RFID Indoor Positioning Method Based on Received Signal Strength Indication

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Abstract. RFID indoor positioning technology has a good application prospect. This paper analyzes the RFID indoor positioning method based on received signal strength indication (RSSI). First, the indoor signal propagation model is constructed, the model parameters are estimated using the weighted least squares method, and then the received signal strength indication is used to estimate the distance between the target to be located and the reader at the known position. This method has certain practical value.

1. Introduction

With the continuous deepening and development of pervasive computing research, and more applications need to know the location information of objects, Location-Based Services has received more and more attention¹, ². Indoor positioning technology has attracted much attention for its good application prospects in positioning search and rescue, public safety, and commerce³, such as warehousing positioning, hospital medical equipment management, coal mine personnel positioning, park or museum tourist navigation, prison inmates and other areas of supervision.

The main method of RFID positioning is to use the tag as the unique identification characteristic of the object, and measure the spatial position according to the received signal strength indication (RSSI) of the radio communication between the reader and the tag mounted on the object. Ranging based on RSSI is a relatively inexpensive indoor positioning technology. This method can estimate the spatial position of indoor objects more accurately, and has a good application prospect.

2. Literature Review

Commonly used ranging techniques include TOA (Time of Arrival)⁴, TDOA (Time Difference of Arrival)⁵, AOA (Angle of Arrival)⁶, POA (Phase of Arrival)⁷, RSSI (Received Signal Strength Indication)⁸, etc. However, TOA, TDOA, AOA, and POA methods require special hardware to accurately measure the arrival time or angle, which is impractical for ordinary equipment⁹. For example, TOA and TDOA methods require precise clock synchronization between tags and readers, which is difficult. AOA ranging technology needs to rely on antenna array and other special hardware equipment to obtain angle information.
The RSSI method is low cost and can obtain RSSI values and perform ranging without additional hardware, thus becoming the most commonly used method for RFID positioning.

3. Theoretical Model

3.1. Signal propagation model

Received Signal Strength Indication (RSSI), which is a received signal strength, is a value indicating the amount of electromagnetic energy in the current medium. Since the signal strength will decrease during the propagation of the signal, the distance between the signal point and the receiving point can be determined by the strength of the received signal, and then the positioning calculation can be performed according to the corresponding data. At present, RFID positioning is mostly based on signal strength positioning technology. It uses the RSSI to determine the position of the object to be located. According to the characteristic that the signal energy decays exponentially with distance, the distance information between the tag and the reader is reflected.

Using theory and experience, the law of electromagnetic wave energy in the process of propagation is in accordance with the following formula [10, 11].

\[
PL(d) = PL(d_0) - 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma
\]  

Where \(d_0\) is an arbitrary reference distance and \(d\) is the true distance between the reader and the tag. \(\gamma\) is the path loss index, depending on the environment. \(PL(d)\) is the received signal strength indication at a distance \(d\) from the transmission; \(PL(d_0)\) is the received signal strength indication at a distance \(d_0\) from the transmission; \(X_\sigma\) is a Gaussian random variable with a mean of zero and a variance of \(\sigma^2\) (dB).

Available from formula (1),

\[
d = d_010^{\frac{(PL(d_0)-PL(d)+X_\sigma)}{10\gamma}}
\]  

3.2. Model parameter estimation

According to the formula (2), if \(\gamma, X_\sigma\) can be known, then the distance \(d\) of the tag to be positioned can be calculated. These two parameters have different values in different environments and need to be determined by machine learning or parameter estimation [12, 13]. This paper uses a linear regression fit method to estimate these parameters, namely the weighted least squares method.

If formula (1) is changed, it can be described as

\[
y(k) = ax(k) + b = g^T(k)\zeta
\]  

Among them,

\[
y(k) = PL(d_k) - PL(d_0)
\]

\[
x(k) = 10\log_{10}\left(\frac{d_k}{d_0}\right)
\]

\[
a = -\gamma
\]

\[
b = X_\sigma
\]

\[
g(k) = \begin{bmatrix} x(k) \end{bmatrix}^T
\]

\[
\zeta = [a \ b]^T
\]

Solving by weighted least squares method, you can get...
\[ \zeta = (X^T \Lambda X)^{-1} X^T \Lambda Y \]  
\[(4)\]

Among them,
\[ X = \begin{bmatrix} x(l) & 1 \\ \vdots & \vdots \\ x(l) & 1 \end{bmatrix}, \Lambda = \text{diag}(\lambda(1) \cdots \lambda(l)), \]
\[ Y = [y(1) \cdots y(l)]^T \]

In this way, the parameters of the indoor signal propagation model are determined.

3.3. RSSI-based indoor positioning algorithm

Since the parameters of equation (2) have been determined, then by this indoor signal propagation model, the distance from any tag to be located to the reader can be calculated from the RSSI.

3.3.1. Centroid method. For calculating the distance, it can be solved by the trilateration method\cite{14}, as shown in equation (5).

\[ \sqrt{(x-x_1)^2 + (y-y_1)^2} = d_1 \]
\[ \sqrt{(x-x_2)^2 + (y-y_2)^2} = d_2 \]
\[ \sqrt{(x-x_3)^2 + (y-y_3)^2} = d_3 \]
\[(5)\]

Solving the system of equations gives the coordinates \((x, y)\) of the tag to be located. Since the RSSI attenuation has a random component, it is not accurate enough to determine the coordinates of the tag by only one-time three-side ranging. Therefore, the centroid method can be used to construct multiple trilateral ranging triangles by multiple readings, and generate more coordinates. The centroid of these coordinates is found, with the centroid as the coordinate of the tag to be positioned.

For the triangle centroid, it can be calculated using equation (6):
\[ \left( \frac{x_1 + x_2 + x_3}{3}, \frac{y_1 + y_2 + y_3}{3} \right) \]
\[(6)\]

3.3.2. Least squares method. The essence of the least squares method is to use mathematical tools to give a systematic solution to the equation, rather than using the mean to combat random errors, like the centroid method. The main idea is as follows. If a tag receives the RSSI values of \(n\) RFID readers, \(n\) distances can be estimated according to RSSI, and then form the following nonlinear equations, as shown in equation (7).

\[ \sqrt{(x-x_1)^2 + (y-y_1)^2} = d_1 \]
\[ \sqrt{(x-x_2)^2 + (y-y_2)^2} = d_2 \]
\[ \cdots \]
\[ \sqrt{(x-x_n)^2 + (y-y_n)^2} = d_n \]
\[(7)\]

If \(n \geq 3\), equation (7) becomes an overdetermined nonlinear equations. Since the overdetermined equations have no definite solution, they can only be modified to the least squares solution, which can be solved by Gauss-Newton method. The Gauss-Newton method can be used to solve the problem of nonlinear regression prediction.
3.4. Algorithm simulation
The experiment was carried out in an open area of 10m × 10m. Firstly, the parameters of the indoor signal propagation model were estimated, and then the unknown tag position was estimated.

3.4.1. Parameter estimation of the indoor signal propagation model. In this region (0-9) m, one node was set every 1 meter, and the RSSI of nodes 1-9 to 0 was measured. According to the algorithm in this paper, the attenuation signal between reference nodes was processed, and the parameters γ and $X_σ$ of the indoor signal propagation model were calculated. In general, γ was 2.5 according to experience, and $X_σ$ was 0 according to zero gauss distribution. Through experiments, the parameters γ and $X_σ$ estimated by this algorithm are better than the empirical values, and can effectively reduce the ranging error.

3.4.2. Position estimation. Set the unknown tag node coordinates to (4m, 6m). The reference nodes were added step by step, and the position of unknown tag node was estimated by the centroid method and the least square method. In this experiment, at most 8 reference nodes were introduced. The positioning accuracy of the two methods is shown in Figure 1.

![Positioning error of two methods](image)

Figure 1. Positioning error of two methods

It can be seen from Figure 1 that with the increase of the number of nodes, the positioning accuracy of both the centroid method and the least square method is improving. In comparison, the least square method is more accurate than the centroid method.

4. Conclusion
In the RSSI positioning algorithm, the parameters of the RSSI model are estimated by linear regression method, and then the position of the target tag is estimated by centroid method or least square method. The results show that the indoor positioning algorithm based on RSSI is effective. And with the increase of the number of nodes involved in positioning, the positioning accuracy is also significantly improved.

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