Indoor Localization Based on Centroid Constraints of AP Quadrilateral Networks

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Abstract. With the development of wireless communication technology at home and abroad, wireless indoor positioning technology has become an indispensable technology. In the current indoor scenes, due to the extensive deployment of Wireless Local Area Network (WLAN) infrastructure, indoor WLAN location method has become a research hotspot. There are a variety of WLAN Access Points (APs) in indoor environment, which can be used in indoor localization. While existing indoor positioning technology often works along with high cost and low system stability especially in complex indoor environment. To solve this problem, a centroid constraint indoor location method based on AP quadrilateral network is proposed. By collecting and processing the Received Signal Strength (RSS) of APs, this method exploits propagation models and trilateration method to get the target quadrilateral centroid set, which can be applied to obtain the ultimate estimate coordinates of pending points under the condition of geometric constraints. This method enhances the robustness of indoor localization system and implements low-cost indoor localization.

Keywords: Indoor localization · Centroid constraint · Quadrilateral network · WLAN

1 Introduction

Since the Federal Communications Commission (FCC) established the E-911 positioning standard [1], wireless positioning technology has attracted the attention of various companies due to its practicality. Many foreign universities, research institutes and major companies have increased their investment into the research of wireless positioning technology [2]. At the same time, many journals and related patents have been published gradually in various magazines and periodicals. Domestic research on indoor positioning technology starts late, but with the increase of domestic attention to indoor positioning technology, has also obtained a lot of achievements. Outdoor positioning technology such as GPS is basically mature [3]. However, due to the complexity of indoor environment, many indoor positioning algorithms are often not unfaithful in actual environment. For example, the traditional APIT algorithm is prone to misjudge whether the pending points are located in the triangle, which will lead to

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the reduction of positioning accuracy [4]. On the other hand, the location results of APIT location algorithm are excessively dependent on network connectivity and the density of APs deployment, which will lead to high volatility of location results [5]. Moreover, the general use of polygon centroid positioning algorithm requires the deployment of numerous AP, which will lead to excessive positioning system overhead. Therefore, it is very important to reduce the positioning cost while ensuring the stability of the positioning system. To the end, we propose a centroid constraint indoor location method based on AP quadrilateral network to obtain the ultimate estimate coordinates of pending points under complex indoor environment. In this way, it is dispensable to collect fingerprint and build fingerprint database in the offline phase. We simply deploy some known APs in the test area and combine them into a number of quadrangles. Then, the initial estimated coordinates are calculated by using the propagation model and tri-lateral measurement positioning method. Finally, all quadrangles containing the initial estimated coordinates are extracted to obtain the target quadrangle set, which will be utilized to obtain the ultimate estimate coordinates of pending points under the constraint of centroids. The structure of this paper is as follows. The related work is introduced in Sect. 2 and the proposed method is described in Sect. 3. The experimental results are presented in Sect. 4. Finally, we conclude this paper and provide an outlook of future work in Sect. 5.

2 Related Work

In the information era with the rapid development of the Internet, wireless users can enjoy the convenience anytime and anywhere by using intelligent portable devices. Therefore, people's demand for Location-Based Service (LBS) shows a significant growth trend. However, in the indoor environment, it is not easy to capture the satellite signals of the Global Positioning System (GPS) continuously and stably. Therefore GPS which is commonly used outdoor cannot meet the positioning accuracy requirements of most indoor LBS. We can see that indoor positioning technology has a good development prospect. Among numerous indoor positioning technologies, WLAN-based indoor positioning has the advantages of wide coverage, low deployment cost and it does not need special hardware equipment [6]. Therefore, WLAN location based on RSS has gradually become the mainstream of indoor positioning technology.

The indoor localization methods based on WLAN RSS can be roughly divided into propagation model method and location fingerprint method. The former establishes the mathematical relationship between the propagation distance and RSS through the signal propagation model, and then estimates the location of the pending points according to the known location of WLAN AP by using geometric positioning algorithms such as trilateral measurement positioning method. However, in this way, it is difficult to establish accurate signal propagation model in complex indoor environment, which will affect the positioning accuracy [7]. The latter mainly includes offline and online stages. In the offline stage, the location fingerprint database is built by collecting RSS from different APs at a certain number of pre-calibrated Reference Points (RP). Afterwards, in the online phase, the newly acquired RSS is matched with the location fingerprint database to obtain the estimated location of the pending points.

3 Approach Overview

3.1 Collecting and Processing RSS Sequences

Existing studies have shown that the indoor propagation model can better reflect the relationship between physical location and RSS data. Deploy n APs in the test area, whose communication range covers the entire test area. It is necessary to ensure that the APs can form at least one quadrilateral containing the test area, as shown in Fig. 3. APs are combined in the test area to get p ($p \leq C_n^4$, p is an integer) different initial quadrangles and the set of their centroid coordinates is obtained accordingly. RSS of APs was collected at the pending point, then the RSS set: can be represented as

$$\mathbf{RSS} = \begin{bmatrix} rss_1^1 & rss_1^2 & \cdots & rss_1^n \\ rss_2^1 & rss_2^2 & \cdots & rss_2^n \\ \vdots & \vdots & rss_j^l & \vdots \\ rss_k^1 & rss_k^2 & \cdots & rss_k^n \end{bmatrix} \tag{1}$$

where rss_j^l ($j = 1, 2, \cdots, k$; $l = 1, 2, \cdots, n$) is the RSS from the l-th AP, which is collected for the j-th time at the pending point. From this set, whole RSS data from the l-th AP can be easily represented as

$$\mathbf{RSS}^l = \left\{ rss_1^l,\ rss_2^l,\ \cdots,\ rss_k^l \right\} \tag{2}$$

In this way, we can get RSS data of all Aps. Finally, the mean value of each $\mathbf{RSS}^l$ ($l = 1, 2, \cdots, n$) is calculated to obtain the average received signal strength set $\overline{\mathbf{RSS}}$, which can be represented as

$$\overline{\mathbf{RSS}} = \left\{ \overline{RSS^1},\ \cdots,\ \overline{RSS^l},\ \cdots,\ \overline{RSS^n} \right\} \tag{3}$$

3.2 Calculation of Initial Estimated Coordinates

Based on $\overline{\mathbf{RSS}}$ and propagation model, the propagation distance from the pending point to each AP in the test area can be worked out accordingly by

$$d = d_0 10^{\frac{RSS_0 - \overline{RSS_l} + Z}{10\rho}} \tag{4}$$

where RSS_0 is the signal strength at reference distance d_0 and $\overline{\mathrm{RSS}_l}$ is the average received signal strength from the l-th AP. ρ is path attenuation index and Z is Gaussian noise. we usually set ρ to 2, the mean value of Z to 2, and the variance of Z to 4 dBm.

We sort the propagation distance of the positioning point to each AP and extract the AP coordinates corresponding to the minimum three propagation distances. It is necessary to ensure that the three APs are not on the same line and the extracted AP coordinates are recorded as: $(x_{\min 1}, y_{\min 1})$, $(x_{\min 2}, y_{\min 2})$, $(x_{\min 3}, y_{\min 3})$. According to the

AP coordinates corresponding to the minimum three propagation distances and the distance from the pending points to these three APs (We can write them as d_1, d_2, d_3), then the equation set can be obtained as

$$\begin{cases} \sqrt{(\hat{x} - x_{\min 1})^2 + (\hat{y} - y_{\min 1})^2} = d_1 \\ \sqrt{(\hat{x} - x_{\min 2})^2 + (\hat{y} - y_{\min 2})^2} = d_2 \\ \sqrt{(\hat{x} - x_{\min 3})^2 + (\hat{y} - y_{\min 3})^2} = d_3 \end{cases} \tag{5}$$

Due to the influence of noise and multi-path effect, the initial estimated coordinates of the pending points can't be obtained accurately. Therefore, its estimated coordinates $(\hat{x}, \hat{y})$ are used to express the position. The above equations can be expressed by

$$\mathbf{H}\hat{\mathbf{X}} = \hat{\mathbf{b}} \tag{6}$$

$$\mathbf{H} = \begin{bmatrix} 2(x_{\min 2} - x_{\min 1}) & 2(y_{\min 2} - y_{\min 1}) \\ 2(x_{\min 3} - x_{\min 1}) & 2(y_{\min 3} - y_{\min 1}) \end{bmatrix} \tag{7}$$

$$\widehat{\mathbf{b}} = \begin{bmatrix} x_{\min 2}^2 - x_{\min 1}^2 + y_{\min 2}^2 - y_{\min 1}^2 + d_{\min 1}^2 - d_{\min 2}^2 \\ x_{\min 3}^2 - x_{\min 1}^2 + y_{\min 3}^2 - y_{\min 1}^2 + d_{\min 1}^2 - d_{\min 3}^2 \end{bmatrix} \tag{8}$$

where $\hat{\mathbf{X}} = \begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix}$ is the preliminary estimated coordinate of the pending points, which can be calculated by

$$\hat{\mathbf{X}} = \left(\mathbf{H}^{\mathrm{T}}\mathbf{H}\right)^{-1}\mathbf{H}^{\mathrm{T}}\hat{\mathbf{b}} \tag{9}$$

3.3 Final Estimated Coordinates Under the Centroid Constraint

Based on the estimated coordinates of the pending points, the set of the target quadrilaterals can be obtained by extracting all the quadrilaterals containing the pending points with the method of inner angle sum method. We can assume that the four vertices of the quadrilateral are A, B, C, and D. If the pending points are on the line which connects any two adjacent vertices of the quadrilateral, it is determined that the pending points are outside the quadrilateral. At this time, this quadrilateral is not target quadrilateral. The decision diagram is shown in Fig. 1.

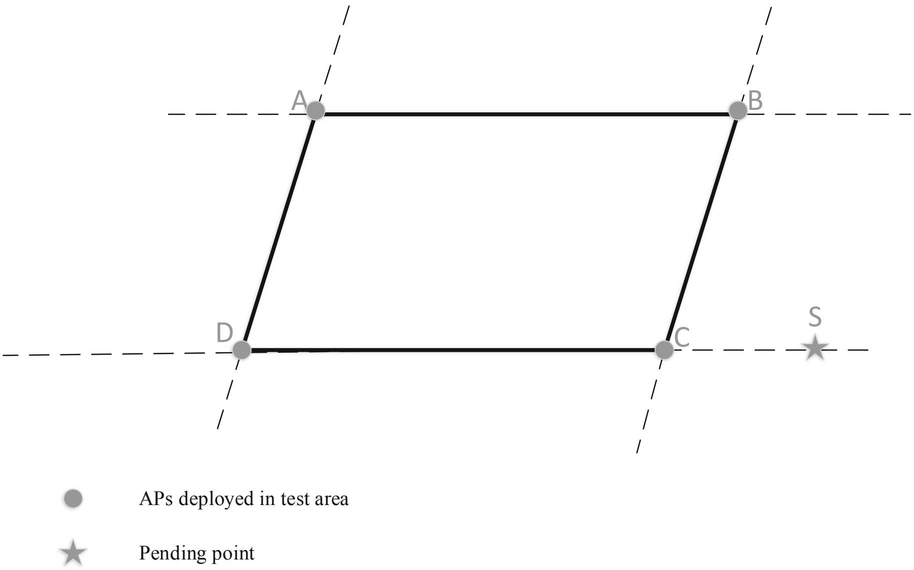

Fig. 1. Diagram of decision when the pending point is located on the line of any two adjacent vertices of the quadrilateral.

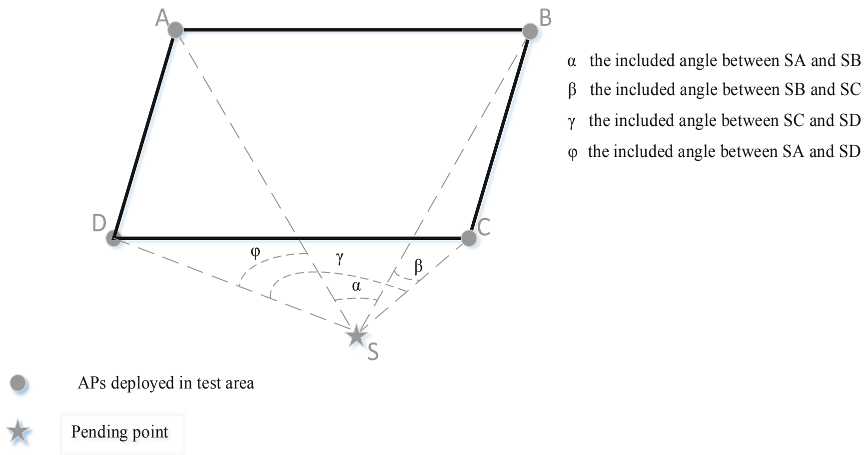

Fig. 2. Diagram of decision when the pending point is not located on the line of any two adjacent vertices of the quadrilateral.

When the pending points are not on the line of any two vertices of the quadrilateral, the pending points are connected with the four vertices of the quadrilateral, A, B, C and D. Then, the triangle cosine theorem is used to calculate the four included angles formed by connecting the pending points with the four vertices. If the sum of included angles is equal to 2π, the pending points are determined to be within the quadrilateral, that is to say, this quadrilateral is the target quadrilateral. Otherwise, the pending points are determined to be located outside the quadrilateral, that is to say, the quadrilateral is not the target quadrilateral. The decision diagram is shown in Fig. 2. Following this step, we can obtain all quadrangles containing the preliminary estimated coordinates of the pending points, that is to say, the set of target quadrangles can be obtained.

Based on the target quadrangle set, the centroid coordinates corresponding to each target quadrangle in the set are obtained and we can calculate the average values of all the centroid coordinates $(\bar{x}, \bar{y})$, Which is calculated by

$$\begin{cases} \bar{x} = \sum_{i=1}^{p} x_i / i \\ \bar{y} = \sum_{i=1}^{p} y_i / i \end{cases} \tag{10}$$

where x_i is the x-coordinate of the i-th $(i = 1, 2, \cdots, p)$ quadrilateral. In the same way and y_i can be calculated accordingly. Finally, the initial estimated coordinates of the pending points are weighted and fused with the mean value of the centroid coordinates of the target quadrilateral set to obtain the final estimated coordinates of the pending points (x, y), Which is calculated by

$$\begin{cases} x = \lambda_1 \hat{x} + \lambda_2 \bar{x} \\ y = \lambda_1 \hat{y} + \lambda_2 \bar{y} \end{cases} \tag{11}$$

among them, λ_1 and λ_2 are the fusion weights, we usually set λ_1 = 0.8 and λ_2 = 0.2.

4 Experimental Result

4.1 Environmental Layout

As shown in Fig. 3, the experimental environment is selected on the 5th floor in a building with the dimensions of 57 m × 25 m. Nine D-Link2310 APs are deployed in test area which includes a straight corridor and a lab.

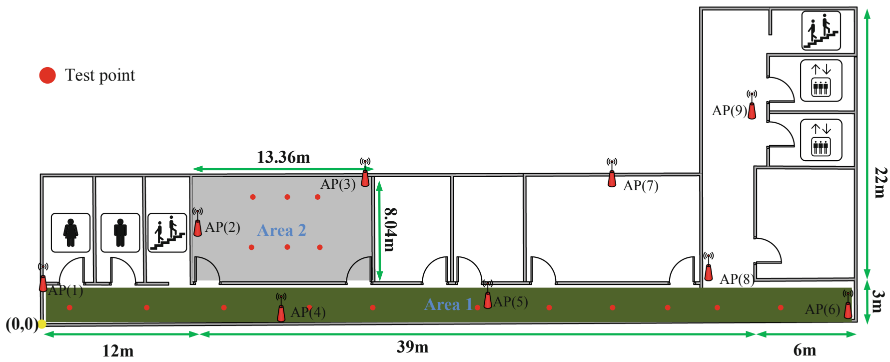

Fig. 3. Diagram of decision when the pending point is not located on the line of any two adjacent vertices of the quadrilateral.

4.2 Test Results

In order to perform the experiment conveniently, as shown in Fig. 3, we randomly selected 17 pending points for testing. The received signal strength from APs is then collected orderly at the pending points to calculate the initial estimated coordinates. Afterwards, the interior Angle sum method is used to extract all quadrangles which contain the initial estimated coordinates. That is to say, the target quadrangle set is obtained. Finally, the final estimated coordinates of the pending points are obtained by weighted fusion. The cumulative probability distribution diagram of positioning error of experimental results is shown in Fig. 4. It can be seen that compared with the least square method, our method improves the accuracy of positioning system in complex indoor environment.

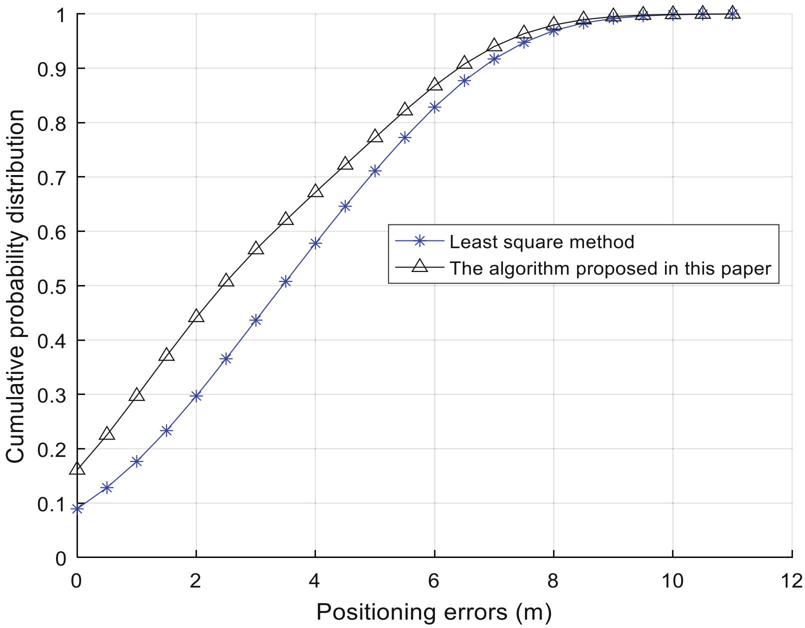

Fig. 4. Comparison diagram of cumulative probability distribution of positioning errors.

Based on Fig. 4, Table 1 can be obtained easily. It can be seen that, compared with the least square method, the average positioning error and the maximum positioning error of the algorithm proposed in this paper are both smaller than the least square method, which indicates that our method also enhances the stability of the positioning system under complex indoor environment.

Table 1. Positioning performance comparison.

Localization algorithm/Performance indicators	Error probability within 5 meters	Mean localization error	Maximum localization error
Least square method	67.87%	3.62 m	7.89 m
The algorithm proposed in this paper	77.26%	2.71 m	6.10 m

In addition, we also tested the influence of different fusion weights on the positioning performance of the experiment, and the results are shown in Fig. 5. Based on a large number of experimental data, $\lambda_1 = 0.8$ and $\lambda_2 = 0.2$ are selected as the fusion weight.

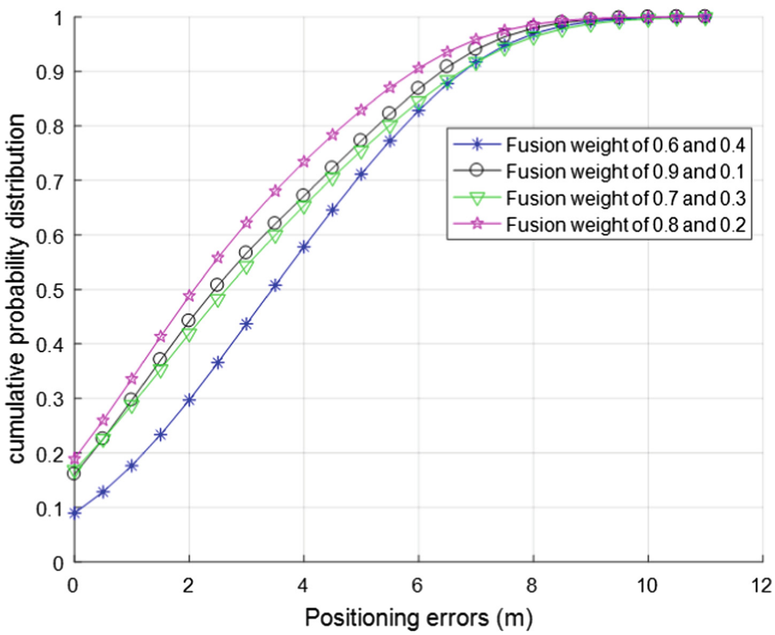

Fig. 5. Comparison diagram of cumulative probability distribution of positioning errors corresponding to different fusion weights.

5 Conclusion

In this paper, a new indoor localization method based on polygonal centroid is proposed. This method does not need to collect fingerprint and build fingerprint database in the off-line stage. We should only deploy a certain number of known APs in the test area and combine them to obtain the initial quadrilaterals which contain the test area. Then, the received signal strength from APs is collected at the pending points, and the preliminary estimated coordinates of the pending points are calculated by combining the propagation model formula and trilateral measurement positioning method. Based on the initial estimated coordinates, the target quadrilateral set containing the initial estimated coordinates is extracted by using the method of interior angle sum. Finally, the initial estimated coordinates of the pending points are weighted and fused with the mean value of the centroid coordinates of the target quadrilateral set to obtain the final estimated coordinates of pending points. The experiment results show that the proposed algorithm not only realizes the low-cost indoor positioning, but also effectively enhances the stability of the positioning system in complex indoor environment.

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