International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 3, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n3.06
Journal homepage: https://wepub.org/index.php/IJCSIT/index

An Improved Non-ranging Node Localization Method for Wireless Sensor Networks

Haixu Niu [1, 2, *], Yonghai Li [2], Tianfei Chen [3], Abdullah Muhammad Irsyad [1, *]

[1] Faculty of information Science and Engineering, Management and Science University, Shah Alam, Malaysia

[2] School of Management, Henan University of Technology, Zhengzhou, China

[3] College of Information Science and Engineering, Henan University of Technology, Zhengzhou, China

*Corresponding Author: irsyad@msu.edu.my

ABSTRACT

Node localization is a fundamental research problem in wireless sensor networks, and the implementation of many applications requires the accurate location of sensor nodes. Currently, among the existing localization algorithms, non-ranging algorithms are a class of algorithms that localize sensor nodes through multi-hop connectivity information between them, and the DV_Hop algorithm is one of the most frequently used algorithms. Although the implementation of DV_Hop algorithm is relatively simple, its location accuracy is low, which is difficult to meet the higher requirements of the application. For this reason, this paper proposes an improved non-ranging node localization method for wireless sensor networks. The proposed algorithm adopts the minimum mean square error criterion to calculate the average hop distance of anchor nodes. On this basis, the distance estimation from unknown node to anchor node is replaced. Finally, a nonlinear iterative approach is used to perform the multilateral localization process. The experimental results show that the localization accuracy and stability of the proposed algorithm are also significantly improved.

KEYWORDS

Wireless sensor network; DV_Hop; Minimum mean square error; Nonlinear iteration

1. INTRODUCTION

Wireless sensor network is a wireless multi-hop communication network system, which consists of a large number of functionally limited and battery-powered sensor nodes with low-cost, self-organization, dynamic topology and other characteristics [1]. In recent years, with the rapid development of electronic technology, wireless communication technology, and microelectromechanical systems, sensor nodes have become more functionally rich, which in turn promotes the development of the Internet of Things (IoT), information-physical systems, and other related technologies [2]. At the same time, the application fields of wireless sensor networks have also been further expanded, and now play a crucial role in industrial monitoring, environmental monitoring, military reconnaissance, disaster management, and health care.

In most applications of wireless sensor networks, the location information of nodes is indispensable, otherwise the data collected by sensors is meaningless. However, the assembly of location modules for all nodes not only greatly increases the cost of sensor nodes, but also increases the power consumption of nodes, thereby shortening the life cycle of each node. Usually, a small number of nodes (anchor nodes) of the assembly location module and the existing information in the network are used to calculate the coordinates of unknown nodes [3]. The existing location technology can be roughly divided into two categories : ranging-based location and non-ranging-based location. After obtaining the distance or angle information between nodes, the ranging-based localization algorithm calculates the coordinates of unknown nodes through a multilateral localization method. The range-free localization algorithm only relies on the connectivity between nodes and the network topology to calculate the coordinates of unknown nodes [4].

The representative localization algorithms based on range-free mainly include : centroid method [5], triangle interior point approximation detection method [6], multidimensional scaling method [7] and DV_Hop [8]. DV_Hop algorithm is one of the most popular location algorithms, which has attracted more and more scholars ' attention. The core idea of the algorithm is to use the product of the average hop distance and the minimum hop number to approximate the distance between the corresponding nodes, so its location accuracy is difficult to meet some applications with strict requirements. Some scholars have improved the calculation method of the average hop distance and reduced the distance estimation error. Guo [9] obtained the average hop distance of the network by averaging the average hop distance of all anchor nodes, and used it to calculate the distance between nodes. Liu [10] calculated the estimated distance error caused by the average hop distance of each anchor node according to the real distance between anchor nodes, and used the error to correct the average hop distance of anchor nodes. Similarly, References [11-13] also use the estimated distance error, but the correction equation is slightly different. In the process of performing multilateral location, the traditional DV_Hop algorithm uses the least squares method. Xiao [14] pointed out that the least squares method does not directly minimize the distance estimation error, so the location effect is poor. Tarrío [15] used the weighted least squares method to assign a large weight to a high-precision measurement value to improve the location effect. In recent years, some biological heuristic algorithms have been successfully used to solve the problem of node localization in wireless sensor networks, including : cuckoo search algorithm [16], firefly algorithm [17], gray wolf algorithm [18] and educational learning algorithm [19]. Although the bio-heuristic algorithm avoids setting the initial value of the iteration, the amount of calculation will increase.

In this paper, an improved non-ranging node localization method for wireless sensor networks is proposed. In order to further improve the location accuracy of the node, the proposed algorithm improves the three aspects of the error caused by the standard DV_Hop process, mainly including : the correction of the average hop distance of the anchor node, the estimation of the distance from the unknown node to the anchor node, and the optimization of the multilateral location process. The main contributions of this paper are summarized as follows:

(1) Aiming at the calculation of the average hop distance of anchor nodes, the minimum mean square error criterion is adopted, and the calculation strategy of secondary weighted correction is set to strengthen the influence of anchor nodes with small distance error.

(2) The estimation method of the distance between the unknown node and the anchor node is updated, which avoids the process of calculating the average hop distance of the unknown node and reduces the amount of calculation to a certain extent.

(3) The nonlinear iterative optimization is used to perform the multilateral location process, and the least squares result is used as the initial value of the iteration to further improve the location accuracy.

The remaining chapters of this paper are organized as follows : The second part introduces the traditional DV_Hop algorithm. The third part introduces the proposed algorithm in detail. Chapter 4 gives a large number of simulation experiments and analyzes the location performance. Finally, our conclusion is given in Chapter 5.

2. TRADITIONAL DV_HOP LOCALIZATION ALGORITHM

The specific process of the traditional DV_Hop algorithm mainly includes the following steps:

Step 1: Determine the minimum number of hops between nodes in the network. In this phase, each anchor node uses flooding to disseminate an information packet to the entire network. The content of the information packet contains the anchor node position coordinates, node label, and the hop value, which is initialized to zero. While the anchor node sends the information packet to all connected nodes, each node creates table for storing the received information. When a node receives the information packet, the hop value in the packet is increased by 1. Subsequently, the node records the content of the packet and continues to send it to its neighboring nodes until all the nodes receive the information. When a node receives another information packet from another node, if the packet has a smaller hop value compared to the saved information, record the content of the packet, otherwise ignore the packet. According to the above update rule, all the nodes in the network eventually have the minimum number of hops to other nodes.

Step 2: Calculate the average hop distance of the nodes in the network. This stage consists of two parts: determining the average hop distance of anchor nodes and the average hop distance of unknown nodes. First, each anchor node obtains the actual distance to other anchor nodes, and then the average hop distance of anchor nodes is calculated using equation (1).

$$HopSize_i = \frac{\sum_{j\neq i}^{N_a} D_{ij}}{\sum_{j\neq i}^{N_a} h_{ij}} \tag{1}$$

Where (x_i, y_i), (x_j, y_j) denote the coordinates of anchor node i and anchor node j, respectively, D_{ij} denotes the true distance between anchor node i and anchor node j, and h_{ij} is the minimum number of hops between two anchor nodes. Therefore, $HopSize_i$ represents the average hop distance of anchor node i.

When the computation of the average hop distance of all anchor nodes is completed, flooding is again used to propagate throughout the network. The unknown node takes the average hop distance of the first received anchor node as its own average hop distance, and this rule probabilistically ensures that the unknown node saves the average hop distance of the anchor node closest to it.

Step 3: Estimate the distance from the unknown node to each anchor node. In this step, the estimated distance from an unknown node to an anchor node is equal to the average hop distance of the unknown node multiplied by the minimum number of hops from that unknown node to each anchor node, as shown in Equation (2).

$$d_{ui} = HopSize_u \times h_{ui} \tag{2}$$

Where, u=1, …, N_u, i=1, …, N_a; $HopSize_u$ denotes the average hop distance of the unknown node u, h_{ui} is the minimum number of hops from the unknown node to the anchor node i, and finally d_{ui} denotes the estimated distance from the unknown node u to the anchor node i.

Step 4: Perform multilateral localization to calculate the coordinates of the unknown node. Let (x_u, y_u) denote the position coordinates of the unknown node u. Combined with the estimated distance obtained in the previous step, the following system of equations is obtained.

$$\begin{cases} (x_u - x_1)^2 + (y_u - y_1)^2 = d_{u1}^2 \\ (x_u - x_2)^2 + (y_u - y_2)^2 = d_{u2}^2 \\ \vdots \\ (x_u - x_{N_a})^2 + (y_u - y_{N_a})^2 = d_{uN_a}^2 \end{cases} \tag{3}$$

Equation (3) can be further organized into the form of a matrix **AX**=**B**. The vector **X**=$[x_u, y_u]^T$ denotes the unknown node coordinates, and the matrices **A** and **B** are described in detail as follows:

$$\mathbf{A}=\begin{bmatrix}(x_1-x_{N_a}) & (y_1-y_{N_a})\\ (x_2-x_{N_a}) & (y_2-y_{N_a})\\ \vdots & \vdots\\ (x_{N_a-1}-x_{N_a}) & (y_{N_a-1}-y_{N_a})\end{bmatrix}\quad \mathbf{B}=\begin{bmatrix}x_1^2+x_{N_a}^2+y_1^2+y_{N_a}^2+d_{uN_a}^2-d_{u1}^2\\ x_2^2+x_{N_a}^2+y_2^2+y_{N_a}^2+d_{uN_a}^2-d_{u2}^2\\ \vdots\\ x_{N_a-1}^2+x_{N_a}^2+y_{N_a-1}^2+y_{N_a}^2+d_{uN_a}^2-d_{u(N_a-1)}^2\end{bmatrix}$$

At this point, the coordinates of the nodes can be determined using the least squares solution.

$$\mathbf{X}=(\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{B} \tag{4}$$

3. THE PROPOSED ALGORITHM

The traditional DV_Hop algorithm completes the positioning task by multi-step sequential execution. If the calculation result of the algorithm 's starting calculation step has a large error, it will inevitably lead to the worse the final node positioning accuracy. Therefore, the proposed algorithm improves the order of each execution step of the traditional DV_Hop algorithm to reduce the influence of error accumulation, so as to further improve the node positioning accuracy.

3.1. Weighted Correction for The Average Hop Distance of Anchor Nodes Under The Minimum Mean Square Error Criterion

The traditional DV_Hop algorithm uses an unbiased estimation criterion when calculating the average hop distance of anchor nodes, so that the mean error of the estimated distance is zero. However, the error generally obeys the Gaussian distribution, so the minimum mean square error criterion is used to minimize Equation (5) to calculate the average hop distance of anchor nodes.

$$\sigma=\frac{1}{N_a-1}\sum_{j\neq i}^{N_a}(D_{ij}-HopSize_i\cdot h_{ij})^2 \tag{5}$$

Where σ represents the mean square error of the estimated distance. Derived from the above equation and let it be zero, the estimated value of the average hop distance of the anchor node i is

$$HopSize_i=\sum_{j\neq i}^{N_a}h_{ij}\cdot D_{ij}\Big/\sum_{j\neq i}^{N_a}h_{ij}^2 \tag{6}$$

For Equation (5), each error term has the same weight. However, in the actual network, the remaining anchor nodes do not exert the same effect on the anchor node i. The improved algorithm in this paper gives different weights to anchor nodes according to the value of distance error, and further weakens the influence of anchor nodes with large distance error.

Since the distance error between the anchor node j and the anchor node i to be calculated is unknown at the beginning, we assume that each anchor node has the same influence, that is, the weight value is first set to be consistent. Therefore, under the minimum mean square error criterion, the initial value of the average hop distance of the anchor node i can be obtained by Equations (5) and (6), so that the distance error of the remaining anchor nodes relative to the anchor node i can be further calculated as follows:

$$DE_{(i)j} = D_{ij} - HopSize_i \cdot h_{ij};\ j \neq i \tag{7}$$

Where $DE_{(i)j}$ represents the distance error value corresponding to the *jth* anchor node. After the distance error values of the remaining anchor nodes are known, the corresponding weight values are set as follows.

$$\alpha_{(i)j} = \left(\frac{1}{DE_{(i)j}}\right)^2 \tag{8}$$

As can be seen from Equation (8), this weight value will further increase the influence of anchor nodes with small distance errors. Then, the average hop distance of anchor node i can be corrected by weighting using Equation (9) based on the minimum mean square error criterion, and the corrected average hop distance is expressed instead.

$$HopSize_i' = \sum_{j \neq i}^{N_a} \alpha_{(i)j} \cdot h_{ij} \cdot D_{ij} \Big/ \sum_{j \neq i}^{N_a} \alpha_{(i)j} \cdot h_{ij}^2 \tag{9}$$

3.2. Reconfiguration of the Distance Estimation Method

In the traditional DV_Hop algorithm, the average hop distance of the unknown node is directly replaced by the average hop distance of the nearest anchor node. Considering the randomness of the network topology, the network characteristics of the unknown node and its nearest anchor node will not be completely consistent, if the average hop distance of the nearest anchor node is directly set to the average hop distance of the unknown node, the computational error will be unavoidable, which also causes the accumulation of error and affects the localization accuracy.

The algorithm proposed in this paper breaks the traditional way of inter-node distance estimation, and no longer refers to the average hop distance of the unknown node, but uses the optimal average hop distance of the anchor node obtained in the previous step, and the reconstructed way of inter-node distance estimation can be expressed as follows:

$$d_{ui} = HopSize_i' \times h_{ui} \tag{10}$$

Where d_{ui} and h_{ui} denote the estimated distance from unknown node u to anchor node i and the number of hops, respectively, $HopSize_i'$ is the modified average hop distance of anchor node *i*.

Since the average hop distance of unknown node is based on the estimated value of the average hop distance of anchor node, but the average hop distance of anchor node is not zero error, which will further lead to the accumulation of errors in the localization process. Analyzing from the mathematical point of view, the accuracy of the estimated value will be reduced with each step of mathematical operation. Therefore, deleting the calculation step of the average hop distance of the unknown node not only reduces the network communication overhead, but also significantly improves the accuracy of the estimated distance between the unknown node and the anchor node.

3.3. Nonlinear Weighted Iterative Localization

As can be seen from step 4 of the traditional DV_Hop algorithm, the actual physical meaning of the least squares approach to perform the multilateral localization process is the localization performed by obtaining two distance differences from the unknown node to at least three anchor nodes, and is not a direct minimization of the distance estimation error under the mean square error criterion. This step will perform the nonlinear iterative multilateral localization process by using the least squares localization result as the iterative initial value under the minimum mean square error criterion.

Let the distance error objective function be

$$f\left(x_u,y_u\right)=\sum_{i=1}^{N_a}\left(\sqrt{\left(x_u-x_i\right)^2+\left(y_u-y_i\right)^2}-d_{ui}\right)^2 \tag{11}$$

Equation (11) is a nonlinear function with respect to the coordinates of the unknown node (xu, yu), in this paper, in order to reduce the amount of computation, Taylor's equation will be used to simplify the nonlinear term. The first-order Taylor's equation expansion for $\sqrt{\left(x_u-x_i\right)^2+\left(y_u-y_i\right)^2}$ at the iterative initial coordinates (x0, y0) leads to the following equation

$$\begin{aligned}\sqrt{\left(x_u-x_i\right)^2+\left(y_u-y_i\right)^2}=&\sqrt{\left(x_0-x_i\right)^2+\left(y_0-y_i\right)^2}\\&+\frac{\left(x_0-x_i\right)\cdot\left(x_u-x_0\right)}{\sqrt{\left(x_0-x_i\right)^2+\left(y_0-y_i\right)^2}}+\frac{\left(y_0-y_i\right)\cdot\left(y_u-y_0\right)}{\sqrt{\left(x_0-x_i\right)^2+\left(y_0-y_i\right)^2}}\end{aligned} \tag{12}$$

Let

$$M_i=\sqrt{\left(x_0-x_i\right)^2+\left(y_0-y_i\right)^2};U_i=\frac{x_0-x_i}{M};V_i=\frac{y_0-y_i}{M};$$

Then Equation (11) can be further simplified as

$$f\left(x_u,y_u\right)=\sum_{i=1}^{N_a}\left(M_i+U_i\cdot\left(x_u-x_0\right)+V_i\cdot\left(y_u-y_0\right)-d_{ui}\right)^2 \tag{13}$$

In order to minimize the distance estimation error, Equation (13) takes the partial derivatives of x_u and y_u, respectively, and makes the partial derivatives zero to get

$$\begin{aligned}&\frac{\partial f\left(x_u,y_u\right)}{\partial x_u}=0;\\&\frac{\partial f\left(x_u,y_u\right)}{\partial y_u}=0\end{aligned} \tag{14}$$

The solution for the coordinates (x_u, y_u) can be found by simplifying and organizing Equation (14). For ease of description, the following parameters are defined

$$\begin{aligned}&P=\sum_{i=1}^{N_a}U_i^2\\&Q=\sum_{i=1}^{N_a}U_i\cdot V_i\\&N=\sum_{i=1}^{N_a}V_i^2\\&S=x_0\cdot P+y_0\cdot Q+\sum_{i=1}^{N_a}U_i\cdot\left(d_{ui}-M_i\right)\\&T=x_0\cdot Q+y_0\cdot N+\sum_{i=1}^{N_a}V_i\cdot\left(d_{ui}-M_i\right)\end{aligned}$$

In turn, the coordinates (x_u, y_u) result in

$$
\begin{aligned}
x_u &= \frac{T \times Q - S \times N}{Q^2 - P \times N} \\
y_u &= \frac{S \times Q - T \times P}{Q^2 - P \times N}
\end{aligned}
\tag{15}
$$

From the above procedure, it can be seen that the calculation result of (x_u, y_u) depends on the initial coordinates (x_0, y_0), which can be viewed as a further optimization based on (x_0, y_0). The initial value of iteration can be chosen as the linear calculation result of least squares. On this basis, the judgment conditions are set as follows

$$
\sqrt{\left(x_u - x_0\right)^2 + \left(y_u - y_0\right)^2} < \eta_t \tag{16}
$$

where η_t is the iteration stopping threshold. If this condition is not satisfied, the computation result of (x_u, y_u) is reassigned to (x_0, y_0), i.e., $x_0=x_u$, $y_0=y_u$. If the condition is satisfied, the iteration stops, and the final computation result of (x_u, y_u) is the localization coordinates of the unknown node.

At this point, the detailed process description of the improved localization algorithm in this paper is completed.

4. SIMULATION EXPERIMENT ANALYSIS AND DISCUSSION

In order to objectively evaluate the performance of the improved algorithm in this paper, a comparative simulation study was carried out on the hardware platform (detailed configuration: Windows 11 operating system, 32.0 GB memory, Intel Core i7 processor with main frequency of 2.30 GHz) by using Matlab R2019a simulation software.

4.1. Simulation Parameter Settings

In order to facilitate performance comparison and without loss of generality, we make the following assumptions for the simulation environment : the simulation area is set to 100m*100m, and all nodes are randomly generated in this area with uniform distribution, and anchor nodes are randomly selected from them. At the same time, set the maximum communication radius of the node R=30m, the total number of nodes N=100, the number of anchor nodes N_a=30, then the number of unknown nodes N_u=70. The iterative stopping threshold of the algorithm in this paper is η_t=0.25m, and the iterative initial value is calculated by the least square linear calculation result. In addition, the evaluation parameters of the positioning performance are based on the simulation results of *num*=200 times in the same experimental environment, and the network environment parameters such as the network area, the total number of nodes, the number of anchor nodes and the communication radius of nodes remain unchanged during each simulation.

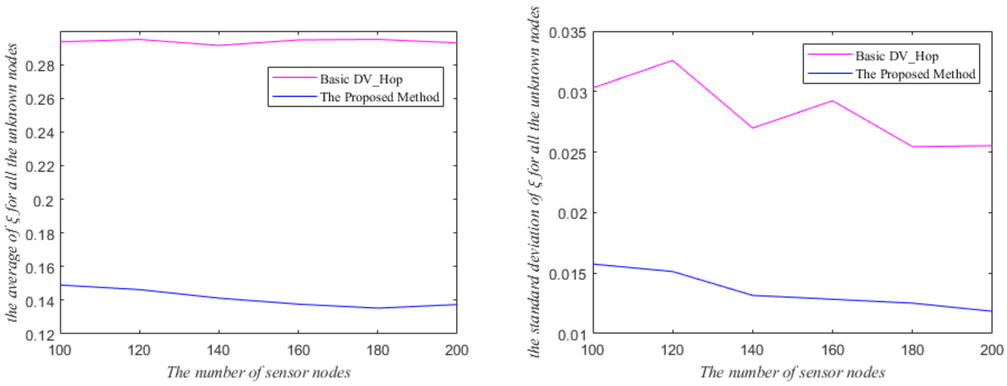
The evaluation equation of node positioning accuracy is as follows

$$
\phi = \frac{\sum_{1}^{num} \sum_{u=1}^{N-N_a} \sqrt{\left(x_u^{true} - x_u^{est}\right)^2 + \left(y_u^{true} - y_u^{est}\right)^2}}{num \cdot \left(N - N_a\right) \cdot R} \tag{17}
$$

Where φ denotes the average normalized localization error of the whole network based on num times of simulation results, (x_u^{true}, y_u^{true}) denotes the true coordinate value of the unknown node u, and (x_u^{est}, y_u^{est}) is the coordinate of the unknown node calculated by the localization algorithm.

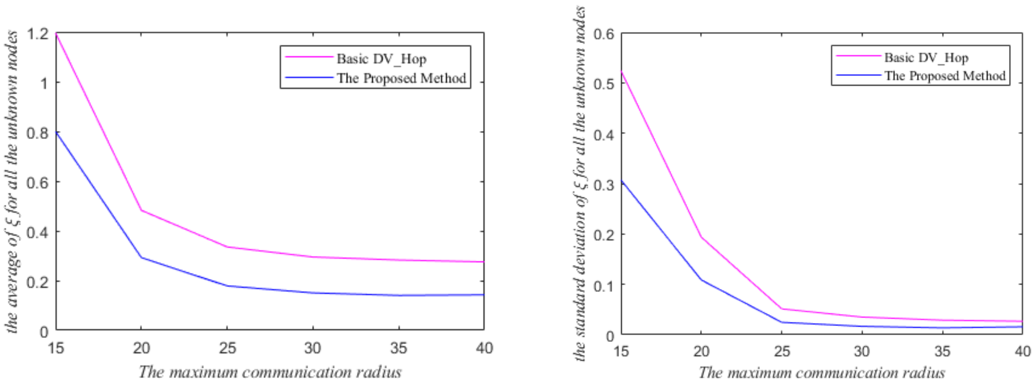
4.2. Performance Evaluation of the Proposed Algorithm

In order to evaluate the overall localization accuracy of this paper's algorithm, it is chosen to compare with the traditional DV_Hop algorithm. This paper's method is a localization algorithm based on nonlinear iterative solving, and here the iteration stopping threshold η_t=0.25m is set for this paper's method. Based on the simulation environment described in subsection 4.1, the localization performance of the algorithms is shown in Figure 1 when the number of anchor nodes is kept constant and the total number of nodes is varied from 100 to 200. Figure 1(a) depicts the average localization error variation curve for the unknown nodes in the network, while Figure 1(b) shows the standard deviation variation of the localization error. It can be seen that this paper's algorithm is much better than the traditional DV_Hop algorithm in terms of localization accuracy, and it gradually decreases with the increase of the total number of nodes. In terms of localization stability, this paper's algorithm also shows remarkable performance.



(a) (b)

Figure 1. Localization Performance vs. Total Number of Nodes

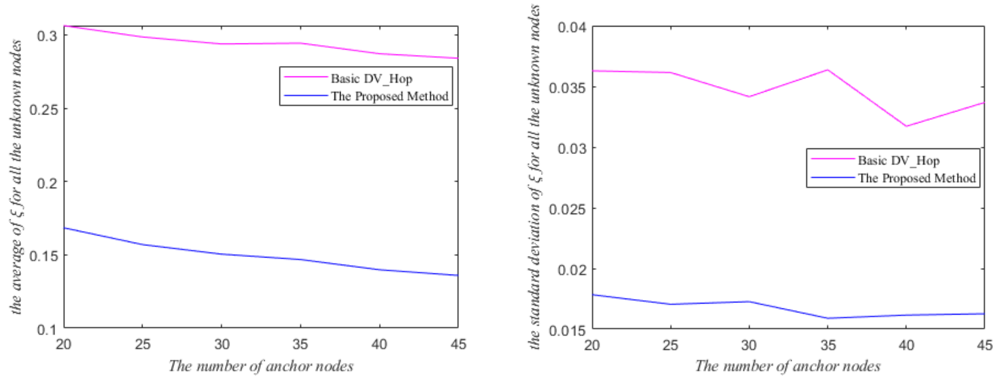


(a) (b)

Figure 2. Relationship Between Localization Performance and Maximum Communication Radius

Figure 2 depicts the localization performance of the algorithms with respect to the maximum communication radius. As a whole, it can be seen that the two algorithms show a decreasing trend in terms of average localization error with increasing communication radius, and the localization stability gradually improves. In the case of smaller communication radius, the proposed algorithm outperforms the traditional DV_Hop algorithm. As the maximum communication radius becomes larger, the anisotropy of the network decreases, and both algorithms in this paper show better performance in terms of localization accuracy and and localization stability compared with the traditional DV_Hop algorithm.

Figure 3 shows the variation curve of localization performance with the total number of anchor nodes. In Figure 3(a), the localization errors all show a decreasing trend with the increase of the total number of anchor nodes, and this paper's algorithm is significantly better than the traditional DV_Hop algorithm. In Figure 3(b), although the localization stability of this paper's algorithm and the standard DV_Hop algorithm basically remains constant with the increase of the total number of anchor nodes, this paper's algorithm is also better than the traditional DV_Hop algorithm in terms of localization stability, and its localization stability is stronger.



(a) (b)

Figure 3. Relationship Between Localization Performance and Total Number of Anchor Nodes

In the simulation environment described in subsection 4.1, a graph comparing the running time of the two algorithms is shown in Figure 4. The traditional DV_Hop algorithm is a linear solution method, so its running time is minimized. Compared with the traditional DV_Hop algorithm, the algorithm proposed in this paper is further optimized on the basis of the traditional DV_Hop solution result, so it is slightly higher than the traditional DV_Hop algorithm.

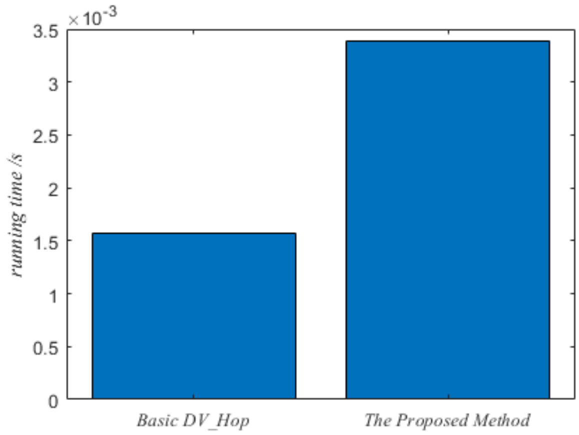


Figure 4. Algorithm Running Time Comparison

5. SUMMARY

In this paper, an improved non-ranging node localization method for wireless sensor networks is proposed. The method correctly calculates the average hop distance of the anchor node under the least squares criterion, and completes the reconstruction of the distance estimation method from the unknown node to the anchor node, and finally employs the nonlinear iterative optimization to perform the multilateral localization process. The experimental results verify that the algorithm in this paper shows good computational performance in all aspects and further improves the localization accuracy.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China under Grant (No. 62173127), the Scientific and Technological Innovation Leaders in Central Plains under Grant (No. 224200510008), Top Young Talents in Central Plains under Grant (No.(2023)11), the Innovative Funds Plans of Henan University of Technology under Grant (No. 2020ZKCJ06), the Zhengzhou Science and Technology Collaborative Innovation Project under Grant (No. 21ZZXTCX06), the Open Fund from Research Platform of Grain Information Processing Center in Henan University of Technology under Grant (No. KFJJ-2022-003).

REFERENCES

[1] Akyildiz I F, Su W, Sankarasubramaniam Y, et al. A survey on sensor networks [J]. IEEE Communications magazine, 2002, 40(8): 102-114.

[2] Khaitan S K, McCalley J D. Design techniques and applications of cyberphysical systems: A survey [J]. IEEE Systems Journal, 2014, 9(2): 350-365.

[3] Sun L, Chen T. Difference DV_distance localization algorithm using correction coefficients of unknown nodes [J]. Sensors, 2018, 18(9): 2860.

[4] Singh S P, Sharma S C. Range free localization techniques in wireless sensor networks: A review [J]. Procedia Computer Science, 2015, 57: 7-16.

[5] Bulusu N, Heidemann J, Estrin D. GPS-less low-cost outdoor localization for very small devices [J]. IEEE personal communications, 2000, 7(5): 28-34.

[6] Liu J, Wang Z, Yao M, et al. VN-APIT: Virtual nodes-based range-free APIT localization scheme for WSN [J]. Wireless Networks, 2016, 22(3): 867-878.

[7] Fang X, Jiang Z, Nan L, et al. Noise-aware localization algorithms for wireless sensor networks based on multidimensional scaling and adaptive Kalman filtering [J]. Computer Communications, 2017, 101: 57-68.

[8] Niculescu D, Nath B. DV based positioning in ad hoc networks [J]. Telecommunication Systems, 2003, 22(1-4): 267-280.

[9] Guo Z, Guo Y, Hong F, et al. Perpendicular intersection: locating wireless sensors with mobile beacon [J]. IEEE Transactions on Vehicular Technology, 2010, 59(7): 3501-3509.

[10] Liu Y, Chen J, Xu Z. Improved DV-Hop Localization Algorithm Based on Bat Algorithm in Wireless Sensor Networks [J]. KSII Transactions on Internet & Information Systems, 2017, 11(1): 215-236.

[11] Prashar D, Jyoti K. Distance Error Correction Based Hop Localization Algorithm for Wireless Sensor Network [J]. Wireless Personal Communications, 2019, 106(3): 1465-1488.

[12] Chen H, Sezaki K, Deng P, et al. An improved DV-Hop localization algorithm with reduced node location error for wireless sensor networks [J]. IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, 2008, 91(8): 2232-2236.

[13] Shen S, Yang B, Qian K, et al. On Improved DV-Hop Localization Algorithm for Accurate Node Localization in Wireless Sensor Networks [J]. Chinese Journal of Electronics, 2019, 28(3): 658-666.

[14] Xiao F, Wu M, Huang H, et al. Novel node localization algorithm based on nonlinear weighting least square for wireless sensor networks [J]. International Journal of Distributed Sensor Networks, 2012, 8(11): 803840.

[15] Tarrío P, Bernardos A M, Casar J R. Weighted least squares techniques for improved received signal strength based localization [J]. Sensors, 2011, 11(9): 8569-8592.

[16] Cui Z, Sun B, Wang G, et al. A novel oriented cuckoo search algorithm to improve DV-Hop performance for cyber–physical systems [J]. Journal of Parallel and Distributed Computing, 2017, 103: 42-52.

[17] Song L, Zhao L, Ye J. DV-Hop Node Location Algorithm Based on GSO in Wireless Sensor Networks [J]. Journal of Sensors, 2019, 2019: 2986954

[18] Kaur A, Kumar P, Gupta G P. Nature inspired algorithm-based improved variants of DV-Hop algorithm for randomly deployed 2D and 3D wireless sensor networks [J]. Wireless Personal Communications, 2018, 101(1): 567-582.

[19] Sharma G, Kumar A. Improved DV-Hop localization algorithm using teaching learning based optimization for wireless sensor networks [J]. Telecommunication Systems, 2018, 67(2): 163-178.