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Research on an Improved Particle Swarm Algorithm in DV-HOP Algorithm

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Abstract

The node positioning error in wireless sensor has always been the focus of research. A way of an improved particle swarm optimization algorithm being proposed to correct the DV-Hop error positioning method, which can reduce the estimate error for the distance between unknown nodes and anchor nodes. The matlab simulation results show that the improved algorithm can effectively improve the positioning accuracy of the sensor nodes than the traditional algorithm. The simulation results have verified the effectiveness of the improved algorithm.

Keywords: *Wireless sensor networks; DV-Hop Algorithm; Positioning Accuracy*

1. Introduction

Wireless sensor networks (WSN) consist of many limited energy sensor nodes. It has broad application prospects in the fields of military, environmental monitoring, health care and so on [1]. However, if these applications are out of position information, then they are meaningless. Therefore, to improve the positioning accuracy of sensor nodes is always a hot topic in the field of wireless sensor networks [2].

Aiming at the positioning problem of wireless sensor network nodes, a large number of domestic and foreign scholars have conducted a lot of researches. There are generally two positioning algorithms of the nodes: the range-based and the range-free [2]. The range-based algorithm needs to use the distance or the angle information to carry on the nodes positioning. They mainly are the received signal strength indication (rssi), time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA), etc. They have high positioning accuracy, but with the power consumption, high cost, they are not suitable for applications in low power consumption and low cost [3-5]. The range-free algorithm is based on the connectivity of the network to achieve node positioning. They mainly are centroid algorithm and DV-Hop, etc. They have the advantages of less hardware and simple calculation, but with low positioning accuracy [6-8]. DV-Hop is one of the most widely used range-free algorithms. In the view of low positioning accuracy of the problem, many scholars have improved the algorithm, such as setting threshold value to modify the number of hops between the nodes to improve the precision of distance estimation; Using the genetic algorithm, shuffled frog leaping algorithm, simulated annealing algorithm and particle swarm optimization algorithm to correct the positioning error of DV-Hop, which has improved the sensor's node positioning accuracy [9-11].

In order to improve the positioning accuracy of wireless sensor node, this paper firstly puts forward a kind of distance correction value strategy on analysing the error between estimated distance and real distance in anchor node to reduce the distance between

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unknown nodes and anchor nodes; secondly use the GPSO algorithm to correct the positioning error of DV-hop algorithm; at last use the simulation experiment to test performance of the algorithm.

2. DV-Hop Algorithm and Improved PSO Algorithm

2.1. DV-Hop Algorithm

According to the distance vector and the principle of GPS positioning, Nieuleseu, *et. al.* proposed DV-hop positioning algorithm of sensor nodes in 2001. DV-hop positioning algorithm contains only a few anchor nodes, and the others for unknown nodes which needs to determine their position by the positioning algorithm. It does not need to measure the distance, low hardware requirements, and has been widely used in the hardware condition of limited WSN. The location steps in DV-hop algorithm are as follows:

(1)Each anchor node passes its own position information to the neighbor nodes in the communication range. The received node records the minimum hop count of each anchor node while ignoring the larger hop count's information from the same anchor node, and then adds the hop value by 1 to the neighbor node.

(2)According to the record of the other anchor nodes in the coordinates of information and the number of hops, each anchor node estimates average distance of hop distance by Formula (1)

$$HopSize_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \neq i} hopS_{ij}} \qquad (1)$$

In Formula (1), j is the number of other anchor nodes in the anchor node i data table, $hopS_{ij}$ is the hop number between anchor node i and anchor node j. By the anchor node transferring the calculated average hop distance to the entire network, the unknown nodes only record the first received average hop distance, and transmit to the neighbor nodes; after being received the average hop distance, the unknown node gets the distance of someone on the anchor nodes by the estimated unknown nodes in Formula (2):

$$L_i = S_i \times HopSize \qquad (2)$$

(3)Suppose $P_1(x_1, y_1), P_2(x_2, y_2), \cdots P_n(x_n, y_n)$ stands for the position coordinate of n beacon nodes, the position of location node D is (x, y), the estimated distance between the to-be-positioned node D and each beacon node is $d_1, d_2, \cdots d_n$, so we can get Formula (3) is as follows:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = d_2^2 \\ \vdots \\ (x_n - x)^2 + (y_n - y)^2 = d_n^2 \end{cases} \qquad (3)$$

Each equation subtracts the last equation, then the Formula (4):

$$\begin{cases} 2(x_1 - x_n)x + 2(y_1 - y_n)y = x_1^2 - x_n^2 + y_1^2 - y_n^2 - d_1^2 + d_n^2 \\ 2(x_2 - x_n)x + 2(y_2 - y_n)y = x_2^2 - x_n^2 + y_2^2 - y_n^2 - d_2^2 + d_n^2 \\ \quad\vdots \\ 2(x_{n-1} - x_n)x + 2(y_{n-1} - y_n)y = x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 - d_{n-1}^2 + d_n^2 \end{cases} \quad (4)$$

Use linear equations to express $AL = b$

In the ranging process, due to the impact of a variety of factors, they produce some random errors. The most reasonable linear equations should be

$$L = (A^T A)^{-1} A^T b \qquad (5)$$

2.2. PSO Algorithm

According to the migration and cluster behavior in the foraging process of birds, Kennedy propose a algorithm of particle swarm optimization (PSO), if particle swarms search in d dimensional spaces, the velocity and position of the particle i respectively are $v_i = (v_{i1}, v_{i2}, \cdots, v_{id})$ and $x_i = (x_{i1}, x_{i2}, \cdots x_{id})$, the optimal position of swarm history is $p_g = (p_{g1}, p_{g2}, \cdots p_{gd})$, the speed and position update equations are:

$$v_{id}^{k+1} = \omega_{id}^k + c_1 r_1 (p_{id} - x_{id}^{k+1}) + c_2 r_2 (p_{gd} - x_{id}^k) \qquad (6)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \qquad (7)$$

In the formulas, c_1 and c_2 are acceleration constants, r_1 and r_2 generally the random functions ranges in [0, 1], k is iteration, ω is inertia weight.

2.3. Improved Particle Swarm Optimization Algorithm

Basic particle swarm optimization algorithm is prone to premature, easy to fall into the local best of the phenomenon, it is difficult to find the optimal solution of the problem. In order to solve the problem, this paper has improved the particle swarm algorithm. Firstly, divide the search range of all the particles into a number of the same size of the particle swarm; secondly, improve each local particle swarm algorithm; At last, the minimum or maximum value of the particle swarm optimization algorithm is the optimal solution. This improved algorithm solves the problem of PSO algorithm trapping into local optimum, which leads to inaccurate positioning of sensor nodes.

3 Improved Node Positioning Algorithm Based on Particle Swarm Optimization

3.1. Error Analysis

In Formula (4), d_n is the measuring distance with error, each element of vectors contains d_n, if the error of d_n is quite an hour, then the node positioning results of least squares method can meet the actual requirements, if the error of d_n is quite large, then the error of node positioning is also very large, even though the error of $d_1, d_2, \cdots d_{n-1}$ is quite small.

Suppose the distance between anchor node (x_i, y_i), $i = 1, 2, \cdots n$ and unknown node (x, y) is r_i, $r = 1, 2, \cdots n$, range error is ε_i, then $|r_i - d_i| < \varepsilon_i$, $i = 1, 2, \cdots n$. According to the Formula (2), (x, y) should meet the following constraints

$$\begin{cases} d_1^2 - \varepsilon_1^2 \le (x_1 - x)^2 + (y_1 - y)^2 \le d_1^2 + \varepsilon_1^2 \\ d_2^2 - \varepsilon_1^2 \le (x_2 - x)^2 + (y_2 - y)^2 \le d_2^2 + \varepsilon_2^2 \\ \vdots \\ d_n^2 - \varepsilon_1^2 \le (x_n - x)^2 + (y_n - y)^2 \le d_n^2 + \varepsilon_n^2 \end{cases} \quad (8)$$

Solve (x, y), then

$$f(x, y) = \sum_{i=1}^{n} \sqrt{(x_i - x)^2 + (y_i - y)^2 - d_i^2} \quad (9)$$

When the formula (9) obtains the minimum value, the total error is the smallest. The solution of the unknown node is closest to the true value, and the coordinate (x, y) is the optimum solution, which meet the next type of unknown node coordinates

$$fitness(x, y) = \min\left(\sum_{i}^{n} \sqrt{(x_i - x)^2 + (y_i - y)^2 - d_i^2} \right) \quad (10)$$

Based on the above analysis, the node positioning problem is successfully transformed into a global optimization problem. The solution of the formula (14) is a nonlinear optimization problem, and the traditional mathematical method has great difficulty in solving this problem. Particle swarm optimization (PSO) algorithm is one of the effective methods, which used to solve the nonlinear optimization problem. For this reason, through the exchange of information between the particles and collaborate with each other, and find the nonlinear problem of the optimal solution, the formula (14) as the objective function of the GPSO algorithm, achieve the accuracy calculation of unknown node coordinates .

3.2. Steffensen Corrected DV-Hop Positioning Error

In addition to the setting of error coefficient, the necessary condition for (10) getting the minimum value is:

$$\frac{\partial f}{\partial x_i} = \frac{\partial f}{\partial y_i} = 0, (m < i \le n) \quad (11)$$

In which:

$$\begin{cases} \dfrac{\partial f}{\partial x_i} = \sum\limits_{\substack{m<i\le n \\ 1\le j\le m}} (2(x_i - x_j) - \dfrac{2l_{ij}(x_i - x_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}) \\ \dfrac{\partial f}{\partial y_i} = \sum\limits_{\substack{m<i\le n \\ 1\le j\le m}} (2(y_i - y_j) - \dfrac{2l_{ij}(y_i - y_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}) \end{cases} \quad (12)$$

Let:

$$\Delta_i = \sqrt{(\frac{\partial f}{\partial x_i})^2 + (\frac{\partial f}{\partial y_i})^2} \quad (13)$$

Then the problem for getting the best solution of min(fitness()) is transformed to the problem of the unknown node coordinate (x_i,y_i) when getting the minimum value of Δ_i. The detailed steps as following:

（1）Iterate variables x_i and y_i according to the first step pf Steffensen iterative

$$\begin{cases} \bar{x}_i = \varphi(x_i) = \dfrac{\sum_{1\le j\le m} \left(x_j + \dfrac{l_{ij}(x_i - x_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}\right)}{m} \\ \bar{y}_i = \varphi(y_i) = \dfrac{\sum_{1\le j\le m} \left(y_j + \dfrac{l_{ij}(y_i - y_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}\right)}{m} \end{cases} \tag{14}$$

$$\begin{cases} \tilde{x}_i = \varphi(\bar{x}_i) = \dfrac{\sum_{1\le j\le m} \left(x_j + \dfrac{l_{ij}(\bar{x}_i - x_j)}{\sqrt{(\bar{x}_i - x_j)^2 + (y_i - y_j)^2}}\right)}{m} \\ \tilde{y}_i = \varphi(\bar{y}_i) = \dfrac{\sum_{1\le j\le m} \left(y_j + \dfrac{l_{ij}(\bar{y}_i - y_j)}{\sqrt{(x_i - x_j)^2 + (\bar{y}_i - y_j)^2}}\right)}{m} \end{cases} \tag{15}$$

In the formula, x_i and y_i are the estimated position of the sensor nodes applying DV-Hop algorithm and take it as the iteration initial value.

（2）Update the iteration for the unknown nodes

$$\begin{cases} x_i^{'} = \tilde{x}_i - \dfrac{(\tilde{x}_i - \bar{x}_i)^2}{\tilde{x}_i - 2\bar{x}_i + x_i} \\ y_i^{'} = \tilde{y}_i - \dfrac{(\tilde{y}_i - \bar{y}_i)^2}{\tilde{y}_i - 2\bar{y}_i + y_i} \end{cases} \tag{16}$$

（3）Substitute the node coordinate (x_i,y_i) of the new unknown sensor into formula (13), and get the value of Δ_i.

（4）When the iterations reach to the set maximum value, iteration algorithm stops. Get the unknown nodes coordinate that is close to the actual value and minimize the positioning error.

3.3. This Paper Algorithm for Error Correction Steps

(1) The approximate coordinates of the unknown sensor nodes are estimated by the three side method or the multi-lateral method, and the node positioning problem is transformed into a nonlinear optimization problem.

(2) Set GPSO related parameters, suppose there are M particles within the simulation range, separate M particle into N independent small particle swarms(suppose M can be divisible by N), the number of particles per small particle swarm are m = M/N.

(3) Initial the velocity and position of each particle in the subgroup, for each particle in the subgroup, calculate the fitness value according to formula (13), save the optimal particle location to p_i, the optimal location of subgroup is saved to P_{kg},(represents the k optimal location of the sub group).

(4) Update the velocity and position of the particle according to Formula (6) ,(7)and(16).

(5) The position of each particle of the subgroup is compared with its own historical optimal position p_i. If it is better than p_i, then p_i is replaced by the position of the

particle.

(6) The position of each particle of the subgroup is compared with the subgroup historical optimal position P_{kg} . If it is better than P_{kg} , then P_{kg} is replaced by the position of the particle.

(7) If the maximum number of iterations is reached, and the loop is done, then compare the fitness value of the optimal position of each sub subgroup. As the positioning target of the sensor nodes is to make positioning error minimum, the optimal position of the whole particle swarm is $p_g = \min(P_{1g}, P_{2g}, \cdots P_{kg}, \cdots P_{Ng})$; otherwise go to step 5 to continue the iteration.

(8) Output p_g coordinates of the corresponding particles as the fixed coordinates of the sensor to be fixed.

4. Simulation Experiment

To test the positioning performance of the sensor nodes in this paper, the simulation experiment is carried out on the Matlab platform. Suppose the nodes are randomly distributed in 100 m×100 m network region, and the coordinates of unknown nodes and anchor nodes are randomly generated. Using DV-Hop algorithm, PSO-DV-Hop algorithm to compare the experiment, and use the normalized average positioning error as an evaluation. The calculation formula is

$$error = \frac{\sum_{i=1}^{m} \sqrt{(x_i - x_i^{'})^2 + (y_i - y_i^{'})^2}}{k \times m \times r} \qquad (17)$$

In the formula, m is the number of unknown nodes; k are the numbers of experiments; r are communication radius; (x_i, y_i) are the estimated coordinates of unknown nodes; $(x_i^{'}, y_i^{'})$ are the real coordinates of unknown nodes.

4.1. Compared with the Convergence Performance of PSO Algorithm

In the case of sensor node positioning target error is 0.5, the positioning error change curve of GPSO algorithm and PSO algorithm have shown in Figure 3. In Figure 3, GPSO algorithm as long as by 30 iterations will find to meet the positioning accuracy requirements of the sensor nodes, while with significantly increased the number of iterations, the PSO algorithm meets the node positioning accuracy requirements latterly in the 70 iteration. This is mainly due to the GPSO algorithm make each subgroup as used to a separate search space. In the space of each subgroup, as the searching range of single particle is small and the search speed is fast, the search ability will be stronger. Each particle of the group convergence rate is obviously accelerated, which is influenced by the moving of the particle itself the best adaptation of the best fitness value and the value of subgroup. Reducing the number of iterations effectively under the premise of ensuring the positioning accuracy, the search efficiency of the optimal solution of the sensor node positioning is improved.

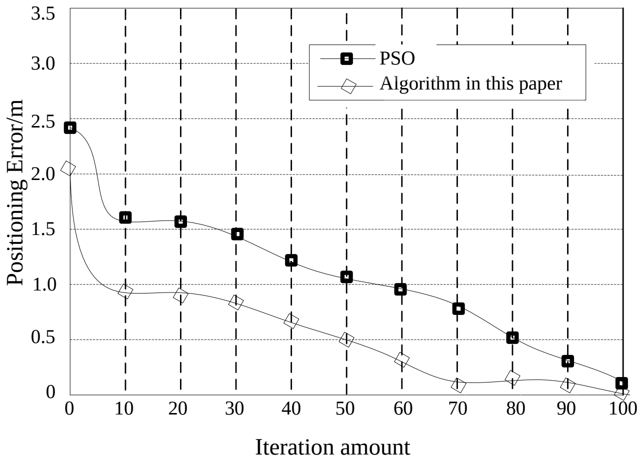

Figure 3. The Position Error Variation Curve of this Paper Algorithm and PSO Algorithm

4.2. Positioning Performance under Different Node Numbers

Under the condition of the node communication radius R = 20 m, and the anchor nodes proportion being 10%, with the change of the number of nodes, the normalized positioning error variation curve of this paper algorithm, PSO-DVHop algorithm and DV-Hop algorithm are shown in figure 4. In figure 4, with the increase of the number of nodes, the average positioning error of the three algorithms is gradually reduced. The positioning error of GPSO-DVHop is significantly less than that of DV-Hop algorithm and PSO-DVHop algorithm, which is reduced by 32.18% and 18.21% respectively.

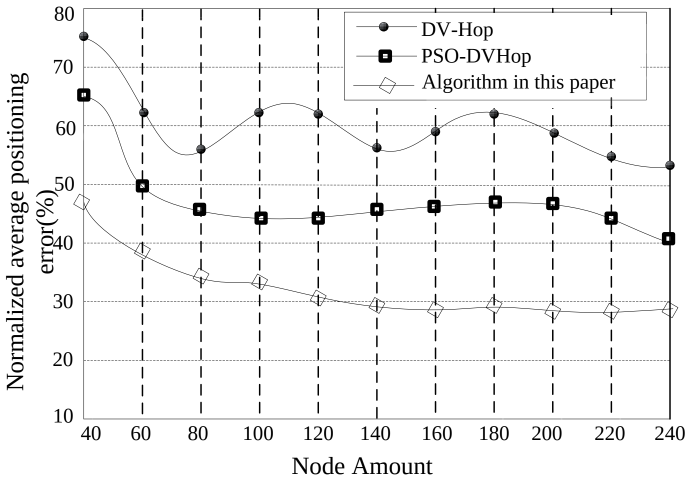

Figure 4. Transformation Curve between Three Algorithms

4.3. Positioning Performance Comparison under Different Anchor Nodes

Under the condition of the total number of nodes is 100 and communication radius r = 20 m, with the change of the number of nodes, the normalized positioning error variation curve of this paper algorithm, PSO-DV-Hop algorithm and DV-Hop algorithm are shown in figure 5. In figure 5, with the increase of the number of nodes, the average positioning error of the three algorithms is gradually reduced and tended to be stable. Compared to the DV-Hop and PSO-DV-Hop algorithms, the average positioning error of the proposed algorithm is reduced by 32.25% and 18.72%.

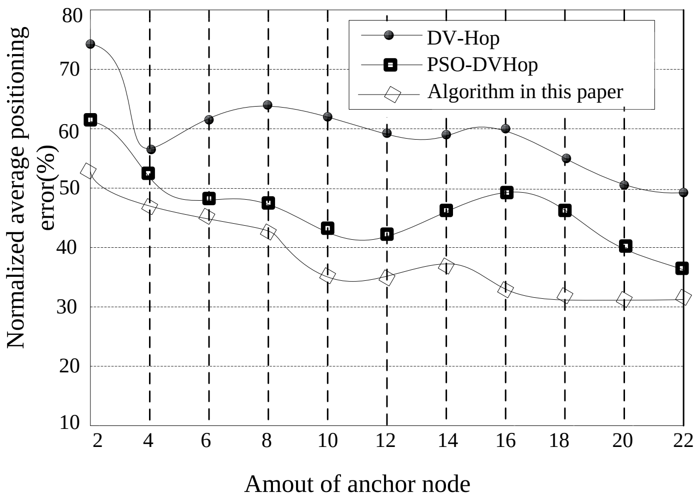

Figure 5. Positioning Performance of Three Algorithms with Different Number of Anchor Nodes

4.4. Positioning Performance Comparison under Different Communication Radius

Under the condition of the total number of nodes is 200 and the anchor nodes proportion being 20%, the influence of communication radius on the performance of this paper algorithm, PSO-DV-Hop algorithm and DV-Hop algorithm is shown in Figure 6. In figure 6, with the increase of the communication radius of nodes, the average positioning error of the three algorithms is gradually reduced. Compared to the DV-Hop and PSO-DV-Hop algorithms, the average positioning error of the proposed algorithm is reduced by 27.25% and 16.34%.

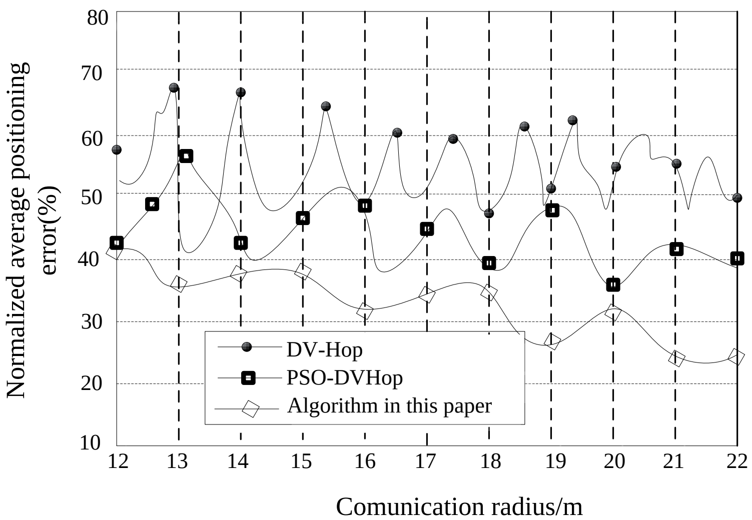

Figure 6. Positioning Performance of the Three Algorithms under Different Communication Radius

5. Conclusion

This paper analyses the reason of wireless sensor network DV-Hop positioning algorithm is low, proposed an improved particle swarm optimization based on the DV-Hop sensor node positioning algorithm. The simulation results show that in different number of nodes, number of anchor nodes and node communication radius, the algorithm in this paper in terms of positioning accuracy and the average position error compared with DV, the algorithm PSO-HOP has obvious advantages, has good wireless sensor network node positioning method.

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