The Research of Positioning Algorithm for Wireless Sensor Networks

Zeng Zhen-dong
Guangdong Youth Vocational College, zengzhendong1980@qq.com

Abstract
The essay researches the issue of improvement on positioning accuracy of wireless sensor network. As for the defects that current accuracy of network positioning algorithm is not high which causes the low accuracy of target positioning of wireless sensor network, the essay proposes a positioning method based on RSSI ranging technology. The main change is that the calculation methods of average hop distance and anchor node distance are improved, and a new unknown node is cloned which is close to each anchor node, and the amendment value could be acquired by analysis and aim to amend the coordinate of node; meanwhile the RSSI ranging technology is applied to the nodes in the range of one hop of anchor node. Mat lab simulation result indicates that the validity on the positioning error is verified which indicates that the algorithm is an efficient and accurate positioning algorithm.

Keywords: Wireless Sensor Networks, DV-hop, RSSI, Positioning

1. Introduction

Wireless network positioning technology processes accurate measurement for position of an individuality or a certain mobile terminal in certain time according to measuring the parameter of radio wave received by using wireless mobile communication network in order to provide positioning information service for mobile terminal user or to supervise and track in a real time. There are two main technologies for wireless sensor networks (WSNs), among which one is positioning for sensor node of WSNs, another is positioning for external object of WSNs. The essay is mainly to discuss the first one. Currently as for the positioning system, the related algorithms could be divided into two categories: the positioning algorithm based on distance and positioning algorithm which has no relation with distance [1]. The distance between nodes and angel information shall be measured by specific hardware equipment by positioning algorithm based on distance, and then the node position shall be calculated by trilateration survey, triangulation survey and maximum likelihood estimation, where the common positioning technologies are RSSI [2], TOA [3], TDOA [4] and AOA [5]. The positioning algorithm based on distance could measure the positioning information of node accurately, but the cost for the hardware is relatively heavy. The positioning method which has no relation with distance could position nodes by the information of network contact, where the common positioning technologies are Centroid [6], APIT [7] and DV-Hop [8]. Compared with positioning algorithm based on distance, there is no need of additional ranging hardware support for positioning algorithm which has no relation with distance. The algorithm which has no relation with distance has been focused by industrial section and academy because it has obvious advantages on power and expansivity although the expense on network density and communication is a little much.

On the basis that the existing positioning algorithms have been researched, according to RSSI ranging technology [9] the essay proposes an improved DV-Hop positioning algorithm which is applicable to WSNs. The procedures of the algorithm are:(1) improve the calculation method of average hop distance and anchor node distance; (2) clone the unknown node by using anchor node, and calculate amendment of amendment value on coordinate of unknown node. (3) The RSSI ranging technology is applied to the positioning of unknown node. Finally, verify the validity and practicality of positioning error and forecast accuracy by adopting stimulation test and math analytical method. It is shown that it is a efficient and dependable positioning algorithm[10].

2. The principle of DV-Hop positioning algorithm

Niculescu D and others proposed DV-Hop algorithm. According to product of average hop distance and hops between anchor nodes on the nodes of WSNs, the distance between unknown node and anchor node could be estimated, and then the coordinate of unknown nodes could be calculated by the
maximum likelihood estimation method. The procedure could be constituted by 3 stages. In the first stage, according to coordinate value and the value of hops recorded, and by the below equation:

\[
\text{Hopsize}_i = \frac{\sum_{j=i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j=i} h_j}
\]  

(1)

Then calculate the average hop distance.

In the second stage, the average hop distance calculated by anchor node is transferred to WSNs according to grouping broadcast[11], and the unknown node only records the first average hop distance, then send it to neighbor node. Meanwhile by the equation \( \text{Distance}_i = \text{Hopsize}_i \times \text{Hopsize}_i \), the average hop distance multiplies the hop value, and then estimate the distance between it and anchor node.

In the third stage, as the distance between the unknown node and 3 anchor nodes or more are acquired, then position it by trilateration method and maximum likelihood method.

3. Improved DV-Hop algorithm

Although the positioning technology of DV-Hop algorithm mentioned in the last chapter has no relation with distance and can realize the itself positioning; but as for the actual application, wireless sensor node scatters around the domain of ranging area, the topology structure of node is at random, and the communication radius of node is fixed commonly. Calculate minimum hop number and average hop distance by DV-Hop algorithm, the production of the two factors could be regarded as estimated value of distance between anchor nodes, then process trilateration survey according to the estimated value. However, there is an error between actual distance of nodes and estimated distance. Also it is the main error of DV-Hop algorithm[12]. Obviously, if the information of distance between unknown node and anchor is recorded and used efficiently, then the performance of the algorithm could be further improved.

Therefore, as for the improvement of DV-Hop algorithm, and on the basis of RSSI ranging technology, the error of actual distance between nodes and estimated distance could be decreased.

3.1. RSSI ranging technology

RSSI (Received Signal Strength Indicator) refers to the ranging technology which measures distance by using signal intensity attenuation. Currently, RSSI technology has been applied to the many positioning algorithms.

As adopt RSSI to measure distance, the anchor node sends signal. In the radius of communication the unknown node receives the signal from anchor node, the distance of anchor node could be judged according to the strength of signal. According to the signal attenuation model, the farther distance to anchor node, the more attenuated signal, the less strength of signal received by the unknown node. However, the unknown node which is close to anchor node would receive stronger signal. Therefore the there is a mapping relationship between signal strength and the distance between nodes.

Set the signal strength of anchor node received by unknown node is \( R \), which is line with one linear model \( \tilde{D} = A + BR \), calculate the distance between the unknown node and anchor node \( \tilde{D} \). The coefficient \( A \), \( B \) could be acquired by method of minimum square.

Set \( N \) observed values \( D_1, \ldots, D_n \) of \( \tilde{D} \), \( N \) observed values \( R_1, \ldots, R_n \) of \( R \), acquire the theoretical curve \( \tilde{D} = F(R) \), then the sum of square of deviation \( \sum_{j=1}^n (D_j - \tilde{D})^2 \) is minimum.
3.2. The error analysis of DV-Hop algorithm

In the DV-Hop algorithm, the recorded coordinate value of all the anchor node and distance hops value are used to calculate the average hop distance of each anchor node. As for each anchor node, the average hop distance calculated by it represents the ratio between anchor node distance and sum hops of all the network, but failing to represent neighbor network information of all the anchor nodes; unknown node only records the first average hop distance. The above strategies ensure that almost nodes could receive the value of average hop distance form closest anchor node, but the information of only one anchor node could be used and others are omitted; meanwhile DV-Hop algorithm heavily depends on the hops. The simulation test indicates as shown in figure 1 due to maldistribution of nodes in the network, there are some cavities in the network[13]. Like A, B district, communication path would bypass the cavity, causing the low value of average hop distance and the bigger positioning error, and failing to represent the actuality. And in the range of one hop all the nodes, no matter of its position, are regarded as having equal distance to anchor node. Above factors are main error source for positioning of DV-Hop algorithm.

![Figure 1. The Distribution of Network Nodes](image)

3.3. Improved DV-Hop algorithm

In the previous chapter, we analyze the reasons of error from positioning algorithm, then we improve the DV-Hop algorithm which could be divided into 4 stages:

In the first stage, each anchor node adopts broadcast model to send data package. The format of broadcast information is \{id, X, Y, Hops\}, including the sign of the node, position coordinate \{X, Y\} and the information of Hops. Meanwhile, the coordinate of anchor node and the distance of hops could be acquired by all the nodes of sensor. Therefore according to the below equation the distance between anchor node \(i\) and \(j\) could be calculated[14].

\[
\text{Hopsize}_i = \frac{\sum_{j \in \text{nbrs}(i)} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \in \text{nbrs}(i)} h_j}
\]

(2)

\(\text{nbrs}(i)\) represents the neighbor range of anchor node \(i\). Set threshold value \(T\), command \(\text{nbrs}(i) \leq T\), the \(T\) value could be changed by anchor node density and distribution of network.

And then the anchor node in the radius of communication sends data package which contains RSSI
value, whose format is \(\{id, RSSI\}\), the unknown node receives the data package from all the anchor nodes, subtracts the received RSSI value \(R\), and maps the codes \(id\) of anchor nodes respectively. And the distance between it and anchor node coded as \(id\) is calculated according to the equation \(\tilde{D} = A + BR\), then record the value.

In the second stage, each anchor node adds an unknown node, whose coordinate is set by the coordinate of anchor node. Set the coordinate of anchor node is \((X, Y)\), then the coordinate of added unknown node is \((X + \xi, Y + \xi)\), \(\xi << 1\). The coordinate of the unknown node is saved by anchor node.

The average hop distance is calculated by the broadcast of each anchor node, and the record of the unknown nodes is from average hop distance of all the anchor nodes, which is corresponding to the anchor nodes, then send the data package to the neighbor node[15]. Each unknown node saves a list which receives anchor nodes corresponding average hop distance.

As calculate the distance between unknown node and certain anchor node, the process below judgment:

- If the number of hops of the distance between anchor node and the unknown node is one, the code \(id\) of the unknown node corresponding \(\tilde{D}\) is regarded as the estimated value of distance to the anchor node;
- If the number of hops of the distance between anchor node and the unknown node is more than one, then the unknown node is calculated as the below equation.

\[
\text{Distance}_{ij} = \text{Ave} \left( \sum_{H \neq H_i} HpSez \right) + \tilde{D}_{last} \quad H_{p_i} > 1
\]  

\(\text{Ave}\) represents averaging, \(\tilde{D}_{last}\) is the estimated distance between last hop node and the anchor node.

In the third stage, as the unknown node acquires the distances to 3 or more anchor nodes, then the coordinate could be calculated by maximum likelihood method. Meanwhile the amendment value is calculated by anchor node adding unknown node. Set the estimated coordinate of unknown node made by anchor node is \((\tilde{X}_i, \tilde{Y}_i)\), \(i=1, 2, ..., n\). The actual coordinate of unknown node is \((X_i, Y_i)\) \(i=1, 2, ..., n\).

The distance between estimated coordinates and actual coordinate is defined

\[
D_i = \sqrt{(X_i - \tilde{X}_i)^2 + (Y_i - \tilde{Y}_i)^2}, \quad i=1, 2, ..., n
\]  

Calculate amendment value \(RX_i\), \(RY_i\).

\[
RX_i = \frac{X_i - \tilde{X}_i}{D_i} \quad i=1, 2, ..., n
\]  

\[
RY_i = \frac{Y_i - \tilde{Y}_i}{D_i} \quad i=1, 2, ..., n
\]  

In the fourth stage, the calculated amendment value is broadcast in the WSNs, and each unknown node only receives the first amendment value and saves it, then send it to the neighbor node until the each acquire the amendment value. Next, each unknown node amends the coordinate estimated value.
according to the received amendment value. Set the coordinate estimated value of certain unknown node \((X, Y)\), and the coordinate amendment values received by it are \(RX\) and \(RY\), then use the equation

\[
X = X + X \ast RX \\
Y = Y + Y \ast RY
\]

(7)

The amended coordinate value of the node is acquired.

4. Simulation test result and performance analytical remark

The test plat is based on the MATLAB7.0, and the method mentioned in the essay process simulation test and analysis. In the simulation test, if one two dimensional WSNs has \(N\) nodes, which is distributed in a square area of \(L \times L\), without obstacle or interruption, and the coordinate of anchor node is known. In case that the communication model of node is the circle of itself, and the radius of communication is represented by \(R\); the communication performance of anchor node and unknown node is equal, and the radius of communication is \(R\); nodes possess the symmetrical communication performance, and the ability of receive and send are equal. The average positioning error is defined as:

\[
\text{Error} = \frac{\sum_{i=1}^{U_{\text{Known}}} \sqrt{(X_{\text{real}} - X_{\text{est}})^2 + (Y_{\text{real}} - Y_{\text{est}})^2}}{U_{\text{Known}}}
\]

(8)

And the \(U_{\text{Known}}\) represents the number of unknown nodes, \((X_{\text{real}}, Y_{\text{real}})\) \((X_{\text{est}}, Y_{\text{est}})\) are respectively actual coordinate and estimated coordinate of unknown nodes, and acquire the simulation result average value for 50 times. The error of positioning is \(\text{Error}/R\); \(R\) is the communication radius of node. In the 500*500 simulation area, 100 nodes are distributed at random, set communication radius of node as 40, the number of anchor nodes is changed, then observe the relative positioning error in the aspect of DV-Hop algorithm and improved DV-Hop algorithm on the different number of anchor node. The result of simulation result is shown in figure 2.

As shown in figure 2, with the increasing of anchor nodes, there is a slow downward trend on the error of DV-Hop positioning algorithm. As the number of anchor nodes reaches 70, the error would never decrease according to the increasing of number of anchor nodes, and is attained at a stable value. The average positioning error is dependable heavily on the DV-Hop algorithm and is decreasing with the increasing of number of anchor nodes. But the upward trend would become slow, finally become stable.

![Figure 2. The Relation of Positioning Error and Number of Anchor Nodes](image-url)
There are 20 anchor nodes at random in the 500*500 simulation area, set the communication radius of node as 40, the number unknown nodes is changed, and observe the relative positioning error in the aspect of DV-Hop algorithm and improved DV-Hop algorithm on the different number of anchor node. The simulation result is shown in figure 3.

In figure 3, with the increasing of anchor nodes, there is a slow downward trend on the error of DV-Hop positioning algorithm. As the number of anchor nodes reaches 110, the error would never decrease according to the increasing of number of nodes, but would be stabilized at 0.32. The average positioning error of improved DV-Hop algorithm is lower than DV-Hop, and the positioning error is decreasing significantly with the increasing of number of nodes. The downward trend becomes slow and stable finally. There are 150 nodes at random in the 500*500 simulation area, set the number of anchor nodes as 40, the communication radius of nodes is changed, and observe the relative positioning error in the aspect of DV-Hop algorithm and improved DV-Hop algorithm on the different number of anchor node. The simulation result is shown in figure 4.

From figure 4, as the communication radius is increased from 20 to 90, the advantage of improved DV-Hop based on RSSI is more and more obvious, and the positioning error is decreasing significantly with the increasing of the communication radius of node. Because the increase of node communication radius leads to the increasing of number of nodes, in order to make more nodes being positioned by RSSI, and to decrease the positioning error.

Therefore, the wireless network positioning algorithm mentioned in the essay possesses high
accuracy and low error and is applicable to all systems.

5. Conclusion

The essay proposes the improved DV-Hop positioning algorithm based RSSI which is applicable to WSNs. By using the algorithm, the calculation method for average hop distance and distance to anchor node is improved; the new unknown node is cloned by anchor node, calculate amendment value and amend the coordinate of unknown node. Meanwhile the RSSI ranging technology is applied to the algorithm. By simulation test, the validity on the positioning error is verified which indicates that the algorithm is an efficient and accurate positioning algorithm.

6. Reference