Journal of Computers Vol. 28, No. 4, 2017, pp. 140-147
doi:10.3966/199115592017082804015

Modification of Weighted Centroid Localization Algorithm Based on Corrected RSSI Measurement

Yong Lu[1*], and Dan Wang[2]

[1] Beijing Jiaotong University,
Beijing, 100044, China
ylu@bjtu.edu.cn

[2] Beijing Jiaotong University,
Beijing, 100044, China
14120028@bjtu.edu.cn

Received 25 October 2016; Revised 13 June 2017; Accepted 26 June 2017

Abstract. Localization technology has been attracted a lot of attention for viewed as one of the core technologies of wireless sensor networks, among which RSSI localization technology is widely used given its advantages in easy accessibility and low cost. The paper analyzed the RSSI localization technology and proposed a RSSI measurement-corrected weighted centroid localization algorithm on the basis of the traditional centroid localization algorithm. The distance was measured by RSSI and was corrected by the reckon method of centroid; the localization was completed by the weighted centroid localization algorithm which has been corrected. The simulation results show that, compared with the traditional localization algorithm, the modified algorithm proposed by this paper shows significant improvements on positioning accuracy.

Keywords: centroid localization, distance correction, RSSI measurement, weight corrected, wireless sensor networks

1 Introduction

With the development of science and technology, wireless sensor networks have been extensively applied in numerous fields including traffic management, environmental monitoring, safety production, smart home, armamentarium [1-2]. Node self-localization of wireless sensor networks [3-4] served as the foundation of other applications. On this basis can people monitor the location of the incident and the outside target can be located and traced.

Many ways can be used to categorize localization technologies in wireless sensor networks, among which the most common categorizations are the Range-Based Localization Technology and the Range-Free Localization Technology [5]. However, the positioning accuracy of the Range-Based Localization Technology is higher than the Range-Free Localization Technology for its localization depended on the range and the angle between nodes Current wireless localization technologies mainly include: Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), Cell Units and RSSI [6]. RSSI is a measurement-based algorithm which turns the propagation loss in air to the corresponding propagation distance by applying theoretical models or empirical models. The algorithm based on the theory that the strength of wireless signal decreases when the distance increases.

Lipo and Krause proposed a RSSI measurement-corrected localization algorithm in wireless sensor networks which calculates an approximate centroid location through the RSSI measurement [7]. Consequently, the unknown node location is determined when the distance is adjusted by taking the approximate centroid location as a reference. Nevertheless, although this method enhances the positioning

* Corresponding Author

accuracy, it does not fully consider the influence of beacon nodes distribution on the precision of centroid localization algorithm; the other article [8] adopted the distance and signal strength between beacon nodes to correct the distance measured by RSSI considered the information of beacon node.

Integrating merits in Lipo and Krause's, Summers and Betz's, this paper corrected the measurement of RSSI by taking advantage of the distance and signal strength between beacon nodes, which had been considering the influence of beacon nodes on the unknown node [7-8]. Additionally, the corrected RSSI measurement was further modified to improve the positioning accuracy of the traditional centroid localization algorithm.

1.1 Wireless Signal Propagation Loss Model

The RSSI-based localization algorithm calculates the energy loss of wireless signal by taking advantage of attenuation character shown by the wireless propagation model after it receives nodes transmitting power, which is turned to the distance between the transmitting node and the receiving node by using theoretical models or empirical models. Finally, the unknown node is estimated by algorithms such as Trilateration.

Common propagation models used in the wireless sensor networks including: Free-Space, Two-Ray Ground Reflection and Shadowing. The first two models are based on an ideal environment and ignoring the interferences to the signal propagation caused by factors such as blockage and multipath reflection. However, the Shadowing model has a more comprehensive consideration in an imperfect environment.

There are two parts in the Shadowing model. The first part is Pass Loss model which equation is:

$$\frac{P_r(d_0)}{P_r(d)} = \left(\frac{d}{d_0}\right)^{\beta} \quad \textbf{(1)}$$

Where, β is the coefficient of Pass Loss which is a constant obtained through an actual measurement with the range from 2 to 6. β increased by the number of obstacle. $P_r(d_0)$ represents the average energy received when the distance is d_0 (usually 1m), and $P_r(d)$ represents the average energy received when the distance is d . The equation (1) estimates the signal strength $P_r(d)$ when the distance is d by taking $P_r(d_0)$ as a reference.

The second part of the Shadowing model is a random variable subjecting to the lognormal distribution. It satisfies the Gaussian distribution when using decibel as the unit. It reflects the change of received energy when the distance is fixed. The completed Shadowing model is:

$$\left[\frac{P_r(d_0)}{P_r(d)}\right]_{dB} = -10\beta \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad \textbf{(2)}$$

Where, X_σ is a random Gaussian variable which the average value is zero. It expands the application of Shadowing model to an imperfect environment.

1.2 RSSI Range Correction Model

Based on the first part of Shadowing model, the distance between the unknown node and the beacon node B_i can be obtained by the equation (1) with taking beacon node B_j as a reference:

$$d_j^i = d_j^i \times \frac{P_i^{\frac{1}{\beta}}}{P_{ij}^{\frac{1}{\beta}}} \quad \textbf{(3)}$$

Where, d_{ij} is the distance between beacon node B_i and beacon node B_j. P_i is the average value (mW) of signal strength received by the unknown node from the beacon node B_j. P_{ij} is the average value of signal strength received by the beacon node B_i from the beacon node B_j .

Assumed that the RSSI average value received by the unknown node from the beacon node B_j is $RSSI_i$ (dBm), and the RSSI average value received by the beacon node B_i from the beacon node B_j is $RSSI_{ij}$ (dBm). Transform relationships between them are shown by equation (4), (5):

$$P_i = \frac{RSSI_i}{10} \tag{4}$$

$$P_i = 10^{\frac{RSSI_{ij}}{10}} \tag{5}$$

The distance d_i from the unknown node to the beacon node B_i can be shown by the average value produced by all possible d_i^j contracting all possible j:

$$d_i = \frac{\sum j d_i^j}{N} \tag{6}$$

Where, N is the number of other beacon nodes in the communication range of beacon node B_i.

1.3 Mathematics Model

The coordinates of three known beacon nodes A, B, and C are $(x_a, y_a), (x_b, y_b)$ and (x_c, y_c) respectively; the coordinate of unknown node is assumed as (x_0, y_0); the distance from the known beacon nodes to the unknown node correspondingly are r_a, r_b and r_c. Three circles are described by regarding A, B, and C as the center of circles and their distance to the unknown node as the radius. As shown by Fig. 1, O is the point met by the three circles.

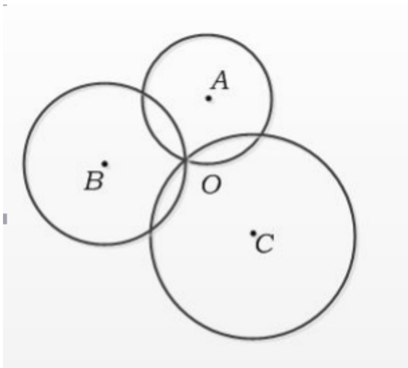

Fig. 1. Trilateration diagram

The point of intersection which is the location of the unknown node is calculated according to the Pythagoras Theorem:

$$\begin{cases} \sqrt{(x_0 - x_a)^2 + (y_0 - y_a)^2} = r_a \\ \sqrt{(x_0 - x_b)^2 + (y_0 - y_b)^2} = r_b \\ \sqrt{(x_0 - x_c)^2 + (y_0 - y_c)^2} = r_c \end{cases} \tag{7}$$

In fact, the distance from the beacon node to the unknown node is larger than actual number because of the influence caused by the multipath fading and the non-ling-of-sight blockage on RSSI. Assumed that the measured distance from beacon node A, B and C to the unknown node respectively are d_a, d_b and d_c. Three circles are described by regarding A, B and C as the center of circles and d_a, d_b and d_c as the radius. As shown by Fig. 2, a zone is met by above three circles rather than a point.

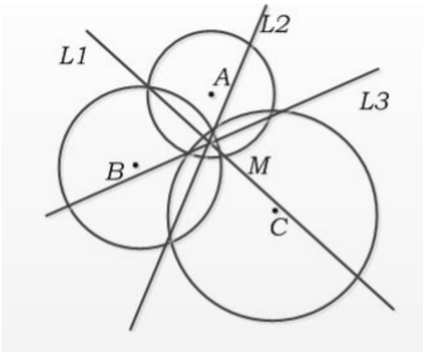

Fig. 2. Real trilateration condition

The centroid M of the zone marked by three intersection points can be viewed as an approximate estimation of the unknown node O. The coordinate of M is assumed as (x_m, y_m) which leads to the following equations:

$$\begin{cases} \sqrt{(x_m - x_a)^2 + (y_m - y_a)^2} = d_a \\ \sqrt{(x_m - x_b)^2 + (y_m - y_b)^2} = d_b \\ \sqrt{(x_m - x_c)^2 + (y_m - y_c)^2} = d_c \end{cases} \tag{8}$$

The equations of l_1, l_2 and l_3 shown by Fig. 2 can be obtained when the results of equation (8) are squared and mutually subtracted subsequently. The coordinate of point M can be solved by these equations:

$$\begin{cases} 2(x_b - x_a)x_m + 2(y_b - y_a) = y_m = d_a^2 - d_b^2 - x_a^2 + x_b^2 - y_a^2 + y_b^2 \\ 2(x_c - x_b)x_m + 2(y_c - y_b) = y_m = d_b^2 - d_c^2 - x_b^2 + x_c^2 - y_b^2 + y_c^2 \\ 2(x_c - x_a)x_m + 2(y_c - y_a) = y_m = d_a^2 - d_c^2 - x_a^2 + x_c^2 - y_a^2 + y_c^2 \end{cases} \tag{9}$$

1.4 Distance Correction

In most actual cases, the predicted $P(d)$ is larger than the real signal energy because of the influences of various barriers; the difference between $P(d)$ and the actual path loss energy will be increased with the enlargement of measured distance. Hence, the distance d_a, d_b and d_c measured by RSSI needed to be corrected.

The distance from beacon node A, B and C to the intersection point of the three lines M are obtained and marked as l_a, l_b and l_c respectively. The equation (10) of the overall correction coefficient is:

$$\sigma = 1 - \sqrt[n]{\frac{l_a^n + l_b^n + l_c^n}{d_a^n + d_b^n + d_c^n}} \tag{10}$$

Because the influences of different beacon nodes on the unknown node are varied, the correcting degree is enhanced for the increasing of relative error of the measurement which is expanded with the growth of distance. The equation (11) of the distance d_a correction coefficient is:

$$\sigma_a = \sigma \times \frac{3 \times d_a}{d_a + d_b + d_c} \tag{11}$$

The distance d_b and d_c are similar with d_a. Consequently, the corrected distance $d_a^{'}$ from the beacon node A to the unknown point O is:

$$d_a^{'} = d_a \times (1 - \sigma_a) \quad \textbf{(12)}$$

By using the corrected $d_a^{'}$, $d_b^{'}$ and $d_c^{'}$ as weighting factors, the estimated coordinate of the unknown node is corrected by $1/(d_a^{'} + d_b^{'} + d_c^{'})$.

2 Algorithm Process

The beacon node periodically sends broadcasting information which contains its ID and location in the same power. Meanwhile, the beacon node B_i records the average value of RSSI, $RSSI_{ij}$, which is sent by the beacon node B_j. P_{ij} and d_{ij} are calculated by equation (3), (4), (5), and (6), and the results would be broadcasted.

When the unknown node receives the information, the RSSI value sent by the same node will be recorded. Regarding the average RSSI value obtained from certain RSSI values as the received RSSI value and using equation (6) to calculate d_i.

The unknown node records all beacon nodes which satisfied the Trilateration.

All qualified combinations will be solved by equation (9), and d_i will be corrected by the described range correcting method. Regarding the corrected $d_a^{'}$, $d_b^{'}$ and $d_c^{'}$ as weighting factors, and the estimated coordinate of the unknown node is corrected by $1/(d_a^{'} + d_b^{'} + d_c^{'})$ to obtain the coordinate of the unknown node O,(x_0, y_0).

3 Simulation Analysis

The experimental simulations were completed by MATLAB, and the simulated environment was $100\text{m} \times 100\text{m}$ wireless sensor networks which randomly produced 100 beacon nodes. Unknown nodes were distributed in the entire zone randomly. In the experimental environment, a group of random number was produced as the Gaussian noise to replace influences caused by factors such as multipath reflection, the interference of the obstructions, and climate changes which possibly appeared in the actual environment. The nodes distribution is shown in Fig. 3.

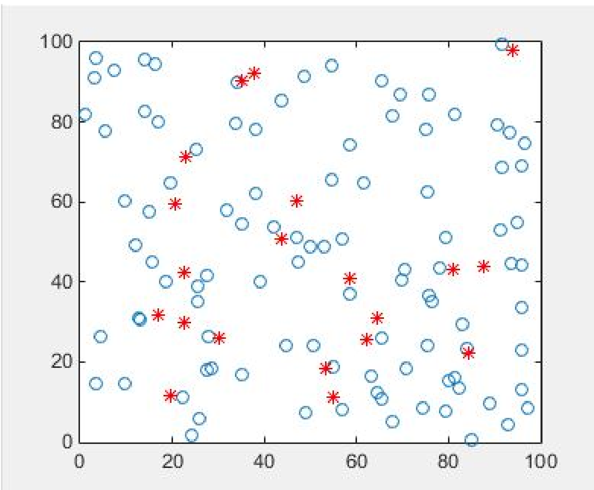

Fig. 3. Nodes distribution

The algorithm performance was analyzed on the perspectives of the number of beacon nodes, the number of unknown nodes, and the propagation radius that based on the simulated comparison between the traditional centroid localization algorithm and the RSSI measurement corrected weighted centroid localization algorithm.

The interval of the number of beacon nodes was five which was gradually increased from 10 to 30. In the number of different beacon nodes, the location errors which were produced by the traditional centroid localization algorithm and the improved centroid localization algorithm proposed by this paper were drawn respectively. The simulating result is shown in Fig. 4.

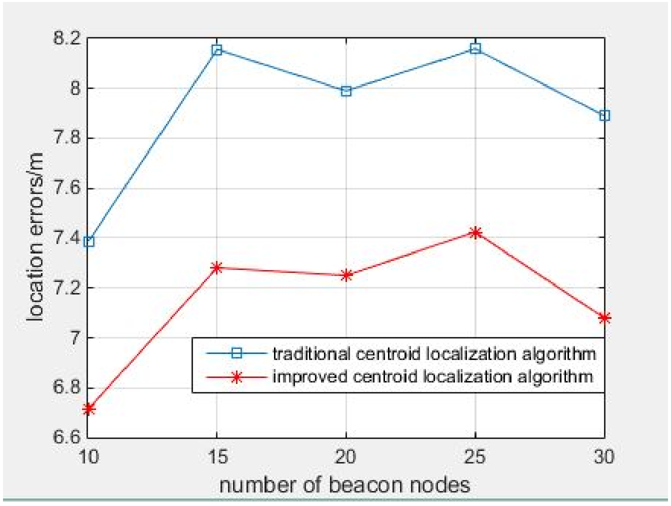

Fig. 4. Location errors under known nodes

As shown by the figure, the minimum location error appears when the number of beacon nodes is 10. The location error significantly decreased as the increase number of beacon nodes. The minimum location error of the traditional centroid localization algorithm is 7.4, while the modified centroid localization algorithm proposed by this paper is 6.7. As shown by the location error curves of the two algorithms, it could be clearly noted that, in the same condition, the location error of the improved centroid localization algorithm is heavily lower than that of the traditional centroid localization algorithm.

The interval of the number of unknown nodes was 10, which was gradually increased from 0 to 100. In the number of different unknown nodes, the location errors which were produced by the traditional centroid localization algorithm and the improved centroid localization algorithm were drawn respectively. The simulating result is shown in Fig. 5.

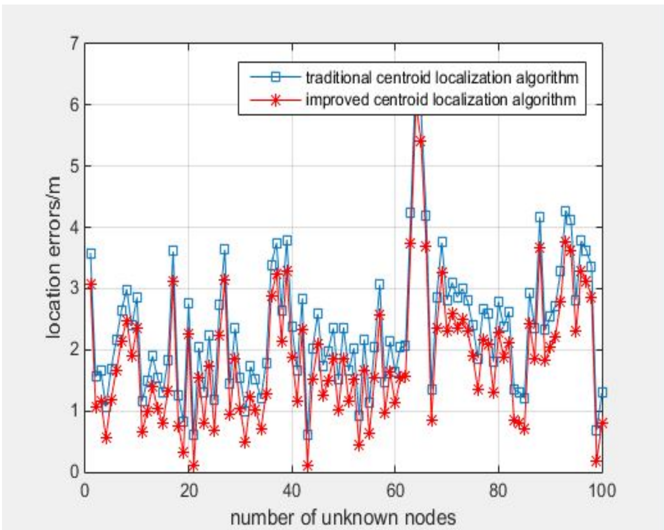

Fig. 5. Location errors under unknown nodes

As shown by the diagram, with the increase of unknown node amounts, the location error maintains within 0-4. However, when unknown nodes are about 65, the location errors produced by the traditional centroid localization algorithm and the improved centroid localization algorithm show a significant change. According to the location error curves of the two algorithms, it could be noted that, in the same condition, the location error of the improved centroid localization algorithm is lower than the traditional centroid localization algorithm.

The interval of the propagation radius was 10, which was gradually increased from 50 to 100. In different propagation radius, the location errors which were produced by the traditional centroid localization algorithm and the improved centroid localization algorithm were drawn respectively. The simulating result is shown in Fig. 6.

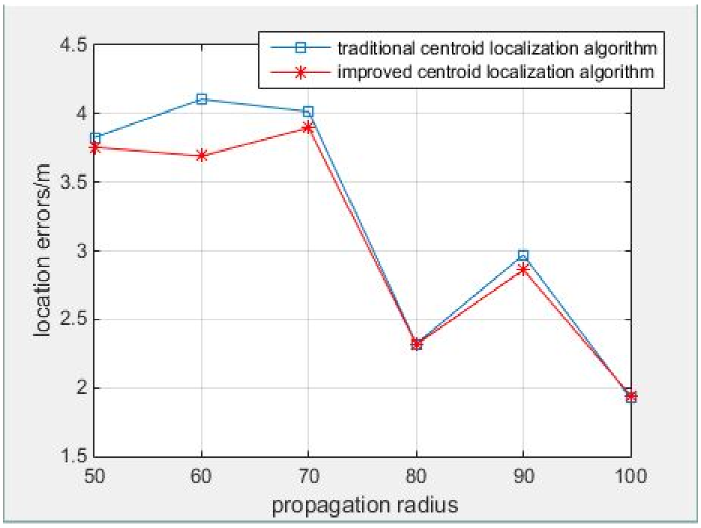

Fig. 6. Location errors under different radius

As shown by the diagram, with the increase of propagation radius, the overall location error presents a declining trend. When the propagation is 100, the location error of the traditional centroid localization algorithm and the improved centroid localization algorithm appears the minimum value, about 1.9. When the propagation is 90, the location error of the traditional centroid localization algorithm and the improved centroid localization algorithm slightly increases. According to the location error curves of the two algorithms, it could be noted that, in the same condition, the location error of the improved centroid localization algorithm is lower than the traditional centroid localization algorithm.

4 Conclusion

This paper proposed a RSSI range corrected weighted centroid localization algorithm on the basis of a comprehensive analysis of current various centroid localization algorithm. It is certified by experimental simulations that the algorithm proposed by this paper increase the positioning accuracy and decreases the location error. Since the Gaussian noise was simply replaced by random number in the algorithm, the range measuring model cannot be well verified because of lacking of actual RSSI data. Therefore, further researches will improve the algorithm to reduce the location error deeply by performing localization experiments with strong interference.

References

[1] X. Wu, Research on node location algorithm for mobile wireless sensor networks based on RSSI ranging, [dissertation] Guangdong: South China Normal University, 2015.

[2] J. Sun, H. Zhang, Wireless location method based on RSSI and genetic algorithm and its implementation, Wireless Internet Technology 10(2017) 11-15.

[3] Y. Chen, Y. Yang, Research on weighted centering algorithm of wireless sensor network, Software Guide 16(4)(2017) 41-43.

[4] E.H. Callaway, Wireless Sensor Network s: Architectures and Protocols, CR C Press, Boca Raton, Florida, 2004.

[5] J. Tao, Research on location algorithm based on RSSI ranging in wireless sensor networks, [dissertation] Hunan: Hunan

University, 2014.

[6] L. Shi, H. Zhu, An intrinsic centering algorithm for regional superposition based on RSSI, Intelligent Computer and Applications 3(2017) 55-57.

[7] Z. Zhao, X. Chen, RSSI based improved localization algorithm in wireless sensor networks, Chinese Journal of Sensors and Actuatros, 2009(03).

[8] C. Chen, W. Da, J. Zhou, RSSI based range corrected localization algorithm in wireless sensor networks, Communication Technology, 2011(02).