An Electric Power Tools Localization Algorithm Based on Active RFID

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Abstracts: In order to solve the problems of low positioning accuracy and poor stability of indoor electric power tools positioning technology in practical applications, this paper proposes a spatial positioning algorithm based on active Radio Frequency Identification (RFID). The algorithm first uses the Received Signal Strength Indicator (RSSI) ranging model to convert the signal strength of the target position to the distance from the target position to the locator, then obtains more accurate position information through the multilateral positioning model, and finally reduces the positioning error through the least squares estimation algorithm. In addition, a localization software system is designed for the algorithm, which displays the target's position and detailed coordinate information on top of the system interface, providing an intuitive display for indoor localization. The experimental results show that the algorithm can meet the basic needs of indoor positioning of electric apparatus, and the designed positioning software system can accurately display the position coordinates of electric apparatus.

Keywords: Radio Frequency Identification; Least Squares Estimation; Multilateral Localization Algorithm; Spatial Localization

1. Introduction

With the vigorous advancement of life intelligence and informatization, which puts forward higher requirements for accurate location services, indoor positioning technology has received extensive attention in recent years [1].With the rapid development of artificial intelligence, machine vision and wireless positioning technology have been effectively applied to the monitoring system, enabling object recognition, tracking, and safety warning [2].

A variety of indoor localization techniques have emerged from previous research in related fields, such as Wi-Fi localization [3], Bluetooth iBeacon [4] localization, Infrared localization [5], and so on. However, these technologies have certain limitations in signal penetration ability, positioning accuracy, etc., and cannot realize real-time indoor positioning in complex indoor environments [6]. As for the RFID positioning technology, the equipment used in this technology has low cost and better anti-interference.

In view of the above problems, this paper proposes an indoor electric work equipment localization algorithm based on RFID technology [7]. The algorithm utilizes RSSI ranging and positioning principle multilateral positioning model and least squares estimation algorithm to complete the calculation of position coordinates. And through the design of indoor electric apparatus positioning software, the visualization of positioning information is realized.

In this paper, the preliminary positioning and precise positioning of electrical work equipment carrying positioning tags are carried out to obtain the detailed location information of electric power tools. The results show that the proposed method has significant advantages in accuracy and provides a more practical and precise solution for localization in indoor environments.

2. Introduction to RFID-based RSSI Positioning Algorithms

RFID-based RSSI positioning algorithm is an indoor positioning algorithm based on RF signal strength indicators [8]. The main workflow of the algorithm is to first transmit electromagnetic waves through the locator, the electronic tag receives the electromagnetic waves and produces an inductive current, and sends out the internal information and signal strength through the antenna, the locator then receives the signal returned by the electronic tag and converts the signal to RSSI value, and determines the approximate location of the tag through the RSSI ranging and positioning principle. Finally, the exact position of the tag is calculated by multilateral positioning algorithm and least squares estimation method.

When the number of detections of the locator to the positioning tag increases, more RSSI data can be obtained for positioning calculations to improve positioning accuracy, but it cannot be increased indefinitely because with the increase in the number of detections, it will lead to a huge amount of calculations and delays, which will affect the real-time positioning and the response speed.

The advantage of this localization algorithm is that it can utilize existing RFID devices for indoor localization without additional hardware investment, and it can achieve high localization accuracy. However, due to the complexity of the indoor environment and factors such as signal interference, and the signal is susceptible to environmental interference and multipath effects [9],the accuracy of this algorithm may be somewhat limited.

3. Positioning System Overall Architecture

The localization scheme in this paper adopts dual-frequency semi-active RFID technology and combines area-awareness and RSSI localization technology to realize the precise positioning of the electric power work apparatus carrying the localization tags. Firstly, the area-aware identification technology is used to determine the area in which the electric work apparatus is located, and then the RFID-based RSSI technology is used for precise positioning in the confirmed area.

RFID positioning system is mainly divided into three parts, respectively: positioning tags, low-frequency locator and positioning system software three parts.

(1) Positioning Tags: dual-frequency active RFID tags, which are timed to send 2.5GHz signals to the outside, and receive 125KHz activation signal. Tag built-in battery, because the tag's power consumption is low, so under normal circumstances the tag of a battery can be used for 1-3 years, and the battery can be replaced.

(2) Low Frequency Locator: The locator is responsible for communicating with the locator tag, sending signals and receiving signals returned by the tag. The distance of the tag relative to the locator is calculated by measuring the strength of the signal.

(3) Positioning software system: the system consists of computers, servers and network equipment. It is mainly responsible for accepting the positioning information from the locator and displaying the position of the tag on the user interface. The overall architecture of the indoor positioning system is shown in Figure 1.

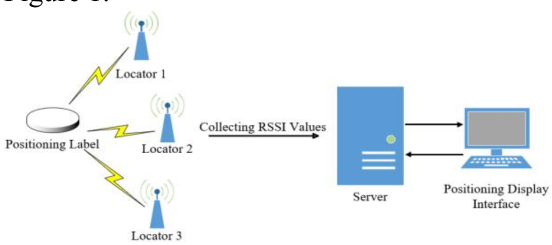

Figure 1. Overall System Architecture

4. Positioning Algorithms and Model Analysis

4.1 RSSI-based Ranging and Positioning Principle

Wireless signals suffer attenuation as they propagate, with signal strength diminishing as the distance traveled increases. In free space, the signal attenuation is inversely proportional to the square of the distance, but in the real environment, the signal attenuation will be more complicated due to the presence of walls, buildings and other obstacles. The commonly used signal transmission models are lognormal distribution model and free space attenuation model. However, the free space attenuation model is usually used in outdoor open environment and is not suitable for indoor complex environment, so the RSSI calculation formula used in this paper is as follows.

$$P_L(d) = P_L\left(d_0\right) - 10n\lg\frac{d}{d_0} - N_0 \quad (1)$$

Where $P_L(d)$ is the signal strength at a distance d meters from the sending node and

$PL(d_0)$ is the same. The variable d_0 is the reference distance, N_0 is the Gaussian noise with mean value 0, and n is the environmental attenuation factor. d_0 takes the value of 1, and the signal strength at the reference distance of 1.0 m is taken as the reference value, which is denoted as R. Then the equation (1) can be simplified as:

$$P_L(d) = R - 10n\lg d \tag{2}$$

The above equation (2) is the commonly used signal transmission formula model, which realizes the conversion of signal strength and distance.

4.2 Multilateral localization Models and Least Squares Estimation Algorithms

In practice, ranging and localization is in error, in order to get more accurate position information, this paper further adopts the multilateral localization algorithm to design the localization algorithm for the target point. Multilateral localization model is a model used to achieve target detection and localization. In this paper, the multilateral localization algorithm is used to introduce at least four localizers to participate in the localization service of the target location in order to provide accurate location information.The schematic diagram of multilateral positioning is shown in Figure 2.

Assuming that the number of localizers is n, their coordinates are distributed as $X_i = (x_i, y_i, z_i), i = 1,2, \dots, n$, and the distance between these readers and the unknown node $X = (x, y, z)$ is $r_i, i = 1,2, \dots, n$, respectively, and also according to the localization model of the Pythagorean theorem multilateral algorithm, the following system of equations is established:

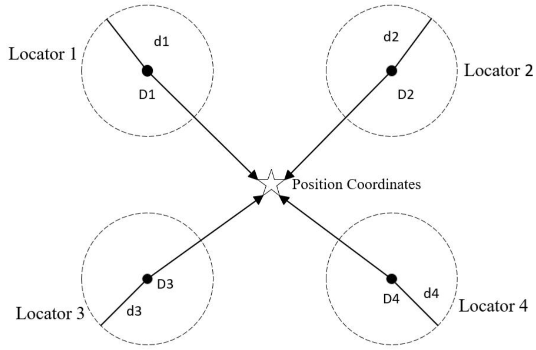

Figure 2. Schematic Diagram of Multilateral Positioning

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = r_1^2 \\ (x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2 = r_2^2 \\ \cdots \\ (x-x_n)^2 + (y-y_n)^2 + (z-z_n)^2 = r_n^2 \end{cases} \tag{3}$$

Subtract the last equation from the first, so that the squared terms of the coordinates of the unknown nodes in the system of equations can be eliminated to obtain the following n-1 dimensional system of linear equations equations:

$$\begin{cases} 2(x_n - x_1)x + 2(y_n - y_1)y + 2(z_n - z_1)z = r_1^2 - r_n^2 - x_1^2 - y_1^2 - z_1^2 + x_n^2 + y_n^2 + z_n^2 \\ 2(x_n - x_2)x + 2(y_n - y_2)y + 2(z_n - z_2)z = r_2^2 - r_n^2 - x_2^2 - y_2^2 - z_2^2 + x_n^2 + y_n^2 + z_n^2 \\ \dots \\ 2(x_n - x_{n-1})x + 2(y_n - y_{n-1})y + 2(z_n - z_{n-1})z = r_{n-1}^2 - r_n^2 - x_{n-1}^2 - y_{n-1}^2 - z_{n-1}^2 + x_n^2 + y_n^2 + z_n^2 \end{cases} \tag{4}$$

The matrix representation of this system of equations takes the form:

$$AX = B \tag{5}$$

Where the coefficient matrix A and the value vector B on the right-hand side are:

$$\boldsymbol{A} = \begin{bmatrix} 2(x_n - x_1) & 2(y_n - y_1) & 2(y_n - y_1) \\ 2(x_n - x_2) & 2(y_n - y_2) & 2(y_n - y_2) \\ \vdots & \vdots & \vdots \\ 2(x_n - x_{n-1}) & 2(y_n - y_{n-1}) & 2(y_n - y_{n-1}) \end{bmatrix} \tag{6}$$

$$\boldsymbol{B} = \begin{bmatrix} r_1^2 - r_n^2 - x_1^2 - y_1^2 - z_1^2 + x_n^2 + y_n^2 + z_n^2 \\ r_2^2 - r_n^2 - x_2^2 - y_2^2 - z_2^2 + x_n^2 + y_n^2 + z_n^2 \\ \vdots \\ r_{n-1}^2 - r_n^2 - x_{n-1}^2 - y_{n-1}^2 - z_{n-1}^2 + x_n^2 + y_n^2 + z_n^2 \end{bmatrix} \tag{7}$$

The unknown node $\boldsymbol{X}$ is:

$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{8}$$

Due to the presence of measurement error, the actual system of linear equations should be expressed as:

$$AX + N = B \tag{9}$$

Where N is the $n-1$ dimensional random error vector.

For this linear system of equations, the principle of least squares can be used to minimize the random error vector $N = B - AX$ mode squared, i.e., $||N||^2 = ||B - AX||^2$ is minimized, thus ensuring that the ranging error has the least impact on the positioning results.

$$||B - AX||^2 = (B - AX)^T(B - AX) = B^TB - B^TAX - X^TA^TB + X^TA^TAX \tag{10}$$

This is obtained by treating equation (10) as a function of $\boldsymbol{X}$ and taking the derivative of it, then making the derivative equal to zero:

$$\boldsymbol{A^T A X - A^T B = 0} \quad (11)$$

This equation is the regular equation for the linear least squares problem. This equation has a unique solution $X = (A^T A)^{-1} A^T B$ when the matrix A is full rank, otherwise the least squares method will no longer work.

From this it is possible to obtain an estimate of the target position by means of the least squares estimation algorithm.

$$\boldsymbol{X = (A^T A)^{-1} A^T B} \quad (12)$$

Since the position and detection ability of each locator varies when detecting the target position, it is inevitable that errors will occur when measuring the distance, so in order to reduce the impact of positioning errors, this paper utilizes a multilateral positioning model along with a least squares estimation algorithm to calculate the distance measurement error. The least squares estimation algorithm[10] is a method used in linear regression analysis that aims to find the best-fitting straight line to minimize the sum of squares of the errors between the actual data points and the predicted values.

5. Positioning Realization Methods and Results

In this paper, the localization of indoor electric work equipment is mainly divided into two steps.First of all, the preliminary regional localization of the electric power tools carrying the positioning tag is carried out to determine the regional information in which the electric power tools is located. After completing the preliminary localization, the precise positioning of the electric power tools is carried out to determine the detailed coordinate information of the electric power tools located in the region.

5.1 Methodology for the Realization of the Initial Positioning of the Region

The experimental environment is tentatively set as an indoor environment containing three areas, we install a low-frequency locator at the entrance of each area, the locator will send signals to the positioning tag and accept the signal returned by the tag, at the same time, the locator calculates the distance of the positioning tag relative to the locator through the measurement of the signal strength and the use of the RSSI ranging and positioning principle, and sends the information to the positioning software system to complete the calculation of the Positioning display.

After the tag enters into the A zone, the locator 1 located in the A zone, the locator 2 located in the B zone and the locator 3 located in the C zone detect the tag at the same time, and all three locators transmit the detected signal strength of the tag to the localization server, due to the fact that the signal detected by the locator 1 is not blocked by the wall, the signal is the strongest, so the system easily determines the tag's current location in the A zone. The preliminary indoor positioning map is shown in Figure 3.

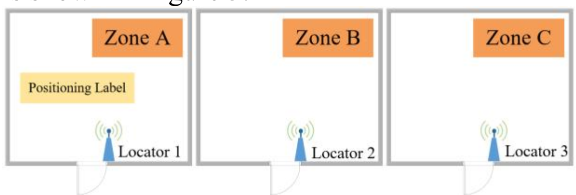

Figure 3. Indoor Preliminary Positioning Schematic

5.2 Simulation Results of Preliminary Regional Localization

The target location is generated by random numbers in order to simulate the arbitrary location of the electric power tools carrying the positioning tags in reality. The experimental environment is initially simulated as an indoor environment containing three rooms, each with an area size of 10m×7m, which can be changed by subsequent users according to the actual situation. The experimental results are shown in Figure 4.

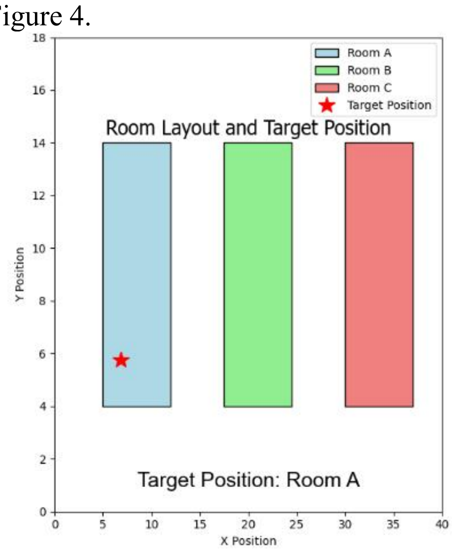

Figure 4. Preliminary Location Map of Electric Power Tools

In figure 4, the pentagram represents the electric power tools carrying the locator tag. It can be observed that when the pentagram is located in Room A, Target Position: Room A is displayed, indicating that the target's current position is located in Room A.

5.3 Precise Positioning Realization Method and Simulation Results

In practical applications, only the two-dimensional area information of the electric power tools is not enough, especially in the vertical structure of the complex environment, the user also needs to obtain the detailed coordinate information of the electric power tools in three-dimensional space to determine the precise location of the electric power tools, to facilitate the management of the electric power tools and find. Precise positioning can provide the exact position of the electric power tools in space, thus greatly improving the accuracy and practicality of positioning. According to the aforementioned, the steps of the precise positioning algorithm are firstly to convert the signal strength into distance by RSSI ranging principle, then to realize the positioning of the target location according to the multilateral positioning model, and finally to reduce the positioning error by using the least squares estimation algorithm, so as to complete the precise positioning of the electric power tools. The precise localization simulation is shown in Figure 5.

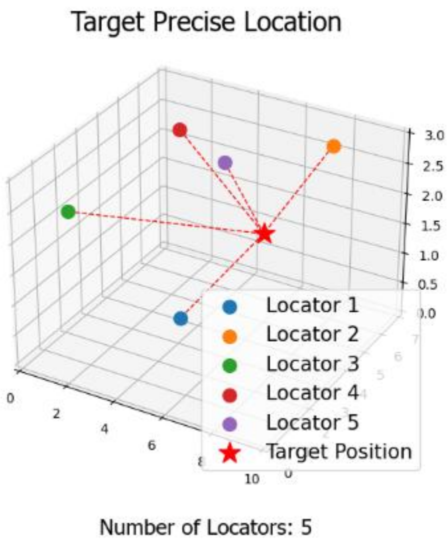

Figure 5. Precise Positioning Simulation

5.4 Indoor Positioning Software Design

The ultimate goal of the algorithm design in this paper is to visualize the specific location of electrical work equipment in the room, so on the basis of the previous paper, the main content of this chapter is to design the RFID-based electric power tools positioning software system, and the effect of the PC side of the demonstration, in order to complete the precise location of electric power tools located in the indoor and visualization of the demonstration.

5.5 Software Interface Design

The initial interface of the software consists of the two functions described in the previous section: the initial positioning of the room in which the electric power tools is located and the precise positioning of the electric power tools in a certain position in the room. The functions correspond to the “Basic Positioning” and “Advanced Position” buttons on the interface. As shown in Figure 6.

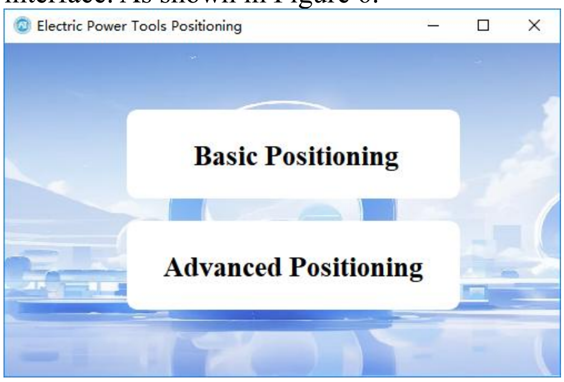

Figure 6. Software Initialization Interface

5.6 Advanced Positioning Interface

Users can click the button of “Advanced Positioning” to complete the precise positioning of the electric apparatus. The interface that appears after clicking the button is shown in Figure 7.

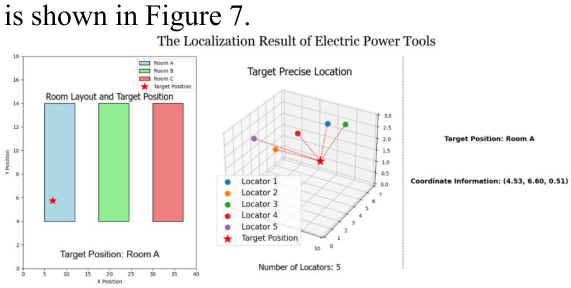

Figure 7. Display of the Software's Positioning Results

In figure 7, it can be observed that the localization result map is divided into three panels, the first panel being the initial localization of the electrical workpiece to determine the specific room in which the target location is located. After the initial localization of the target location is completed, the second panel will display detailed coordinate information of the target location within the room. The third panel will display the room in which the electrical work tool is located and the specific coordinate information within the room.

In this experiment, the number of locators is set to five, and in the subsequent use process, users can adjust themselves according to the actual needs. In the analysis of the experimental results, it is found that the accuracy of positioning is affected by the number of locators, the number of detections of locator tags by locators and other factors. The more the number of locators, the more the number of detections, the higher the positioning accuracy, but these two cannot be increased indefinitely, which will result in increased costs and slower response time. Positioning technology is affected by more factors such as meteorological factors, geographic factors [11], for such problems, the noise difference can be modeled by constructing appropriate, further reducing model parameters and computational load to improve detection speed [12].

6. Summary

This paper mainly focuses on the problems existing in the indoor localization technology of electric power work equipment, and carries out in-depth research and discussion based on radio frequency identification technology. By using the least squares estimation algorithm and the multilateral positioning algorithm, the indoor precise positioning of the electric power tools is completed. In addition, the interface design of the positioning software is also completed, which provides an intuitive display for indoor positioning.

The positioning system can complete the preliminary positioning and precise positioning of electrical work equipment. In the preliminary positioning function, the user can determine the room information where the target location is located. In the precise positioning function, the user can determine the detailed coordinate information in the room where the target position is located. Through testing in a number of actual indoor environments, the positioning system shows high accuracy and practicality, providing effective technical support for the application of indoor positioning technology.

In summary, the active RFID-based electric work equipment positioning technology has a broad application prospect in the field of electric work equipment management, searching, positioning, etc., and is of great significance in improving the accuracy of indoor positioning. The stability and accuracy of the system can be further improved in the future to meet a wider range of practical needs.

Acknowledgments

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