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Personnel Localization Algorithm of Prison Supervision System Based on RFID

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Abstract

The particularity of the prison decides the importance of its security system, and how to improve the accuracy of personnel positioning for prison monitoring system is the problem to be solved to realize intelligent prison monitoring management. RFID positioning technology with non line-of-sight transmission and large transmission range is widely applied in the personnel positioning system. RFID technology is used to design the monitoring and management system of prison in this paper. The Trilateral Ranging Method was adopted to realize personnel positioning. RSSI positioning algorithm its technology is relatively simple was adopted when calculating the trilateral distance and correcting the errors in order to improve the positioning precision. Simulation test results show that the positioning precision for the distance between a single reader and the tag is increased by 2.17% on average, up to 4.54% after the error correction. The personnel location coordinates, X direction average error is 2.96%, average error is 3.12%, Y direction, and meeting the requirements of the system design.

***Keywords**: prison supervision; personnel positioning algorithm; RFID*

1. Introduction

RFID technology as a non-contact automatic identification technology has the characteristics that are easy to read, faster recognition, great capacity of data, the dynamic real-time communication and high security, widely be used in the personnel positioning system. Prison as a special department of education and management to criminals, made its security system design with the requirements of higher safety and real-time[1]. The requirements of the prison informatization construction for prison security system are not only security monitoring, that also involve the supervision to the work of the police officers and the regulation to the daily operations of the prisoner[2,3]. Therefore, RFID technology is used to design the monitoring and management system of prison in this paper. Because of RFID localization accuracy is related to the number of readers, therefore, how to improve the positioning precision without increasing the number of readers is the problem to be solved for RFID positioning technology.

There are varied localization algorithms that suitable for RFID. Such as AOA (Angle-of-Arrival) technology that has high positioning accuracy, but be affected by external environment influence greatly. TOA/TDOA (Time of Arrival/Time Difference of Arrival) needs to maintain accurate clock synchronization in order to ensure the high precision of algorithm, and it has higher requirements for hardware[3]. Relative to the first two

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algorithms, RSSI (Received Signal Strength Indicator) which the positioning accuracy is slightly worse, but can meet most of the applications, and has the advantages that the technology is simple and the cost is low, so it is widely used[3~7].

On the bases of the in-depth analysis of various positioning algorithm for RFID technology and combining with the characteristics of prison monitoring, the Trilateral Ranging Method is applied to calculate the position of the personnel. In order to improve the positioning accuracy, using RSSI algorithm to calculate the length of the three sides for the triangle, and improve the positioning accuracy by correcting the system error and random error produced by RSSI algorithm.

2. The Structure for Monitoring System of the Prison

The system is mainly composed of the active electronic tags, the long distance RFID readers and the management terminals. The overall framework of the system is shown in Figure 1.

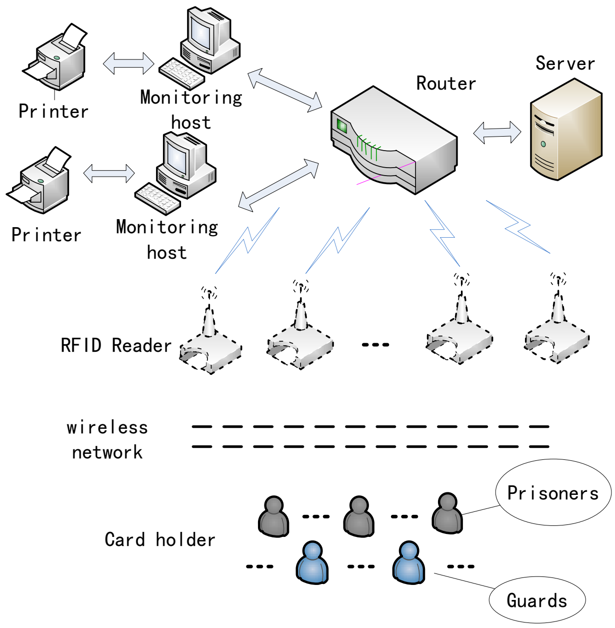


Figure 1. Overall Framework of System

2.1 The Design of Tag

Personnel information is stored in RFID tag for identification of person. The form of radio frequency cards is used in RFID system generally. But taking into account the particularity of the prisoners, RFID tags are divided into two categories in the system. The tags designed for prisoners are detachable bracelet form, and that designed for the guards still are the card form.

Electronic tag is an important part of RFID system, which is mainly composed of the antenna and the chip. The chip is composed of a memory, a controller, an encoder and a modulator. Its structure is shown in Fig.2. Tag uses 433MHz band, and its maximum identification distance is 150m, effective distance 80m. The personnel identity information of the holder is recorded in the electronic tag[8,9].

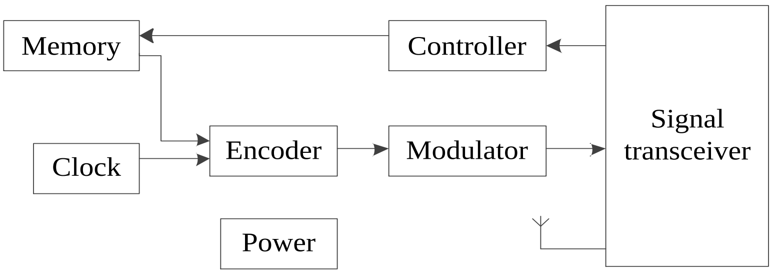


Figure 2. The Structure of Electronic Tag

2.2 The Design of Reader

The reader is the key terminal of the RFID system, which transmits the radio frequency modulation signal to the electronic tag by the antenna and receives the radio frequency modulation signal which containing information returned from a tag by the antenna. The signal is transmitted to the application system after be processed. The typical reader terminal consists of antenna module, radio frequency module, control module, interface and so on. Its internal structure is shown in Fig.3.

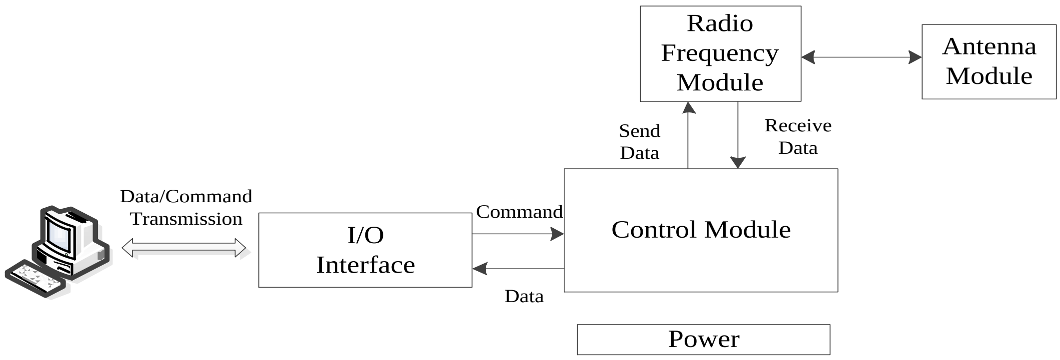


Figure 3. The Internal Structure of Reader

2.3 The Position Matrix of Reader

The area of prison is generally approximated as a rectangle. The longer side in the two adjacent boundaries of the monitoring area is defined as the X axis, and the other shorter boundary is defined as the Y axis. Put a reader at coordinate (80, 80), and put other readers according to the principle that the span of adjacent two readers is 80 meters. The reader's position in the whole large area forms a similar matrix, so that the recognition range covers the whole prison. Schematic diagram is shown in Figure 4. When the person wearing the tag enters the reading range of the reader, the reader reads the information in electronic tag, calculates the position information and updates the data, and then uploads the data to the management terminals through the computer network system.

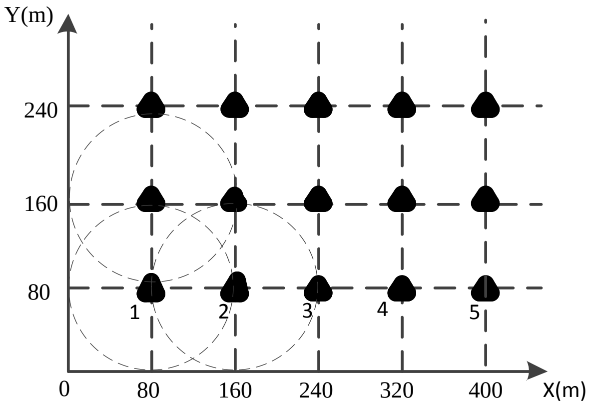


Figure 4. Schematic of the Readers Display

3. RFID System and its Localization Algorithm

3.1. Structure and Working Principle of the System

RFID is a automatic identification technology, to do read and write operations to the information of the specific target by the radio signal which has the particular frequency. The principle diagram of typical RFID system is shown in Figure 5. When the tag enters into the area covered by the reader, the electronic tag obtains energy by coupling elements and transfers the data to reader[10~12]. The reader reads the information within the tag and sends it to the data exchange and management system.

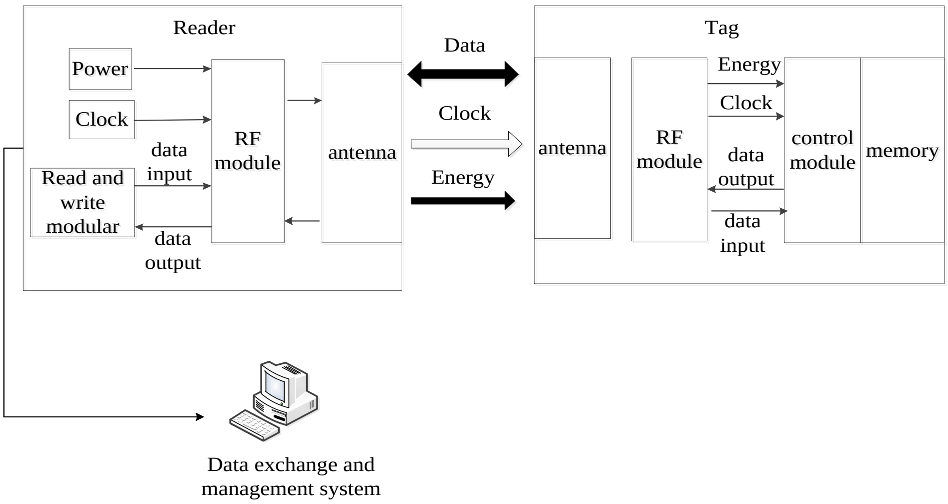


Figure 5. The Principle Diagram of RFID System

3.2. Localization Algorithm

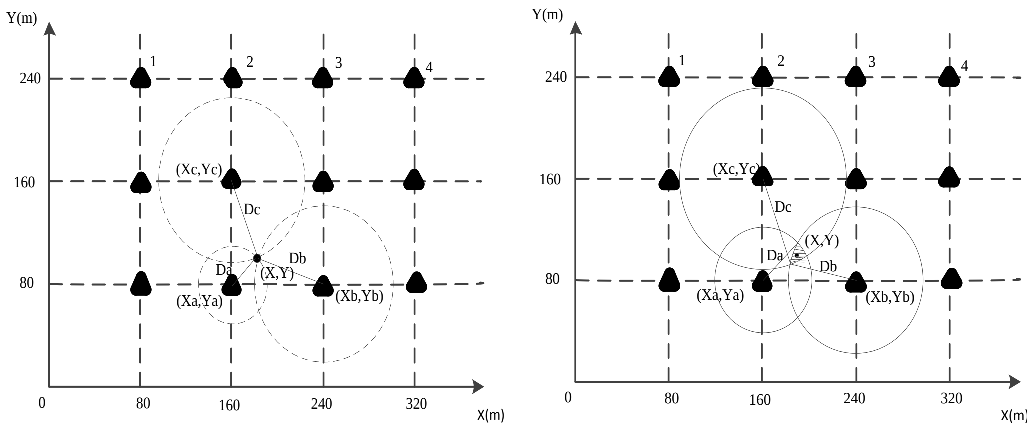
System uses the Trilateral Ranging Method to achieve the positioning of the tag. The length of the trilateral side is calculated by the RSSI localization algorithm which technology is relatively simple. Because RSSI localization algorithm calculates the distance based on signal strength, the greater the signal intensity of under test tag and the greater decision of the position. Thus three readers received the stronger signal intensity are selected as reference readers, realize the localization by calculating the distance from under test point to three reference readers. Reader position coordinates are set to (X_i, Y_i), where i (i=1, 2, 3) is the ith reader reference point. The coordinates of the under test tag are calculated by the geometric relationships. As shown in the formula (1).

$$D^2 = (X_i - X)^2 + (Y_i - Y)^2 \tag{1}$$

Among them, D_i represents the distance between the under test tag and the ith reference reader, (X, Y) indicate the coordinates of the under test tag, (Xi, Yi) indicate the coordinates of the ith reference reader. According to the formula (1), a set of equations can be set up to calculate the coordinates of the tag to be positioned.

Ideally, three circles which centers of the circle are the coordinates of the ith reader, radiuses are Di should intersect at a point, and this point's coordinate is the coordinate of under test tag, as shown in figure 6 a). But in reality, due to the influence of the various uncontrollable factors, the calculation of the distance will have a certain error. Three circles will not intersect at a point, but form the shadow area as shown in Figure 6 b). With the intersection points of three circles and shaded area as the three vertices of the triangle, the coordinates of the gravity center of the triangle is the coordinates of the tag under test. Calculation method is shown as the following.

If the coordinate of three vertexes is (X_1, Y_1), (X_2, Y_2), (X_3, Y_3) respectively, the coordinate of the gravity center G of the triangle is (($X_1 + X_2 + X_3$) / 3, ($Y_1 + Y_2 + Y_3$) / 3).



a) The coordinates of under test labels calculated by the Trilateral Ranging Method under the ideally situation

b) The coordinates of under test labels calculated by the Trilateral Ranging Method under the actual situation

Figure 6. The Coordinate Graphs of the Trilateral Ranging

The distance between the reader and the tag is calculated using RSSI localization algorithm. When a RFID tag entered into the recognition range of the reader, the tag sends the information such as ID, RSSI value etc, to the reader in the form of radio frequency. According to the model, the relationship between the signal power and the distance can be got, as the formula (2).

$$P(d)[dBm] = P(d_0)[dBm] - 10n\log(\frac{d}{d_0}) - X_0 \tag{2}$$

$P(d)$ indicates the signal power received by reader when the distance between the tag and reader is d. $P(d_0)$ indicates the signal power received by reader when the distance between the tag and reader is d_0, n indicates the attenuation factor of signal intensity with distance, the range values of n is between 2 to 5, the value is 3 in this paper. X_0 is a Gauss distribution random variable with zero mean value, the range values of X_0 is between 4 to 10, the value is 4 in this paper. d_0 represents the distance between the reference tag and the tag, d_0 =1m is often used in practical applications. d represents the distance between the reader and the tag.

If the system error of the measured value is not considered, the calculated distance d is

$$d = d_0 \times 10^{\frac{1}{10n}(P(d_0)-P(d)-X_0)} \tag{3}$$

As $d= f(d_0, P(d_0), P(d))$, the system error of distance d is

$$\Delta d = \frac{\partial f}{\partial d_0}\Delta d_0 + \frac{\partial f}{\partial P(d_0)}\Delta P(d_0) + \frac{\partial f}{\partial P(d)}\Delta P(d) \tag{4}$$

$\triangle d_0$, $\triangle P(d_0)$, $\triangle P(d)$ respectively represents the distance between the reference tag and the under test tag, the signal strength received by reader at the reference position d_0, the signal strength which the reader gets and be sent back by the undetermined tag. $\triangle d$ which the system error of distance can be decreased by correcting, and the distance between the reader and tag is $D=d\pm\triangle d$.

In addition to there are the system error and the random error in the actual measurement, the random error is assessed by standard deviation, therefore the random error of distance d is

$$\sigma_d = \sqrt{\left(\frac{\partial f}{\partial d_0}\right)^2 \sigma_{d_0}^2 + \left(\frac{\partial f}{\partial P(d_0)}\right)^2 \sigma_{P(d_0)}^2 + \left(\frac{\partial f}{\partial P(d)}\right)^2 \sigma_{P(d)}^2} \tag{5}$$

Then the final result of the distance D is $D= (d-\triangle d) \pm \sigma d$.

4. Algorithm Simulation and Result Analysis

Simulation experiments have been done for the result of error correction in the first place. To select the RF tag of 433MHz, and put the tag in 3 meters away from the reader, then each increase of 3 meters, to do the experimental test 8 times respectively. The measured distance before and after correction is recorded. The error between measured distance and the actual distance and the error decrease percentage after error correcting are calculated. The results of the experiment are shown in table 1.

The results of the experiments showed that the distance measured by a single reader is more close to the actual distance value after error correction. This method can effectively reduce the error of distance-measuring between reader and tag, and the positioning accuracy can be increased by an average of 2.17%.

The simulation experiments have been done for the Trilateral Ranging Method. Three readers were placed at coordinates (0, 0), (0, 20), (20, 0), and under test tags were placed at coordinates (5, 5), (10, 10), (15, 15), (20, 20), (25, 25). The test data are shown in Table 2. X direction average error is 2.96%, the Y direction is 3.12%. Although there are still some errors in the results of testing, meet the requirements of prison monitoring system for personnel positioning accuracy.

Table 1. Correction the Result of Error

NO.	1	2	3	4	5	6	7	8
Actual distance (m)	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00
Calculated distance (m)	3.10	5.80	9.35	11.50	14.21	19.46	19.08	21.59
Relative error before correction (%)	3.33	3.33	3.89	4.17	8.07	8.11	9.14	10.04
Correction distance (m)	3.05	4.8	8.05	10.09	12.97	15.23	16.66	20.24
Relative error after correction (%)	1.67	2.50	2.22	2.83	3.53	5.83	6.29	5.71
Error decrease percentage (%)	1.66	0.83	1.67	1.34	4.54	2.28	2.85	4.33

Table 2. Test Data of Positioning Coordinates

tag	1	2	3	4	5
Actual coordinates	(5.00, 5.00）	(10.00, 10.00)	(15.00, 15.00)	(20.00, 20.00)	(25.00, 25.00)
Calculated coordinates	(4.93, 5.12)	(9.52, 10.47)	(15.46, 14.53)	(19.74, 20.39)	(25.93, 25.86)
X direction error	1.40%	5.20%	3.17%	1.30%	3.72%
Y direction error	2.40%	4.70%	3.13%	1.95%	3.44%

5. Conclusion

To personnel positioning accuracy problem of the prison monitoring system, in the system based on RFID technology, the Trilateral Ranging Method is used to determine the specific location of personnel, and select RSSI algorithm to calculate the distance between tag and reader. The positioning precision is improved by correcting the error. The simulation test results show that the positioning precision of the distance between a single reader and tag increased by 2.17% on average, up to 4.54%. The personnel location coordinates calculated by the Trilateral Ranging Method, X direction average error is 2.96%, Y direction is 3.12%, meets the requirements of system design.

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