RFID Indoor Localization Algorithm Based on Adaptive Self-Correction

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Abstract

With the rapid development of wireless communication and embedded system, wireless positioning systems are paid more and more attention to. Radio Frequency Identification (RFID) localization system is getting more important, due to its own advantages, such as no contact, non-line-of-sight nature, promising transmission range and cost-effectiveness. To improve the accuracy of active RFID indoor location system, some traditional RFID indoor localization systems were studied, such as LANDMARC. On this basis, an adaptive self-correction location algorithm was presented, which uses a positioning correction value to correct the positioning result. N minimum errors and position results are obtained by using adaptive K-nearest neighbor algorithm N times. The positioning correction value calculated with N minimum errors in weighted way. The sum of the positioning average value and the positioning correction value would be the final positioning results. Experimental results show that compared with adaptive K-nearest neighbor algorithm and error self-correction algorithm, the proposed method provides a higher accuracy and stability.

Keywords: *RFID, indoor localization, positioning correction value, adaptive K-nearest neighbor algorithm; LANDMARC*

1. Introduction

The current locating-aware is becoming an important characteristic in the areas of ubiquitous computing, people have a great application requirement of location-based services in many application scenarios. As one of the core technology to provide location-based services, there have been many universities and research centers doing researches on indoor positioning. Indoor localization technology has a wide range of applications, not only can be used for positioning the object (such as warehouse location, hospital medical equipment management etc.), but also be used for personnel localization (such as coal mine personnel positioning, the hospital staff positioning etc.). From the practical point of view, indoor positioning technology can effectively improve the production management level and work efficiency; From the perspective of life, indoor localization technology greatly convenient access to location information. Existing localization mechanisms, including the Global Positioning System (GPS), infrared positioning, Ultrasonic positioning, Wi-Fi positioning, Radio Frequency Identification (RFID) [1~3]. RFID technology using RF non-contact form of two-way communication, automatic identification tag, access to relevant data, has the advantages of high precision, non line of sight, strong anti-interference, high security, can identify the high-speed movement of label and also identify multiple tags, is becoming the preferred technique for indoor localization system[4~5].

At present, there have been many typical indoor localization positioning algorithm based on RFID technology, such as RADAR [6], SpotON [7], LANDMARC [8~10] , all these have

laid a good foundation for us to study the indoor positioning technology. RADAR using fingerprint method to record the training data in the location space, will be divided into off-line training and real-time matching two stages, when the environment of off-line training phase and the environment of real-time matching phase are not the same, the positioning effect becomes worse. SpotON using iterative computing method to approach the true value gradually, finally get a minimum error result, positioning accuracy is influenced by the starting point and the step size, and spend a large amount of calculation. LANDMARC is based on the Received Signal Strength Indicator (RSSI), using the method of active reference tags aided positioning, not only reduce the number of reader and costs at the same time, but also further enhance the positioning accuracy. Active tag has a better reliability, signal transmission distance farther and RF power smaller reader need compared to passive tag. LANDMARC is very effectively, there are also some areas of improvement. An error self-correction algorithm was put forward [11], which selects K adjacent reference tags. The method estimates its coordinates sequentially and computes the errors, and takes the average value of errors as the positioning correction value, so reduces the error caused by the environment. K-nearest neighbor algorithm was proposed [12]. K is automatically adjusted according to the environment in this algorithm. It improved the ability of system to adapt the environment. To improve the accuracy of RFID indoor location system furthermore, we present an adaptive self-correction location algorithm based on LANDMARC, which uses a positioning correction value to correct the positioning result. The algorithm will solve the problems that exist in error self-correction algorithm, recalculate the positioning correction value by using adaptive K neighbor algorithm N times to correct positioning results. Experimental results show that compared with adaptive K-nearest neighbor algorithm and error self-correction algorithm, the proposed method provides a higher accuracy and stability.

The remainder of this paper is organized as follows: The main content of this paper is constructed in 6 sections as follows: Section 2 gives analyzing of LANDMARC and error self-correction. Section 3 describes the adaptive K-nearest neighbor algorithm to make adaptive self-correction. Section 4 describes the RFID indoor localization algorithm based on adaptive self-correction. Section 5 discusses experiments and analysis. Section 6 concludes our work and future work.

2. Analyzing of LANDMARC and Error Self-correction

In the following section, we will describe the principle of LANDMARC and error self-correction method. Then, we find the problems in these algorithms by analyzing them.

2.1. Principle of LANDMARC

Suppose we have n RF readers along with m tags as reference tags and u tracking tags as objects being tracked. System layout is shown in Figure 1.

The signal strength vector for a tracking tag is defined as $S=(S_1,S_2,\ldots,S_n)$. S_i denotes the signal strength of the tracking tag perceived on reader i, $i\in(1,n)$. The signal strength vector for the reference tag is defined as (1).

$$\vec{\theta} = (\theta_1, \quad \theta_2, \cdots, \quad \theta_n) \qquad (1)$$

Where θ_i denotes the signal strength of the reference tag perceived on reader i, $i\in(1,n)$. The Euclidian distance in signal strength between a tracking tag and a reference tag rj can be defined as (2).
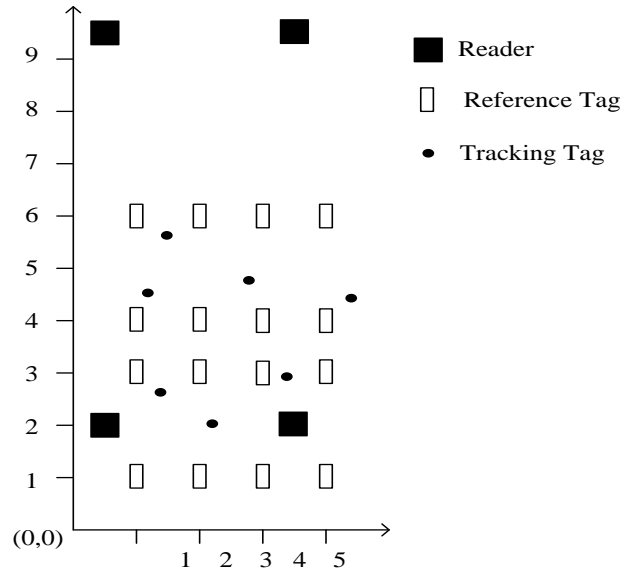
Figure 1. LANDMARC System

$$E_j = \sqrt{\sum_{i=1}^{n}(\theta_i - S_i)^2}, \, j \in (1, m) \tag{2}$$

When there are m reference tags, E vector of a tracking tag is $E=(E_1, E_2, \ldots, E_m)$. K smallest values from the E are selected out and the unknown tracking tag will be located in a cell surrounded by these k reference tags. The unknown tracking tag coordinate is obtained by (3).

$$(x, y) = \sum_{i=1}^{k} w_i(x_i, y_i) \tag{3}$$

Where w_i is the weighting factor of k selected nearest neighbors, it defined as (4).

$$w_i = \frac{\dfrac{1}{E_i^{2}}}{\sum_{j=1}^{k}\dfrac{1}{E_j^{2}}} \tag{4}$$

2.2. Error Self-correction

LANDMARC uses the reference tags aided positioning. However, the algorithm does not take correction value to correct positioning into account, so calculating the correction value to correct positioning results could be added into the algorithm.

Considering the tracking tag and the reference tags may have similar errors due to the neighboring positions, error self-correction algorithm calculates the correction value to correct positioning results by using the reference tags.

First, choose k reference tags with lowest E values as neighboring tags. Second, the k reference tags will be positioned as a tracking tag in turn, which would have an estimated position equal to the average value of the remaining k-1 reference tags, and calculate the error between the actual position and the estimated position. Finally, the average value error will be the positioning correction value, which plus the average value of the k neighboring reference tags will be the final positioning results.

2.3. Problems with Error Self-correction

Through the analysis and Research on error self-correction algorithm, it has the following problems.

(1) Select the same k neighboring reference tags, will get the same positioning results.
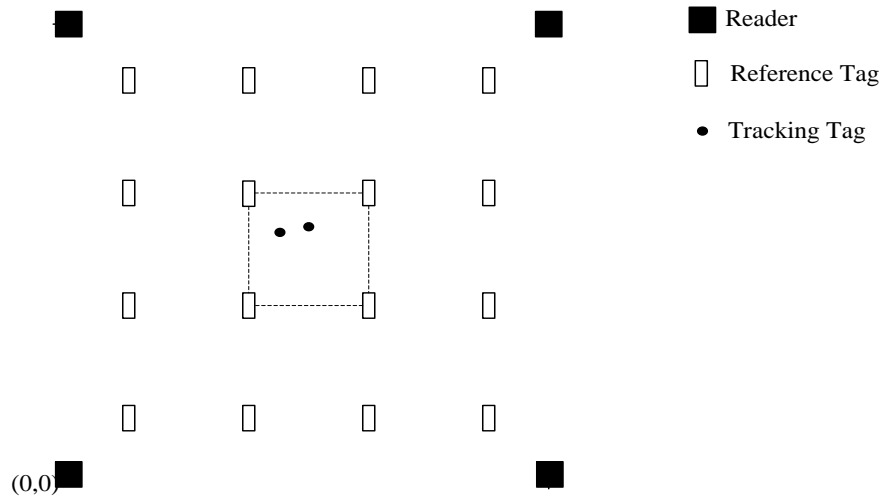
Figure 2. Error Self-correction

Set *k*=4 in Figure 2. Obviously, two adjacent tracking tags are locate in the different positions, select the same reference tags connected by dotted lines to calculate their positions. The algorithm calculates the tracking tag position by using the mean position. Using the mean position of three reference tags as the estimated position of the remaining reference tag, it would lead to a fixed positioning correction value. Using the mean position of four reference tags plus the positioning correction value, it will lead to the same final positioning result. Therefore, as long as the same k neighboring reference tags are selected, we will have the same positioning results.

(2) The positioning correction value is not accurate.
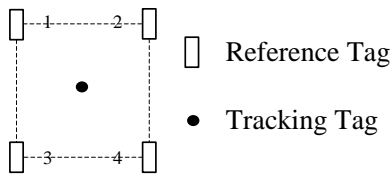
Figure 3. In the Central Region
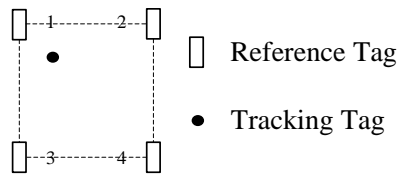

Figure 4. In the Surrounding Region

When the tracking tag locates in the central region (Figure 3), the distances of the tracking tag to four neighboring reference tags are similar. The errors of four neighboring reference tags are involved in calculating the positioning correction value. The value is credible, which could improve the positioning accuracy. But when the tracking tag locates in the surrounding region (Figure 4), the tracking tag is too far away from the 4th reference tag, the environmental impacts are different. Let the 4th reference tag involve in calculation will get a value that is not credible, even reduce the positioning accuracy.

The former problem is caused by using the mean position way, do not use it can solve the problem. This paper focuses on the latter and puts forward a new positioning correction value calculation method.

3. Adaptive Self-correction

Adaptive *K*-nearest neighbor algorithm supposes that the tracking tag and the nearest reference tag will have the same optimal *k* when they locate in the similar environment. This paper based on the assumption. If the tracking tag and the nearest reference tag locate in the similar environment, they will have the similar error when using the same *k* and positioning method. Therefore, we use only the error of the nearest reference tag to calculate the positioning correction value.

Adaptive *K*-nearest neighbor algorithm is shown in Figure 5.
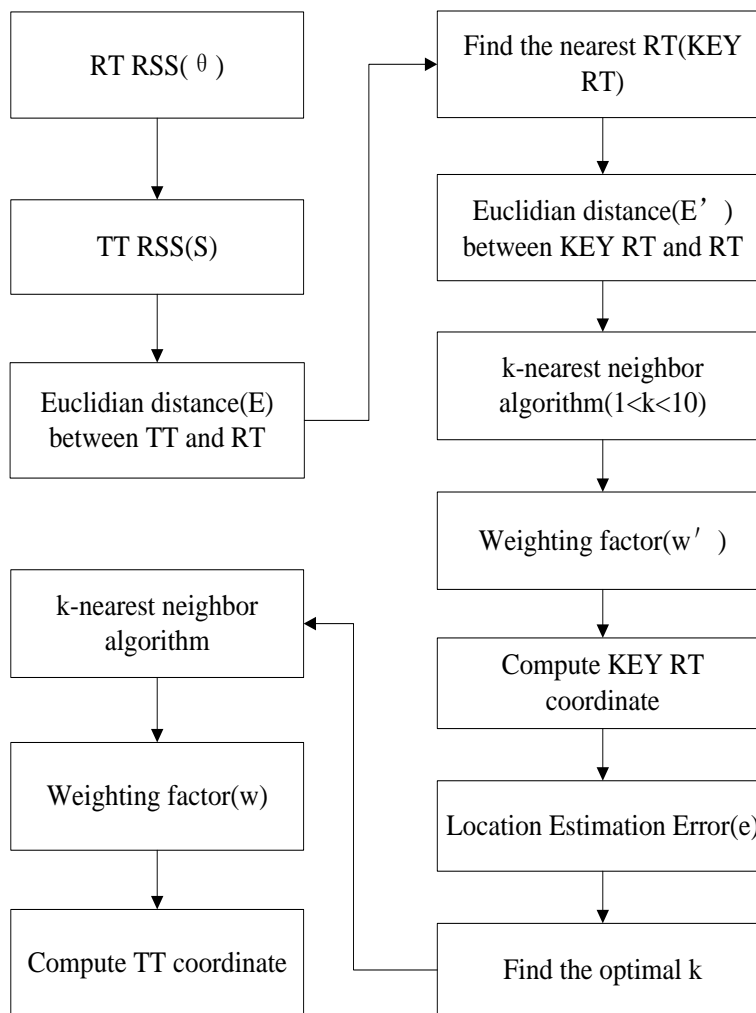
Figure 5. Adaptive *K*-nearest Neighbor Algorithm

First, find the nearest reference tag as a KEY RT. Second, compute KEY RT coordinates and location estimation errors under different *k*. Finally, find the optimal *k* with the minimum error, and use the optimal k to compute the tracking tag coordinate.

The minimum error value should be used to recalculate the positioning correction value. When the Euclidian distance between the nearest reference tag and the tracking tag is too large, in this case, the two tags at this time may be affected by different environmental impact. Therefore, use the minimum error as the positioning correction value is not accurate. Then more minimum error value should be used to calculate an accurate positioning correction value. N minimum errors ($\triangle xe$, $\triangle ye$) and minimum E could be obtained by using adaptive K-nearest neighbor algorithm N times, where N is derived from the experimental. Let EE_i indicate the minimum E and ($\triangle xe_i$, $\triangle ye_i$) indicate the minimum error by time i, the positioning correction value could be calculated as (5).

$$(\Delta x, \Delta y) = \sum_{i=1}^{N} w'i(\Delta xe_i, \Delta ye_i) \tag{5}$$

Where w_i' is calculated as (6).

$$w'_i = \frac{\dfrac{1}{EE_i^{2}}}{\sum_{j=1}^{k} \dfrac{1}{EE_j^{2}}} \tag{6}$$

In this way, when the tracking tag locates in the middle area (Figure 3), four reference tags are likely to be the nearest reference tag, positioning by N times, the errors of them are likely to be involved in calculating the positioning correction value. The value is credible, which could improve the positioning accuracy. When the tracking tag locates in the border area (Figure 4), the first reference tag must be the nearest reference tag, positioning by N times, only the errors of the first reference tag involved in calculating the positioning correction value, the value is credible. Therefore, this method can effectively solve the problem (2), and improve the positioning accuracy.

The steps of adaptive K-nearest neighbor algorithm are described below.
(1) Choose the nearest reference tag as a KEY RT by calculating the each value of E.
(2) Compute the estimated coordinates of KEY RT under different k.
(3) Calculate the errors between the actual coordinate and the estimated under different k.
(4) Use the optimal k with the minimum error to compute the tracking tag coordinate.

4. Localization Algorithm Based on Adaptive Self-correction

Depended on the above discussion, with the calculated position values , plus the average will be the final positioning results, so the RFID indoor localization algorithm based on adaptive self-correction is formed. The algorithm is shown in Figure 6.

The steps of the RFID indoor localization algorithm based on adaptive self-correction are presented below.

Step1. Choose the nearest reference tag as a KEY RT by calculating the each value of E.

Step2. Take adaptive K-nearest neighbor algorithm on KEY RT to obtain the optimal k and the error of the optimal k.

Step3. Use the optimal k to calculate the coordinate of the tracking tag.

Step4. Execute the step1~3 N times, the positioning correction value will be calculated with N minimum errors in weighted way.

Step5. The sum of the mean calculated coordinate and the positioning correction value will be the final positioning results.
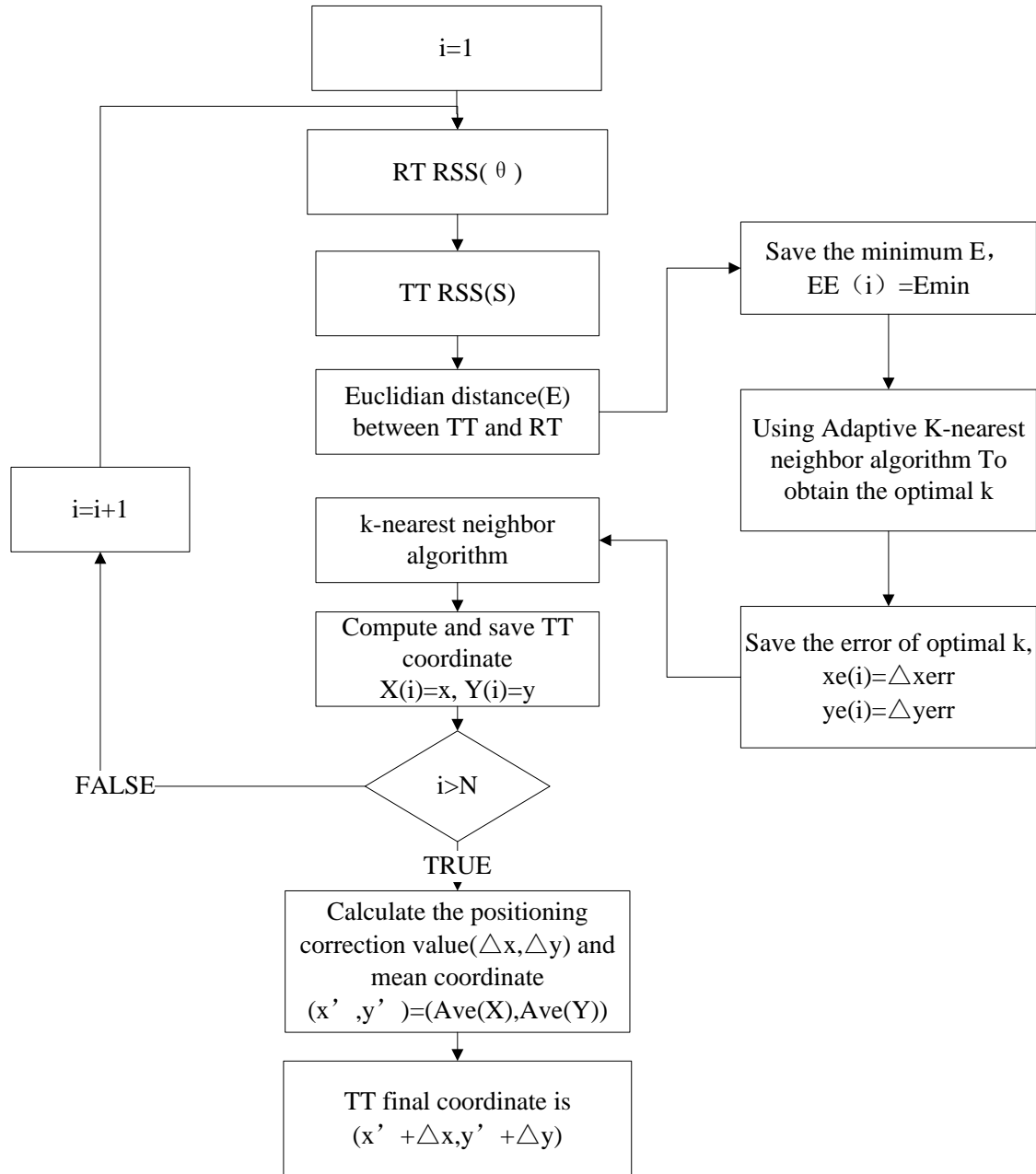
Figure 6. RFID Indoor Localization Algorithm based on Adaptive Self-correction

5. Experiments and Analysis

5.1. Noise Model

In the experiments, we choose the log-distance path loss model, which predicts the average attenuation degree of signal from distance in the indoor environment. The noise model is defined as (7).

$$PL(d) = PL(d_0) + 10N \lg(\frac{d}{d_0}) + X_\sigma \tag{7}$$

Where $PL(d)$ denotes the free space path loss for the distance d, d_0 denotes an arbitrary reference distance (usually 1 meter), N denotes the path loss exponent and X_σ is zero mean Gaussian random variable with variance σ^2 in dB.

The received signal strength instruction may be represented as (8).

$$RSSI(d)_{dB} = P_{ldB} + G_{ldB} - PL(d)_{dB} \tag{8}$$

Where P_{ldB} denotes the transmit power, G_{ldB} denotes the antenna gain of the transmitting node.

The distance d between the reader and the tag can be obtained by using formula (7) and (8), then received signal strength instruction would be calculated as (9).

$$RSSI(d) = RSSI(d_0) - 10N \lg(\frac{d}{d_0}) + X_\sigma \tag{9}$$

In the experiments, the transmit power is 30 dB, the path loss exponent N is 1.8 and the standard deviation σ is 5.2 dB.

5.2. Comparation of the Positioning Average Error under Different N

The first experiment is used to determine the optimal value of N by comparing the mean positioning error under different N.

The distance between reference tags is $1m$. The placement of the reference tags and the readers is shown in Figure 7.
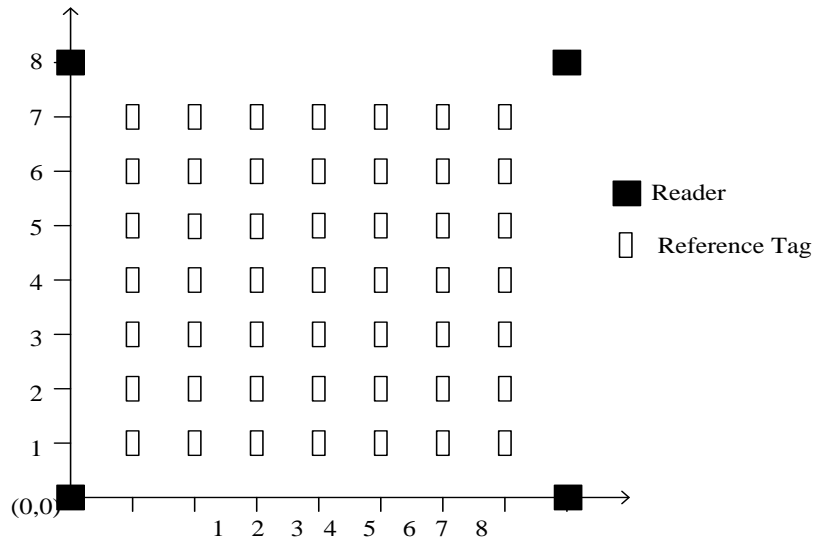

Figure 7. The Structure of Experiments

Define M as the number of the tracking tags. Set $M=1000$ to determine the optimal value of N. The result is shown in Figure 8.

In Figure 8, the mean error decreases along with the value of N becomes large. When N is greater than or equal to 5, the average error tends to be smooth. When $N=9$, the proposed method would have the minimum mean error 0.41803m.
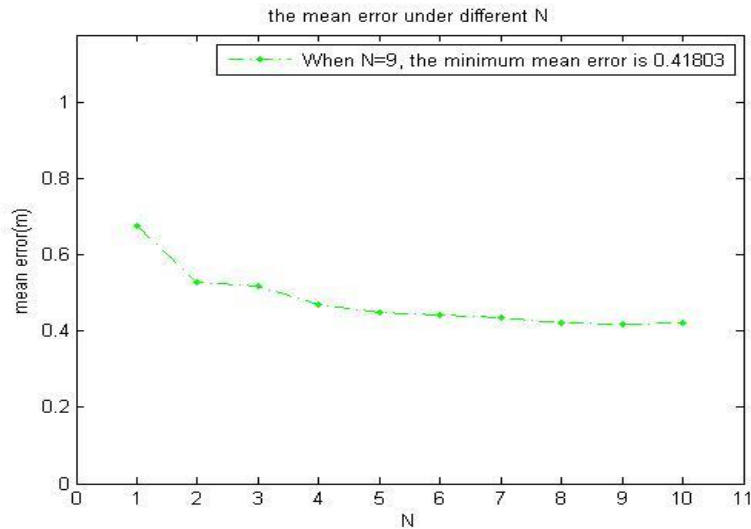

Figure 8. Comparing the Positioning Mean Error under Different N

5.3. Positioning Accuracy

This experiment is used to analyze that whether the proposed method has a higher accuracy than adaptive K-nearest neighbor algorithm and error self-correction algorithm.

Set $N=9$ and $M=1000$, let the proposed method compare with adaptive K-nearest neighbor algorithm and error self-correction algorithm. The results are shown in Figure 9 and Table 1.
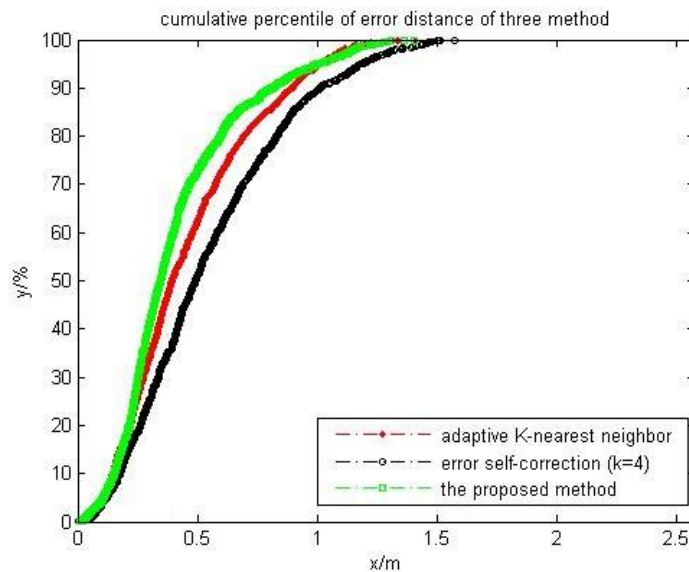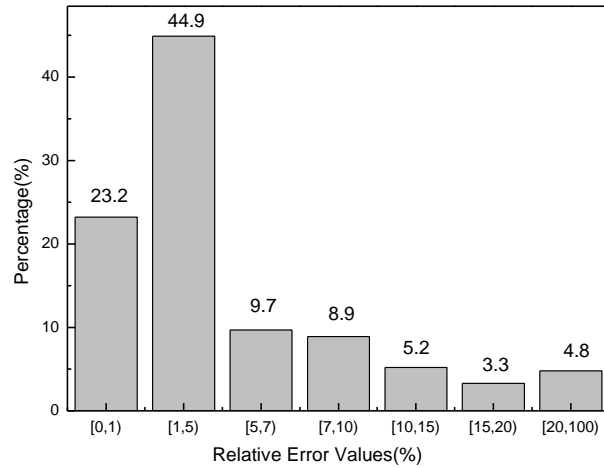
Figure 9. Cumulative Percentile of Error Distance of Three Methods

Table 1. Comparison of Statistical Errors of Three Methods

Algorithm	Average error/m	Worst error/m
Adaptive K-nearest neighbor	0.4607	1.4087
Error self-correction (k=4)	0.5514	1.5722
The proposed method	0.4143	1.4005

In Figure 9, about 70% of the average errors are below 0.5m in the proposed method, it means that the proposed method has a higher stability than adaptive K-nearest neighbor algorithm and error self-correction algorithm. In Table 1, the positioning average error is 0.4607m in adaptive K-nearest neighbor algorithm, the worst is 1.4087m. The positioning average error is 0.5514m in error self-correction algorithm, the worst is 1.5722m. The positioning mean error is 0.4143m in the proposed method, the worst is 1.4005m.

Above data analyzing shows: our method improves the positioning accuracy about 0.0464m and reduces the worst error about 0.0082m than adaptive K-nearest neighbor algorithm. The proposed method improves the positioning accuracy about 0.1371m and reduces the worst error about 0.1717m than error self-correction algorithm.

6. Conclusions and Future Work

Through analysis of the principle of LANDMARC system, we propose a method that recalculate the positioning correction value by using adaptive K neighbor algorithm N times to correct positioning results. Experimental results show that compared with adaptive K-nearest neighbor algorithm and error self-correction algorithm, the proposed method provides a higher accuracy and stability.

Our future work could be extended to the research on three-dimensional indoor localization algorithm. The virtual label system must be created in three-dimensional

space, so the algorithm has the higher computational complexity. However, it has a more broad application prospects.

Acknowledgement

References

[1] Y. Huang, "Internet of Things: radio frequency identification (RFID) technology explain the core (2nd Edition)", Science Press, Beijing **(2012)**

[2] J. Zhou, and J. Shi, "RFID Localization Algorithms and Applications – a Review", Journal of Intelligent Manufacturing, 28,8 **(2008)**

[3] C. Fretzagias and M. Papadopouli, "Cooperative Location-sensing for Wireless Networks. Proceedings of the Second IEEE International Conference on Pervasive Computing and Communication", pp. 121-131, (**2004**).

[4] R. Want, An Introduction to RFID Technology. IEEE Pervasive Computing, 5,1 (**2006**)

[5] Y. Wang and X. D. Hu, "Indoor Localization Algorithm Based on RFID", Journal of Zhejiang Sci-Tech University, vol. 26, no. 2, (**2009**).

[6] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-based User Location and Tracking System", Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies, Proceedings of IEEE, (**2000**)¸ pp. 775-784.

[7] H. Yihua, S. Lv and L. Zongyuan, *et al.* "The topology analysis of reference tag of RFID indoor location system", The 3rd IEEE International Conference on Digital Ecosystems and Technologies, (**2009**), pp. 313-317.

[8] L. M. Ni, Y. Liu, Y. C. L. and A. P. Patil, "LANDMARC: Indoor Location Sensing Using Active RFID", Proceedings of the First IEEE International Conference on Pervasive Computing and Communication, (**2003**), pp. 407-415.

[9] M. Hazas and A. Hopper, "A Novel Broadband Ultrasonic Location System for Improved Indoor Positioning", IEEE Transactions on mobile Computing, vol. 5, no. 5, (**2006**).

[10] X. Li, Y. Hu and J. Song, "Indoor positioning simulation based on Landmarc system", The computer engineering and application, vol. 27, no. 5, (**2008**).

[11] G.-y. Jin, X.-y. Lu and M. S. Park, "An Indoor Localization Mechanism Using Active RFID Tag", Proceeding of the IEEE International Conference on Sensor Network, Ubiquitous, and Trustworthy Computing, (**2006**), pp. 40-43.

[12] Y. R. Zhang, L. P. Tan and H. T. Jiang, "The Simulation and Improved K-nearest Neighbors Algorithm of LANDMARC for Books Positioning", 2012 International Conference on Measurement, Information and Control, (**2012**), pp. 410-414.

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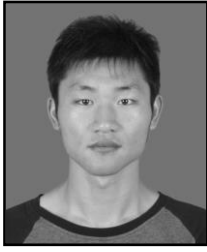
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