www.s2is.org
International Journal on Smart Sensing and Intelligent Systems
ISSN 1178-5608

An indoor positioning algorithm and its experiment research based on RFID

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Submitted:Nov. 15, 201   ***Accepted:Mar. 31, 2014***   ***Published: June 1, 2014***

Abstract- A kind of indoor locating algorithm based on RFID has been put forward since the indoor positioning system can not fully meet the requirements of location services. The algorithm takes the propagation characteristic of signal as the breakthrough point and improves the positioning precision of the algorithm by means of regional division, regional judgment strategy, virtual node, and so on. The optimal target position of the access point was put forward and an effective analysis of the regional division and virtual node was done along with the robustness design through the experimental analysis. The result of the indoor positioning experiment shows that this algorithm is of high positioning precision, providing technical support for developing the indoor positioning system based on RFID.

Index terms*:* Indoor Positioning Algorithm, Experimental Analysis, Virtual Node.

I. INTRODUCTION

With the continuous progress of science and technology, more and more intelligent service have been required to meet the different needs of different groups of people. Nowadays, there have been many universities and research centers doing researches on automatic positioning technology and indoor positioning system for years [1,2]. Indoor positioning system is usually used to locate people or required objects in large buildings and closed environments. Global Positioning System (GPS) [3] is a commonly used localization system nowadays. But for GPS is a system depending on satellite, it generally does not function when the object to be detected in the room. In order to overcome the disadvantage of GPS and locate object accurately in the complicated indoor environments, researchers developed several indoor positioning system, such as: Active Badges [4], the first indoor location sensing system developed by AT&T Cambridge, which used diffuse infrared technology to realize indoor location; Crickets [5], Active Bats [6] and Dolphin [7] are an ultrasonic positioning system, the computer vision system [8] and the Cell Phone positioning system [9] (E-911). All these indoor positioning system have their own advantages and limitation as well, among which the location sensing system use commercially available RFID devices can reduce construction cost. Its working principle is that Received Signal Strength Information (RSSI) was employed to estimate the distances between transmitters and receivers. Usually RF signals are used [10] and those system based on RF signals can be usually split into WaveLAN [11], UltraWide Band [12] and RFID. Some popular RFID location finding systems are called LANDMARC [13] and SpotON [14]. LANDMARC is a successful RFID positioning system where an RFID active tag is preprogrammed with an ID to be identified by the readers. SpotON is a new tagging technology for 3D location detection based on RSS. RADAR [15,16] is another RF based popular system used for locating and tracking objects or people in indoors. With the deepening of research on Internet of things technology, researchers are not only concerned about the reliability of data transmission [17] and the algorithm design [18,19], but also the development of positioning device [20,21] and its application such as the vehicle license plate [22,23], the wrist watch [24] and so on. Not only that, some of the techniques have also been integrated into the indoor position system, such as the Inertial

Navigation System [25] (INS), the Finger Printing Method [26] (FPM), and LF RFID localization system [27].

In this paper, based on some existing indoor positioning system, we propose an indoor positioning algorithm and carry out a series of experimental research on the experimental platform of our own design, and our purpose is to enhance the accuracy of indoor positioning.

II. INDOOR POSITIONING ALGORITHM PRINCIPLE

a. Real-Time Tracking (RTT Algorithm)

The RTT algorithm is an indoor positioning algorithm of real-time location tracking based on ranging technology. The reader is set on the main body of the measured target. Using 3 or more than 3 reference nodes of the known position coordinates to real-time locate the measured target by using trilateration method. If the coordinates of the known node is (x_i,y_i), and that of the target location is (x_p,y_p), then the distance between the reference node i and target node p can be expressed by d_p^i:

$$d_p^i = \sqrt{(x_i - x_p)^2 + (y_i - y_p)^2} \qquad (1)$$

After solving simultaneous equations by bring 3 or more than 3 reference nodes (x_i,y_i) into the formula (1) respectively, the position coordinate of the target node could be obtained.

b. Fingerprint-identifying Technique (FTP Algorithm)

The positioning process of Fingerprint Identification Positioning System (FPT Algorithm) can be divided into two phases: offline and online phases. In the offline phase, when the position coordinates of the target node is known, the RSSI information of each node can be collected and pre-stored in the database in the form of vector for the use in online phase. In the online phase, the RSSI information can be collected in real-time and has an optimal matching with the RSSI information pre-stored in the database in the offline phase, and then the position coordinates of the target node can be estimated. Improved FPT algorithm [13] combined the RTT and FPT technology, using the RTT positioning algorithm when the distance is greater than a certain value. When the distance is less than a predetermined value, improved FPT positioning algorithm was adopted.

Based on the above research results, this paper put forward an indoor positioning algorithm based on RFID, taking the propagation characteristic of signal as the breakthrough point. The sensitivity of the positioning error to RSSI measurement deviation can be reduced by means of regional division, regional judgment strategy, virtual node, and so on.

III. ARITHMETIC DESIGN

a. Overall Design

RFID is a kind of non-contact communication technology. By using the signal's characteristic of transmission through space, the positioning system collects the received signal values, and denotes it as D, which is used to estimate the position of the target that is to be detected. The mathematical model of the wireless signal transmission uses the following function formula between the RFID signal strength D and signal propagation distance d as:

$$D=-(A+10\times n\times \lg d) \qquad (2)$$

The positioning process can be divided into two phases: offline and online measurement phases. In the offline measurement phase, the calibration of signal propagation parameters A and n needs to be completed in the environment by collecting a large number of RSSI values. The online measurement phase can be divided into the following steps:

(1) 12 reference nodes are preset in a rectangular area and sequentially denoted as I_i, (i=1,2,…,12), as shown in figure 1. The position coordinates of each reference node are given, and the RFID reader is denoted by M. The reader collect the signal strength value of each node in real-time, which sequentially denoted as D_i, (i=1,2,…,12), and stored in the array $A[i]$.

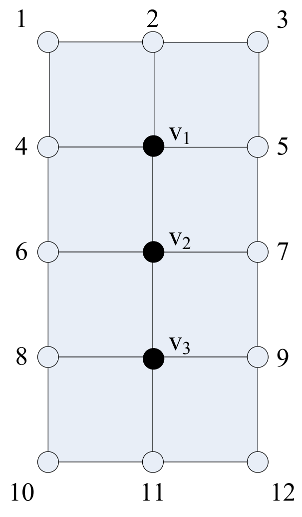

Figure 1. Distribution of reference node

(2) Sort all the elements from large to small in the array $A[i]$, select the maximum value in the $A[i]$ and keep it in the variable D_{max}, and also store it in the variable I_{max} together with D_{max} corresponding ID.

(3) Divide the measured area into four equal size rectangular areas longitudinally by means of D_{max} regional division, as shown in figure 1. Judge the rectangle region of the target reader according to the I_{max} and the D_i auxiliary except the maximum value in $A[i]$.

(4) Set three virtual nodes v_1, v_2, v_3, and calculate the signal strength information of the virtual nodes through the mathematical models of the virtual nodes.

(5) Estimate the position coordinates by the positioning algorithm of 12 nodes based on the results of each step above.

b. Regional Division and Regional Judgment Strategy

b.i Regional Division

The measured area is divided into four equal rectangular regions longitudinally. The four regions from top to bottom were denoted as the first (a rectangular region that is constituted by the reference nodes I_1~I_4~I_5~I_3 called I for short), the second (I_4~I_6~I_7~I_5), the third (I_6~I_8~I_9~I_7) and the fourth (I_8~I_{10}~I_{12}~I_9) rectangular regions.

b.ii I_{max} Regional Judgment Strategy

Judge the location of the target reader which is located in the region of these four rectangular regions. It is obvious that D decreases continuously with the distance d increases from formula (2). In other words, the larger value of D means the corresponding reference node is more close to the target reader. The downward trend of D will grow by the increasing distance d, and there is a faster changing rate of D in the closer regions. This paper adopts I_{max} judgment strategy to judge where the target reader is more appropriate. The flow chart of the I_{max} judgment strategy is shown in figure 2. Note that there are occasional fluctuations in the measured value of D, which has a greater impact on the farther regions than on the nearer ones.

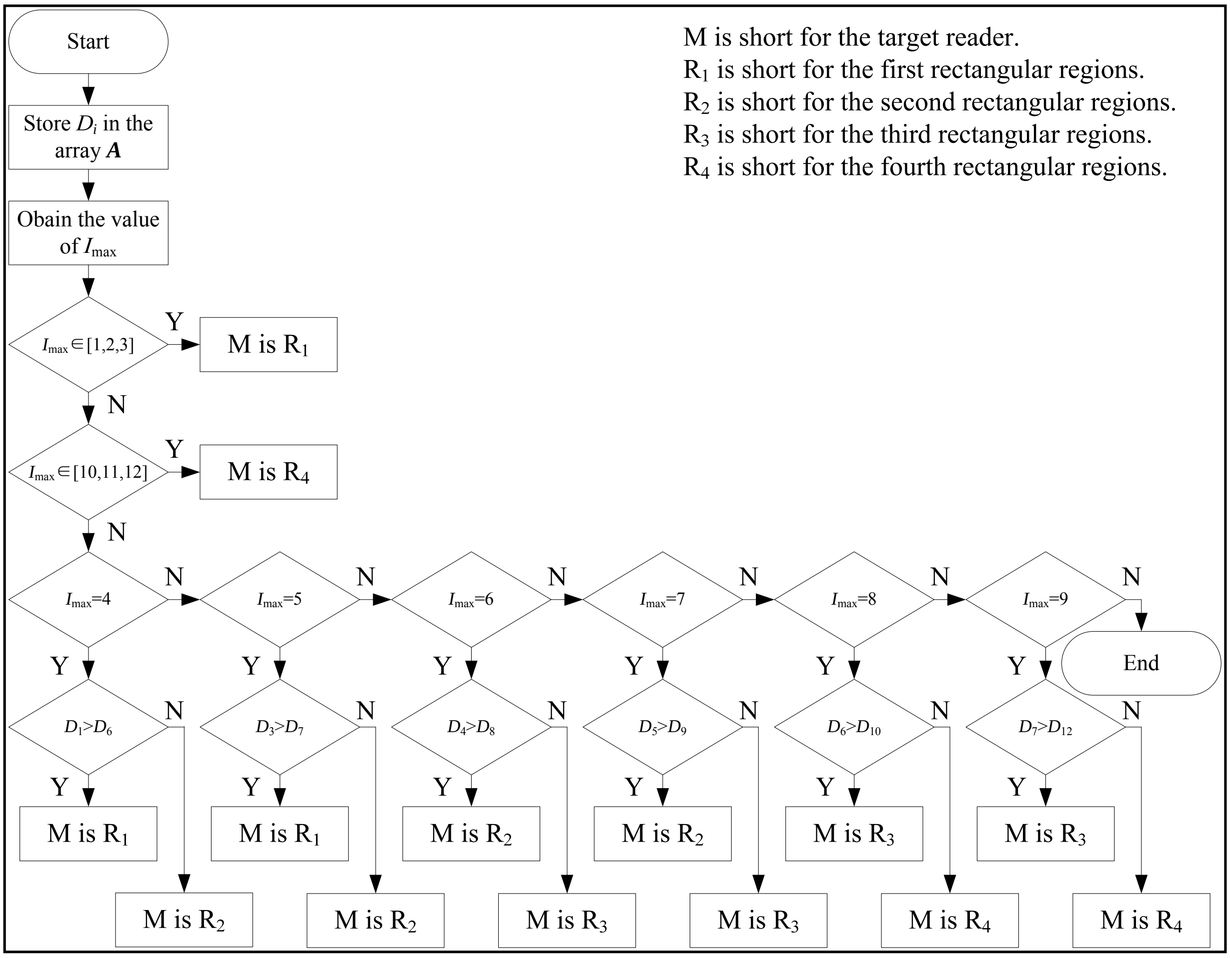

Figure 2. The flow chart of the I_{max} judgment strategy

c. Virtual Nodes

It is necessary to obtain the signal strength information of the 3 midpoints of the lines which between I_4 and I_5, I_6 and I_7, I_8 and I_9. Considering many factors like the cost of equipment, hardware installation in actual applications, the virtual reference node (virtual node for short) is introduced in the above-mentioned 3 positions, marked as I_1^v, I_2^v and I_3^v for each virtual node and the corresponding signal strength values marked as D_1^v, D_2^v and D_3^v. Among them D_i^v can be obtained through a series of calculations of the elements in array $A[i]$. The signal strength values of virtual nodes in each region are shown in Table 1:

Take the first rectangular region as example, D_1^v needs to be worked out if target reader is in the first region. I_1^v is the midpoint of lines which between I_4 and I_5, I_6 and I_7, I_8 and I_9. The distances between each reference node as well as between I_4 and I_5 are known, and D_i can be measured. Bring D_4 and D_5 into equation (2) so as to convert to the distance between the reader and the reference label marked as d_4 and d_5, then the value of the distance between the reader and the virtual node can be obtained through analytic geometry equation. Subsequently, the distance value is converted back to the signal strength values D in the formula (2) and the result of D_1^v can be obtained. According to the above method, the sum of d_4 and d_5 is not less than the distance between I_4 and I_5, which is used for the verification condition. If the condition is true, D_1^v can be trust, otherwise calculate D_1^v again by D_1 and D_7, D_3 and D_6. If D_1^v still unable to meet the validation criteria, this group $A[i]$ can be given up and re-collected. The method of calculating D_2^v and D_3^v is similar to D_1^v, and the difference is that different reference node is adopted. Among them, D_2^v can be calculated using the reference nodes I_6 and I_7, I_4 and I_9, I_5 and I_8, while and D_3^v can be calculated using I_8 and I_9、I_6 and I_{12}、I_7 and I_{10}.

Table 1: Signal strength values of virtual nodes in each region

Rectangular Region	**First**	**Second**	**Third**	**Fourth**
The signal strength value	D_1^v	D_1^v, D_2^v	D_2^v, D_3^v	D_3^v

d. Position Estimation

After comparing D_i^v with all the elements in array $A[i]$ after being calculated, then D_{max} and I_{max} can be recalculated. Taking the position of I_{max} as the reference origin, the position coordinates of the target reader relative to the node I_{max} can be estimated. Then the absolute coordinates of the target reader in the measured region can be worked out according to the position of I_{max} in the whole measured region.

At first, each node near I_{max} was compared, according to descending order, I_i are sequentially arranged and store in the array $B[i]$. D_{max} was convered into d_{max} by using formula (2) and a circle O_1 was drawn with I_{max} and d_{max} as the center and the radius, respectively. The circle was divided into four equal regions by using two lines passes through the center of the circle, and the angle with the X axis are π/2 and -π/2, respectively (referred to as L_1, L_2). The 1/4 circular region should be determined that has been chosen by the position of array $B[1]$ node, then a circle O_2

was drawn with the midpoint of the first arc as the center and two lines L_1, L_2 as the tangent lines. This circle was divided into four equal regions by using two lines (referred to as L_3, L_4) going through the center, making an angle of π/2 and -π/2 with the x axis respectively. The 1/4 circular region was chosen by the position of array *B*[1] node.

Take the first rectangle region as example, set I_{max} as I_2 and $D_1^v > D_3 > D_1$. The position coordinates of target reader can be calculated by the following steps:

(1) Draw a circle O_1, with I_2 as the center and *d* as the radius which convent by D_2 through formula (2). Then divide the circle into four equal regions by using two dotted lines with the slope of 1 and -1.

(2) Select the region at the lower side of I_1^v since $D_1^v > D_3 > D_1$, and draw a circle O_2 with the midpoint of the arc in the region as the center and two dotted lines with the slope of 1 and -1 as the tangent lines. Then divide the circle into four equal regions by using the two dotted lines with the slope of 1 and -1. Select the region on the right side of I_3 since $D_3 > D_1$, draw the circle O_3 and O_4 following the same steps, which as shown in figure 3. The intersection area of circle O_1, O_2, O_3 and O_4 is the region of the target reader.

(3) Set a point *P* as the access point of the target position coordinates in the intersection area of each circle, and calculate the position coordinates of point *P* relative to I_2. Then calculate absolute coordinates of the target reader according to the position of I_2 in the measured region.

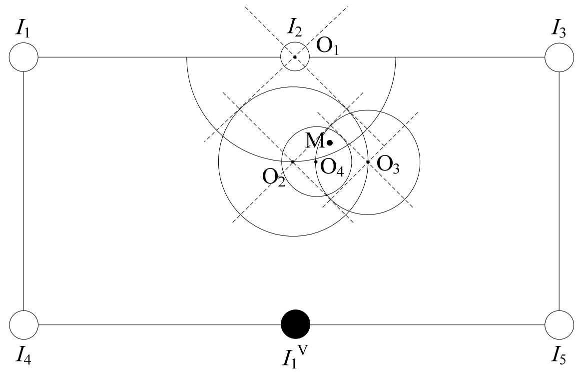

Figure 3. Coordinate estimation

IV. SYSTEMIC CONSTITUTION AND IMPLEMENTATION PROCEDURE

The hardware architecture of indoor positioning system is shown in figure 4, which consist of a wheeled mobile robot, a RFID reader and several RFID tags. The RFID tag can be divided into two categories, active and passive modes [14]. The active tag need power supply while the passive does not. The coverage of RFID system is in the low frequency range of 100-500 kHz, the high frequency range of 13.56MHz, the ultra-high frequency (UHF) range of 860-960 MHz, the microware frequency range of 2.4 GHz and 5.8 GHz. Among them, the application of UHF and microware band is the most prominent [15]. The CC1100 is a low cost truly monolithic UHF transceiver, which is designed for low power wireless applications. It has the features of low power consumption, transmission distance, strong anti-interference ability etc.. In view of its own RSSI signal strength detection function, the CC1100 is used as wireless transceiver of RFID reader and tags in the positioning system designed in this paper. The working principle of the system is as follows. The RFID reader is connected to the wheeled mobile robot through the serial port. When the system is in the working state, the signal intensity of each tag is collected within time period by the RFID reader, and these data will be immediately sent to the host computer of the wheeled mobile robot. After receiving the information from the RFID reader, the current position of the robot can be calculated according to the positioning algorithm present in this paper. By combining the feedback information of electronic compass and encoder, the path planning of the robot is immediately carried out. Finally, the motion instruction of the robot in the next step is transmitted to the console computer through the serial port. Go round and begin again, until the robot reaches the predetermined position.

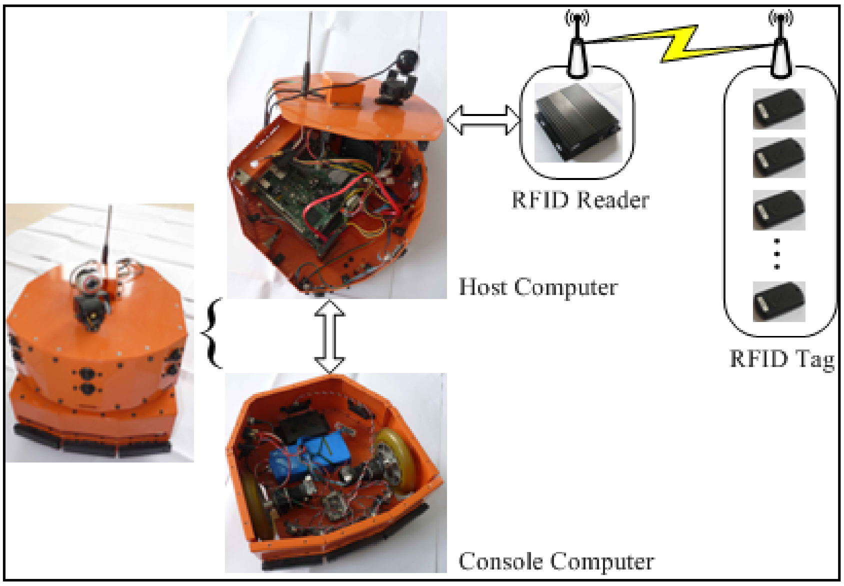

Figure 4. Hardware architecture of indoor positioning system

The data transmission network between RFID reader and tags is shown in figure 5. As can be seen from the graph, the wireless signal is firstly sent in the form of broadcast from the positioning tag to all reference tags. After receiving the signal, each reference tag will immediately send its own RSSI detected to the RFID reader. The RSSI data of all reference tags is uploaded finally to PC according to a certain format through the serious port. The data frame format as shown in Table 2.

Table 2: The data frame format from RFID reader

address	00	01	02,03	04	05
instruction	**Frame synchronization head**	**Reader ID**	**Tag ID**	**Cumulative sum**	**Character of end of frame**
definition	AA	1byte	2byte/4byte		BB

Considering the data being sent at the same time from the multiple reference tags could have a timing conflict and data packet dropout, a communication protocol is proposed in this paper. The protocol noted that the synchronous signal should be broadcasted periodically from the positioning tag, and the RSSI should be send in turn to the RFID reader at a certain time interval. The test results show that this protocol can avoid conflicting phenomenon when multiple reference tags sending data to the RFID reader. The data communication mode is shown in Figure 6. It can be seen from Figure 6 that the periodic parameter is 500ms and the time interval is 30ms.

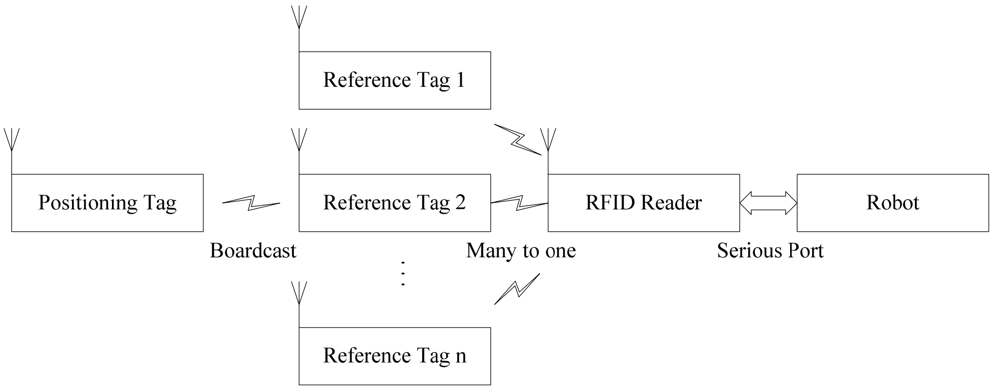

Figure 5. Data transmission network between RFID reader and tags

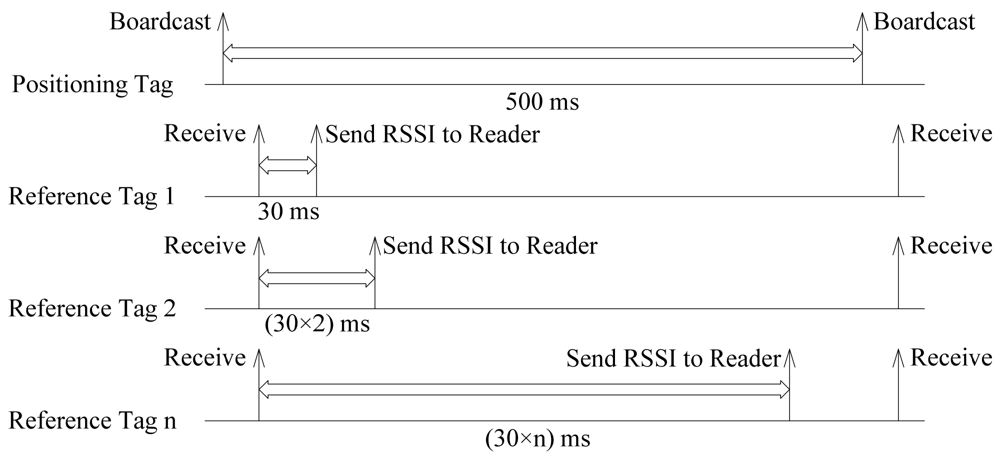

Figure 6. Data communication mode

The function of software system mainly includes the signal acquisition and data transmission of all RFID tags, the data processing in the positioning algorithm, the generation and transmission of motion instruction. Among them, the signal acquisition and data transmission is the key part of the software system. All of the codes are written in Delphi.

```
procedure readEncoderTread.Execute;
var
```

```
   EncoderNum:integer;
   readEncoder, stopMove:string;
begin
   readEncode:='55 aa 10 00 12 21';
   stopMove:='55 aa 10 05 0C 00 00 00 00 00 20';
   while EncoderNum <> DesDistance do
   begin
      SendString(HexStrToStr(readEncoder));
      Sleep(10);
   end;
   run:=False;
   SendString(HexStrToStr(stopMove));
end;
```

V. RESULTS AND DISCUSSION

a. Optimal Choice of Target Position of the Access Point

Set the point which is near to I_{max} among the intersection points of circle O_1 and O_3 as P_1, the point which is near to I_{max} among the intersection points of circle O_1 and O_4 as P_2, and the point which is near to I_{max} among the intersection points of circle O_3 and O_4 as P_3. Get point P_4 and P_5 based on the 3 points above by different proportion weighted calculation.

Set the weight ratio of P_4 as P_1:P_2:P_3=1:2:3, and the coordinates of P_4 are:

$$\begin{cases} x = \frac{1}{6}(x_{13} + 2 * x_{14} + 3 * x_{34}) \\ y = \frac{1}{6}(y_{13} + 2 * y_{14} + 3 * y_{34}) \end{cases} \quad (3)$$

Set the weight ratio of P_5 as P_1:P_2:P_3=1:1:4, and the coordinates of P_5 are:

$$\begin{cases} x = \frac{1}{6}(x_{13} + x_{14} + 4 * x_{34}) \\ y = \frac{1}{6}(y_{13} + y_{14} + 4 * y_{34}) \end{cases} \quad (4)$$

Take point P_1, P_2, P_3, P_4 and P_5 as the access points of the target position, and conduct four positioning experiments respectively. The experimental results and error analysis are shown in table 3 and figure 6. Obviously, scheme 3 has the minimum positioning error, so the algorithm uses P_3 as the access point of the coordinates of the target position.

Table 3: The positioning experiments results by selecting different points

Group / Program	Group 1		Group 2		Group 3		Group 4	
	x	*y*	*x*	*y*	*x*	*y*	*x*	*y*
The actual coordinates of the target reader	2.4800	0.3200	1.0700	0.3100	1.1500	5.0600	2.7000	0.8500
Access point P_1	1.8503	0.2440	1.2921	0.9797	0.7108	4.6675	2.7921	0.5203
Access point P_2	2.0013	0.6196	0.9721	0.8510	0.8144	4.9253	2.4721	0.6490
Access point P_3	2.2134	0.3903	1.1674	0.6703	0.9600	4.7679	2.6674	0.8297
Access point P_4	2.1175	0.4041	1.1156	0.7520	0.8942	4.7774	2.6556	0.7480
Access point P_5	2.0822	0.4423	0.1231	0.7821	0.8700	4.8360	2.6231	0.7179

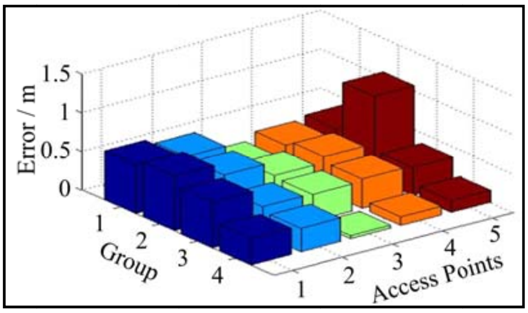

Figure 6. The positioning error of different access points

b. Effective Analysis of Regional Division and Virtual Nodes

Under the same environmental conditions, positioning experiment was conducted based on scheme 1 (before introducing the regional division and virtual nodes) and on scheme 2 (after introducing them) using the four groups of location data, respectively, The experimental results are shown in table 4.

Table 4: The experimental results of two schemes

Ideal Coordinates	Scheme 1		Scheme 2	
	Positioning	Error	Positioning	Error

	Coordinates		**Coordinates**	
(2.7000,0.8500)	(2.1878,0.4030)	0.6798	(2.6674,0.8297)	0.0015
(1.0700,0.3100)	(1.6425,0.8150)	0.7634	(1.1674,0.6703)	0.1393
(1.1500,5.0600)	(0.3903,5.2134)	0.7750	(0.9600,4.7679)	0.1214
(2.4800,0.3100)	(2.6097,0.7866)	0.4939	(2.2134,0.3903)	0.0775

The positioning error of scheme 2 is obviously much less than that of scheme 1 and is of much higher positioning accuracy under the same environmental conditions (see figure 7), so it is necessary to introduce the regional division and virtual node in this algorithm.

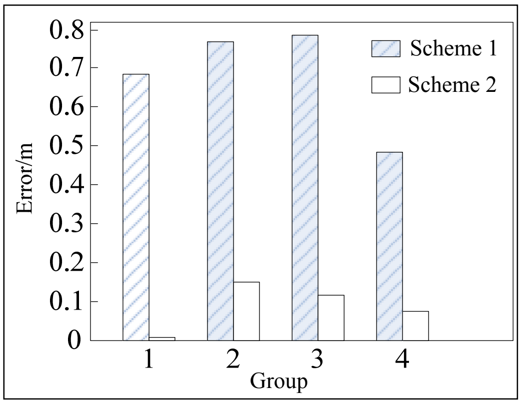

Figure 7. The positioning errors of scheme 1 and scheme 2

c. Robustness Design of the Algorithm

RSSI is vulnerable to great interference by external environmental factors, which is bound to affect the stability of the algorithm, and even lead to serious disorders of the positioning system. The main reason is that there is occasionally some distortion of the signal strength indication of these nodes needed when calculating D_i^v. So, it is worth adjusting the method of calculating D_i^v to improve the robustness of the algorithm. That is, the validity of the D_i^v need to be verified immediately after calculating it. D_i^v is considered to be believable if it meets the precondition, otherwise D_i^v is recalculated by other D_i. Then calculate the coordinates of the target reader by such credible D_i^v. The results before and after adjusting scheme are shown in table 5.

Through analyzing the experiment results, we know that when the positioning system running into serious disorders, the distortion problem can be solved efficiently by adjusting D_i^v and improve the robustness of this indoor positioning algorithm.

Table 5: The positioning experiment results before and after adjusting scheme

	Group 1		**Group 2**	
	x	***y***	***x***	***y***
Theoretical value	0.9300	3.4800	0.6703	3.3326
Before the adjusting scheme	1.5000-0.1585i	3.0000+0.0787i	1.500+0.5797i	3.0000+0.2876i
After the adjusting scheme	1.8700	3.3800	2.2622	3.3661
Error	0.2986		0.2384	

d. Indoor Positioning Experiment

Based on the research results above, there are 10 reference nodes fixed indoor is shown in figure 8. Firstly the signal transmission parameters were calibrated and the values of the signal propagation parameters *A* and *n can be obtained*, i.e., *A*=158.2273, *n*=5.4799. Then 80 groups of positioning experiments were performed by the positioning algorithm proposed in this paper. The error distribution of these positioning experiments is shown in figure 9, and the histogram of the error statistic is shown in figure 10.

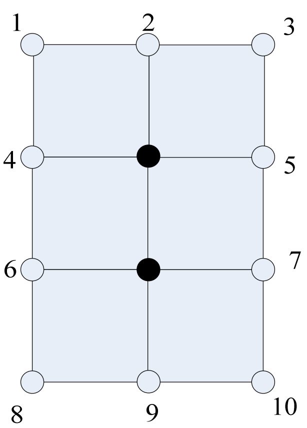

Figure 8. The reference nodes distribution map

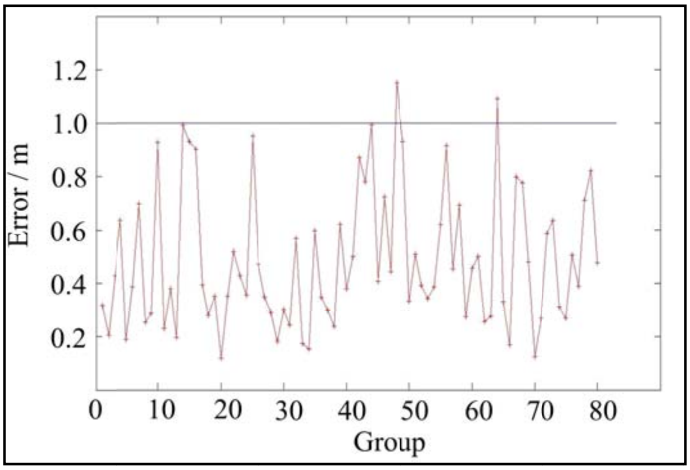

Figure 9. The error distribution of the positioning experiment

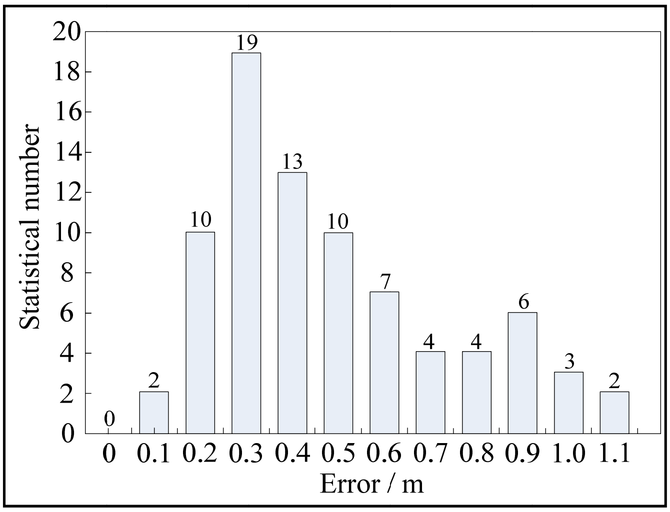

Figure 10. The histogram of the error statistic of the positioning experiment

VI. CONCLUSION

Based on the current study of indoor positioning algorithm by the judging strategy and virtual nodes, a new kind of indoor localization algorithm based on RFID is put forward and some related experimental researches are carried out. The weight ratio is introduced to select the optimal target access points which provide technical support for the further experimental research. The experimental results by introducing the regional division and virtual nodes fully demonstrate that the introduction of regional division and virtual nodes can greatly improve the positioning accuracy. By adjusting the method of calculating D_i^v and applying highly reliable D_i^v to estimate the target position, the robustness of the algorithm can be further improved. The research above provides some technical support for the timeliness, robustness and positioning accuracy of the present indoor positioning algorithm.

ACKNOWLEDGMENT

The research was partially supported by the New Century Excellent Talents in Heilongjiang Provincial University (1252-NCET-021), the Key Project of Chinese Ministry of Education (212042), the Natural Science foundation of Heilongjiang Province (E201254) and the Personnel Training Project of Jiamusi University (RC2009-040).

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