum (DSSS) physical layer bands: they are 868 / 915MHz bands and 2.4GHz band, respectively. The physical layer in the 2.4GHz band can support a transmission rate of 250 kb/s in the air, the solid layer in the 868/915 MHz bands support 20 kb/s and 40 kb/s transmissions rates in the air. Due to packet procedures and processing delays, the actual data rates will be less than the specified bit rate. The IEEE 802.15.4 is clearly defined as a protocol standard for supporting low-rate, low-power, short-range wireless communications in terms of radio frequency, data rate, data transmission model, device type, network work mode, security and so on. At the same time, the protocol model is divided into two layers: the physical layer and the media access control layer.

The ZigBee can use the main bands have three, respectively, they are 2.4GHz ISM band, 915MHz band, and 868MHz band. The channels that can be used in different bands are 16, 10, and 1 respectively. The ZigBee transmission rates are operated between 20kbps to 250kbps, it is different with the use of different bands, and with the transmission distance is slowed down.

At present, there are many methods of wireless positioning technology has been put forward, for example, in 2014, Wang proposed a method of image interpretation to assist in the orientation of space [9], Li using omni-directional imaging technology to help identify direction and location in 2015 [10], in 2016, Lima proposed a radar sensing mode for the calculation of position and direction [11], and so on. These positioning technologies have its advantages respectively; however, there are some problems and obstacles to achieve the factors. So, we want to use a low cost, simple method, there will be no large energy loss, deployment configuration can be relatively simple method. Then, we selected ZigBee's technology, which Texas Instruments successfully developed the ZigBee CC2431 modules, it is a simple module, the module is consistent with our low-cost space positioning technology requirements.

B. *The ZigBee CC2431 module*

The wireless positioning mesh system is made up of the ZigBee CC2431 chip, it can be constructed with 3 to 12 (up to 16) RNs, and can constitute a maximum area of 64 × 64 square meters of wireless positioning network space. This wireless positioning mesh system, is the reference node arranged in space around, constitutes a wireless positioning network. The operation of the system is between the reference nodes, the system follows out the 802.15.4/ZigBee wireless communication standards, and keeps the wireless signal contact and communication, and then system may run through the PC side of the system software calculations. Then, you can calculate all the reference nodes of the wireless parameter configuration, to get the calculation result of the positioning parameter.

The CC2431 module's positioning algorithm is based on the received signal strength indicator (RSSI) value. This RSSI value will be weakened as the distance increases. Fig. 2 shows a simple system for positioning detection. Among them, the use of two types of nodes:

1. Reference node (RN): The RN is a static node at a known location. The node knows its own location and can tell the relationship information of the other nodes when requested. The RN does not need to perform the positioning detection of the hardware; it does not perform any calculations at all. It must be configured with X and Y values to correspond to the corresponding physical locations. The main task of the RN is to provide references X and Y coordinates to the blind node and also as anchor nodes.
2. Blind node (BN): The BN is a node established on CC2431. The node collects signals from the responses requested by all RNs, it collects the X, Y, and RSSI values for each of these nearby nodes, and uses the positioning software system to calculate its own position data based on the received parameters. The calculated position data will be sent to a control station. This control station can be either a PC or another node in the system. The BN must use the CC2431 module.

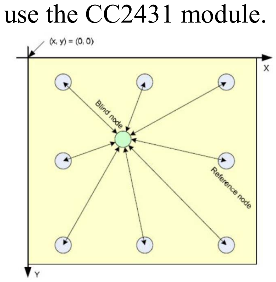

Fig. 2: Positioning estimation diagram.

The information sent from RN to BN, at least, it contains the coordinate parameters of the RN with the horizontal position X and the vertical position Y, where the RSSI value can be calculated from the receiver, i.e. the blind node. The main characteristic of the positioning system calculus mechanism can be performed by each BN. So this algorithm is a distributed structure, this feature reduces the total amount of data transmission in the network.

C. *The Positioning Algorithm*

This positioning algorithm (PA) is used to estimate the location of nodes in a point-to-point wireless network. The coordinates of the RNs are known. The other nodes are the BNs that need to be estimated the coordinates. These BNs are often moved or attached to items that need to be tracked. The PA is using a received signal strength value which is received from the known RNs to perform a decentralized calculation. The usage of nodes decentralized PA is to avoid the large number of network transmission problems which it is caused by centralized computing methods. The PA has the following main features:

1. The PA requires 3-16 reference nodes.
2. The PA is in 0.25 meter units.
3. To calculate the node position to consume from 50us to 13ms.
4. Positioning range is 64 × 64 square meters.
5. The lowest CPU usage can be used to perform the positioning estimate.

The PA expects to get the best accuracy calculation results; it must to use the same characteristics hardware nodes, they include the radiation signal transmission module that has similar characteristics. The estimated positioning error depends on the signal environment differences. A given range of RN should be validated for its layout format and RN density. In general, estimation have more available RNs, it can improve the accuracy of the PA.

The procedure for locating the PA is to acquire the basic set of values which are a set with three to sixteen reference coordinates as a common input. That is, the result obtained from the PA is the result of the estimation of the coordinates. Before writing any input data, the program should be able to locate the calculus program by writing 1 to LOCENG.EN. When you want to stop the PA execution, you should write 0 to the LOCENG.EN to close the clock signal and to turn off the program. Fig. 3 is the PA operation procedure.

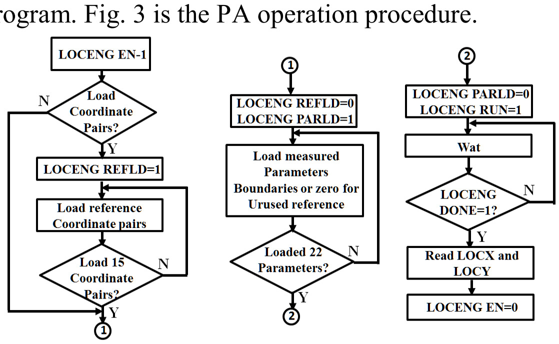

Fig. 3: The PA operation procedure.

III. Wireless positioning Method

A. *Reference coordinate input*

The positioning system needs to enter a set of 3-16 RN's coordinates [x0, y1, x1, y1,···, x15, y15] at the beginning. The RN's coordinates are in meters, they indicate the position of each RN which is an unsigned value in the interval (0, 63.75) meters. The highest precision is 0.25 meters. The format is fixed point data which is the lowest 2 bits representing of the fractional part and the remaining 6 bits representing of the integer part. Therefore, the number 63.75 is expressed as 0xFF.

The system registers the RN's coordinates in the RF register (REFCOORD). Before writing to REFCOORD, the scratchpad address (LOCENG.REFLD) must be written to 1 to indicate that a set of RN's coordinates will be written. Once the RN's coordinate writing process starts (LOCENG.REFLD = 1), the 16 pairs of RN's coordinates must be written once.

However, it is also possible to calculate program using less than 16 RNs coordinates, at this time it will mark the RNs coordinates for the unused. In addition, the system uses 0 to fill in unused RN coordinates. For unused RN coordinates, when they are written as RSSI values, they will be considered unused. The RN coordinates must be written to the register (REFCOORD) in the order of [x0, y1, x1, y1,···, x15, y15]. When all coordinates are written, the register (LOCENG.REFLD) is written to zero.

B. *The received signal strength indication (RSSI)*

The CC2430 / 31 module receives the transmission data packet, it will automatically add the RSSI value to the data packet. The RSSI value is the average of the eight symbol periods (128us) starting from the data packet of the reception signal. The RSSI value is represented by a byte, which is a signed binary complement, Fig. 4. An information packet is read from the FIFO of CC2431 module, and the last second byte contains the RSSI value, which is measured after receiving 8 symbols of the actual data packet. The RSSI value can also be obtained at the same time as the received data packet. At this time, the RSSI value will reflect the strength of the received signal, and it is not necessarily the signal strength of the received data. This situation is likely to be a large number of node data at the same time or in the same channel for interactive processing, so the capture of the RSSI value is wrong.

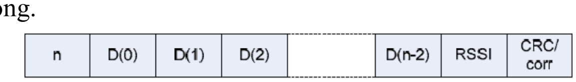

Fig. 4 : CC2430 / 31 module data packet format.

The CC2431 / 31 modules contain a RSSI scratchpad. The register can hold the aforementioned value, but when it receives a data packet, it does not lock the value, so the register value cannot be used for further calculations. The RSSI value that is locked, it is only considered to be the correct RSSI value when the data is received and it is associated with the received data. The RSSI value is expressed as a binary complement. The value cannot be read directly as the received signal strength. It is necessary to convert the received signal strength of the actual read value, must be added with a compensation value. This compensation value is given in the CC2430 / CC2431 module data sheet, the data is approximately -45. In addition, the compensation value also depends on the actual configuration of the transmission hardware [12]. The laboratory measurements show that the RSSI values measured by the module which is matched well with the signal input power. The linear curve as a comparison of the input power with the RSSI value can be seen in the CC2430 module manual, Fig. 5.

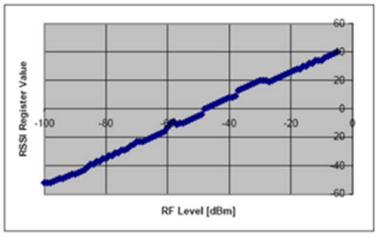

Fig. 5: The contrast between the typical RSSI value and the input power.

C. The Signal propagation calculation

The received signal strength is a function of the distance between the transmission power of the transmitter and the receiver.

D. RSSI= • (10nlog10d+A) (1)

Where

n: Signal propagation constant, also known as propagation index.

d: distance from the transmitter.

A: Received signal strength at a distance of 1 meter from the transmitter.

It can be seen from the formula that the received signal strength will decrease as the distance increases. In the calculation, A is an empirical parameter; it is defined as dBm with the absolute value of the signal strength which is received at a distance of one meter from the transmitter. It is determined by measuring the RSSI value from a meter transferred unit. The expected parameter A of the PA will fall within the range (30.0, 50.0) with an accuracy of 0.5. The parameter A is given using unsigned fixed-point values, the least significant bit is the first decimal place, and the rest is the integer bits. A typical value of A is 40.0.

Theoretically, all values in the direction should be equal. The transmission modules on the transmitter and the receiver are unlikely to have exactly the same radiation characteristics, they are appropriate to use A for the use of the mean. Fig. 6 shows the typical RSSI values which are measured at a distance of one meter from the transmitter. The figure shows the measured values from the P0, P1, P2, P3 positions in Fig. 7. From the figures, the radiation difference of the transmission module can be obtained, so A is used as an average value as a parameter. The average value of the equipment used in this test is approximately -46. The measurements are based on RSSI_OFFSET equal to -45.

Fig. 8 shows how an error value of parameter A affects the position calculation of the BN. The figure does not show which value A is most correct. The rhombic display uses different parameters A, where the BNs calculate the different positions, and the relative X and Y are also different. Usually, in the indoor environment, value A between (45 ~ 49) can give more accurate results. In this example, when the actual position is (22, 26), the position was calculated using the value A between (46 ~ 49), it is approximately (22, 28).

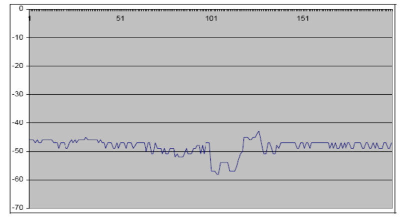

Fig. 6: The RSSI values are measured at distances of 1 meter.

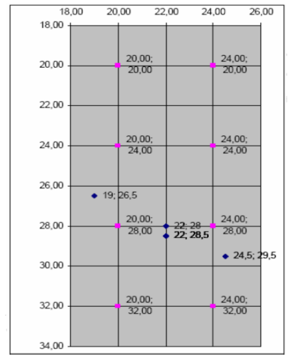

Fig. 7: The effect of parameter A on position calculation.

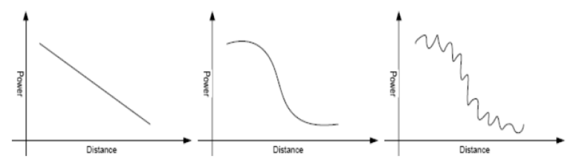

Fig. 8: The comparison of theoretical RSSI values with measured RSSI values.

Another parameter n is defined as the path loss index. It indicates the rate at which the signal energy decays as the distance to the transceiver increases. The value of parameter n depends on the environment, such as the thickness of the wall which it will cause a greater impact. The value can be determined by the empirical value. The parameter d is the distance between the transmitter and the receiver, and the parameter d attenuation is proportional to the parameter n.

The PA in the CC2431 module does not use parameter n directly, but rather uses a value called n_index. The relationship between parameter n and n_index can be found in Table I. This conversion table is used to reduce the complexity of actual hardware execution.

TABLE I

THE N AND N_INDEX.

n_index	N	n_index	N	n_index	N	n_index	N
0	1.000	8	2.375	16	3.375	24	4.375
1	1.250	9	2.500	17	3.500	25	4.500
2	1.500	10	2.625	18	3.625	26	4.625
3	1.750	11	2.750	19	3.750	27	5.000
4	7.875	12	2.875	20	3.875	28	5.500
5	2.000	13	3.000	21	4.000	29	6.000
6	2.125	14	3.125	22	4.125	30	7.000
7	2.250	15	3.250	23	4.250	31	8.000

The RSSI average can be obtained from the selected RNs to request data packet to do a simple calculation. The average of each RSSI can be calculated according to the following formula:

$$\overline{RSSI} = \frac{1}{n}\sum_{i=0}^{i=n} RSSI_i \quad (2)$$

Smoothing RSSI values can be achieved by filtering methods. Two common filtering methods are average filtering and feedback filtering. Average filtering is the most basic type of filtering, but it requires more data packets to be sent. The feedback filtering uses only the most recent RSSI value for each calculation and it sends less information, but increases the waiting time when a new position is to be calculated.

If approximate filtering is used, the following method can be used. In this equation, the typical value of the variable a is 0.75 or greater, which the value ensures that the large difference in the RSSI value is smoothed. The following formula is not recommended which the tracked node moves at a greater distance between each calculation.

$$RSSI_n = a \times RSSI_n + (1 - a)RSSI_{n-1} \quad (3)$$

Fig. 9 shows the figure from left to right; the first diagram shows the theoretical RSSI value. The second diagram shows a slowly changing component. The third diagram shows a rapidly changing component, such as the effects of multipath components. The third diagram shows the signal closest to the real situation. These diagrams are used to indicate some problems when using RSSI values to calculate positions [13].

IV. WIRELESS POSITION METHOD

The wireless positioning system in accordance with the need of the collected information can be divided into two different, respectively. One is the Range-based, and the other is Range-free [14]. The Range-based positioning method needs to rely on the signal source and the receiver between the absolute distance or angle and other information obtained. Each node can use Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), or Received Signal Strength Indication, RSSI) and other methods, calculate the coordinates of the blind node position.

The Range-free positioning method does not need to consider any time, angle or transmit power. In most methods, the unknown node simply gathers information that is broadcasted by the known RN's coordinates to achieve the purpose of positioning. This method eliminates the need to configure additional hardware on each node, and it is possible to configure a simple positioning system by simply configuring the wireless communication mechanism on a small number of RNs. Therefore, it is possible to effectively reduce the cost of the unknown node hardwires and power consumption.

In order to obtain accurate locational position, the positioning method uses the Range-based as the main positioning algorithm. In this positioning mode, there are two main ways to convert a signal to the distance: one is to measure the arrival time of the signal, and the other is to calculate the distance by the strength of the received signal.

Then, we propose a new method to calculate the position of unknown nodes by pre-configuring the RNs, and then using the triangulation method to calculate the intersection of three circles. This method is to take center point of two rounds, uses the two nodes to calculate the two intersections, and judges the distance of the third point on the two relative points, then we can know the right position of the third point.

In addition to using the three-point positioning method, but also joined RSSI algorithm. The RSSI is the use of electromagnetic waves with the distance attenuation characteristics, by receiving the packet to calculate the signal strength value to estimate the distance between the two nodes [15].

Fig. 9 shows two rounds which they were drawn by the two reference nodes measured RSSI values, and then can find the BN that may be in the two rounds. The intersection points P1 and P2 of these two circles are the possible positions of the BNs. After these two points are obtained, the distance between the two RNs is shown in Fig. 10.

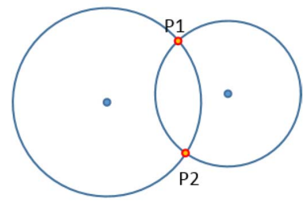

Fig. 9 : The possibility of two-point calculation.

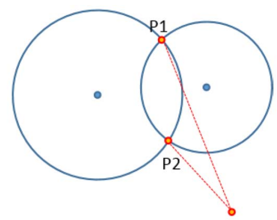

Fig. 10 : Comparison with the distance of the third point.

This method can quickly calculate the possible location of unknown points. But using this method must also grab two RNs at a time. Figure 12 shows the configuration of the experiment. Among them, the point B_m is used to determine the distance point. We select two points in the configuration, that is to say in the choice of A1 also choose A2; select A3 also choose A4 and etc. Here defines an error function:

$$E_n = \text{distance}\,(\overline{P_n B}) - \text{distance}\,(RSSI_B) \quad (4)$$

Where

- P_n is the two unknown solutions.
- B is the decision point.
- $RSSI_B$ is the RSSI value received by reference node B.

It can be reasonably speculated that the smaller error point, that is the location of the BN, meaning min $(|E1|, |E2|)$ for the BN position. If we take B_2 to determine the distance, if distance $(RSSIB) = d$.

$$E_2 = \text{distance}\,(\overline{B_2 P_2}) - \text{d} \quad (5)$$

$$E_2 = \text{distance}\,(\overline{B_2 P_1}) - \text{d} \quad (6)$$

Obviously, $E_1 > E_2$, so E_2 is the correct position of the BN. In space, any RN that can be used to be detected as a decision point. The operations can be repeated multiple times to increase the reliability of the positions of the BNs. In this experiment, we mainly use Point A_3 and A_4 to calculate the distance, and then use the other points to compare the distance to find the most intersecting points, and from which to estimate the most appropriate solution set. Fig. 11 is an experimental position diagram. Fig. 12 shows the position measured in the experiment.

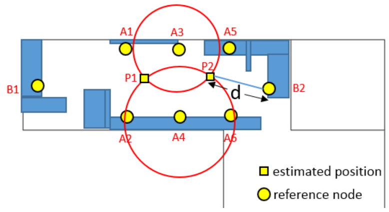

Fig. 11 : The plane position diagram of the experiment.

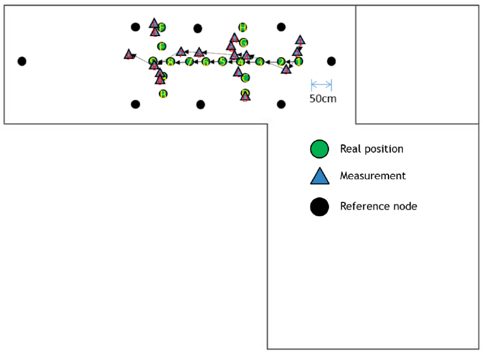

Fig. 12 : The position measured in the experiment.

Experiments show that the signal exceeds a certain distance, the calculation of the environmental loss is existence, and hence, it can use the compensation to correct the error which is caused by the energy error. Therefore, the calculation of the RNs $A_1 \sim A_4$ data to locate the distant nodes positions, and to refer the distance between B_1 and B_2 to determine which set of RNs is more fitting, so it can get the more correct calculation results. Table Ⅱ for the experimental positioning and error.

TABLE Ⅱ
THE POSITIONING AND ERROR OF THE EXPERIMENT

	Real Position	Location by this work	Error (m)		Real Position	Location by this work	Error (m)
1	(19, 8)	(19.10, 6.97)	0.52	9	(11, 6)	(11.50, 8.04)	0.48
2	(18, 8)	(18.93, 7.94)	0.47	A	(12, 10)	(11.76, 8.72)	0.55
3	(18, 8)	(18.01, 8.42)	0.57	B	(16, 9)	(15.81, 8.41)	0.31
4	(16, 8)	(16.29, 7.55)	0.27	C	(16, 10)	(16.04, 10.58)	0.29
5	(15, 8)	(15.97, 7.57)	0.53	D	(11, 6)	(11.01, 5.98)	0.54
6	(14, 8)	(13.50, 7.41)	0.39	E	(11, 6)	(11.76, 6.12)	0.19
7	(13, 8)	(12.35, 7.45)	0.43	F	(16, 7)	(15.49, 7.46)	0.34
8	(11, 8)	(10.90, 7.42)	0.52	G	(16, 7)	(15.80, 7.08)	0.25
Mean error						0.42 (m)	

V. CONCLUSIONS

This article designs a new positioning method. Positioning with a special wireless signal module configuration rules, so that the complexity of the calculation process is reduced and the running time is faster, but it will not lose the precise characteristics with the triangle positioning technology. Because the final answer is calculated by the RNs (or called decision point), this method can quickly replace the RNs, the RN used to calculate the length, and then the length converted with the RSSI value to obtain the length of the request. The replacement of RNs in the calculation does not affect the reference value of the original two RNs. This calculation saves time by comparing the traditional triangulation algorithms. At the same time, it can also use the error in the detection decision point to adjust the two reference nodes for positioning.

Therefore, this method will not only solve the signal in the long distance transmission which will have a greater distortion, but also the appropriate use of the laying of the more sensitive nodes in the edge, so that these nodes can help the main reference node to get closer to the real answer.

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