Research on Location Strategy of Mobile Anchor Node Based on Virtual Force

Xuerui Chen¹, Yanzhu Hu¹, Xinbo Ai¹ and Yanchao Shao², *

¹School of Automation, Beijing University of Posts and Telecommunications, Beijing 100876, China
²Central Research Institute of Building and Construction Co., Ltd, MCC GROUP, Beijing 100088, China

*Corresponding author e-mail: syc-mail@163.com

Abstract. In the process of wireless sensor network location based on mobile anchor nodes, the location strategy of mobile anchor nodes has important influence on the performance of positioning. However, the existing strategy does not traverse empty area effectively, the length of path is too long. Therefore, a dynamic adjustment location strategy based on virtual force is proposed. Firstly, the unknown nodes randomly distributed in the region are adjusted to be evenly distributed under the influence of virtual force. Then a moving anchor node travels from the positive center of the region along the direction of equidistant spiral and adjusts orientation dynamically under the influence of virtual force. The simulation results show that the anchor node can traverse effectively according to the unknown node's distribution, and successfully shorten the length of moving path.

1. Introduction

In industrial production, wireless sensor networks have been applied on a large scale [1]. The location technology of wireless sensor network based on mobile anchor node has more and more applications due to its low cost and high flexibility [2]. Therefore, the research on the location strategy of mobile anchor node has important research significance.

In order to improve the efficiency of traversing empty area, several location strategies have been proposed. A solution is that multiple mobile anchor nodes traverse the entire area. However, such a solution is impractical for many reasons including the cost of the devices and high complexity of algorithm [3-5]. A solution is that mobile anchor node traverses the area along a specified path. However, such a solution has poor adaptability and low accuracy of location [6, 7]. Another solution is that localize the expandable anchor node. However, such a solution cannot completely cover effective area [8-10].

For the questions raised above, the main contribution of this paper is to propose a dynamic adjustment location strategy based on virtual force. The nodes to be located in the region adjusts its position under the influence of virtual force between themselves, so that the node distribution in the region tends to be uniform. After that, the anchor node enters the network region, travels along the direction of equidistant spiral and adjusts orientation dynamically under the influence of virtual force. Positioning adopts the idea of combining the three-point positioning algorithm based on RSSI with the centroid algorithm.
Simulation results show that the method can effectively shorten the length of moving path and maintain a good positioning coverage.

2. Research on Location Strategy of Mobile Anchor Node Based on Virtual Force

2.1. RSSI data processing

The RSSI value is the signal strength for a node to receive data in dBm. Because there are many interference factors such as multipath effect, non-line of sight and obstacles in the actual environment, the received multiple sets of RSSI values have small probability anomalies. Gaussian filtering is used to filter the RSSI data. The multiple sets of RSSI values of the same node approximate the Gaussian distribution, take $0.6 \leq P(RSSI) \leq 1$ as the high probability occurrence area, and take the RSSI value in the high probability occurrence area as the effective value, finally seek the average value as the final RSSI value of the node. In the actual environment, the RSSI will attenuate as the transmission distance increases. As shown in formula (1), the approximate conversion relationship between signal strength and distance is usually achieved by using the classical loss model.

$$d = 10^{(RSSI - A)/10\alpha} \quad (1)$$

In formula (1), $d$ is distance between source and receiver, $A$ is attenuation of RSSI by unit distance, and $\alpha$ is the signal attenuation factor. As shown in formula (2), a new model called polynomial loss model is proposed based on the RSSI filtered data measured in the previous step.

$$d = A \cdot RSSI^2 + B \cdot RSSI + C \quad (2)$$

In formula (2), $d$ is distance between source and receiver, and $A$, $B$ and $C$ are the loss parameters.

2.2. RSSI positioning algorithm

According to the RSSI value received by the anchor node in three different places, the distance $d$ can be obtained by formula (2), and then the position $(x, y)$ of the node to be positioned can be equivalent to the coordinates of the intersection of the three known centers and the radius circle. However, in practical applications, due to the existence of the measurement distance error, there will be three cases where the intersection of the two circles intersects, and only two circles intersect and the three circles do not intersect, as shown in the following figure:

![Figure 1. Three cases of trilateral ranging algorithm.](image)

The centroid algorithm is combined with the trilateration algorithm, and the three cases are handled as follows:

1) When the three circles intersect in the area, connect the intersection points to form a triangle, and replace the position of the node to be located with the triangle centroid point approximation.
2) When only two circles intersect, take the point near the third circle of the two intersection points to replace the position of the node to be located.

3) When the three circles do not intersect, connect the center of the three circles, intercept the line segment between each two circumferences, and make the vertical line, take the intersection of the three vertical lines to replace the position of the node to be positioned.

2.3. Virtual force model and position adjustment of nodes

In the virtual force model, the moving sensor nodes are regarded as charged particles, and there is interaction force between the nodes. The magnitude and direction of the force are related to the importance and distance of nodes. The virtual force of node is generated by combined force of all nodes, and its size and direction guide the movement of nodes. According to whether node participates in the positioning, nodes are divided into two categories:

1) $a_p$: set of actuator nodes participating in positioning
2) $a_f$: set of idle actuator nodes

Since $a_p$ is to perform positioning tasks, virtual power is not counted. It is assumed here that only $a_f$ is subjected to virtual force. Moreover, $a_f$ is affected by $a_p$ and itself, and the force is expressed as vectorized gravitational or repulsive force. Therefore, the virtual force of node $i$ affected by node $j$ can be expressed as formula (3).

$$
\overline{F}_{ij} = \begin{cases} 
    k_{r,p} \left( \frac{1}{d_{ij}} - \frac{1}{r_{th}} \right) & \text{if } 0 < d_{ij} \leq r_{th}, i \in a_f, j \in a_p \\
    k_{r,f} \left( \frac{1}{d_{ij}} - \frac{1}{r_{th}} \right) & \text{if } 0 < d_{ij} \leq r_{th}, i \in a_f, j \in a_f \\
    k_{a,p} (d_{ij} - r_{th}) & \text{if } r_{th} < d_{ij} \leq r_c, i \in a_f, j \in a_p \\
    k_{a,f} (d_{ij} - r_{th}) & \text{if } r_{th} < d_{ij} \leq r_c, i \in a_f, j \in a_f \\
    0 & \text{else}
\end{cases}
$$

$k_{r,p}, k_{r,f}, k_{a,p}$ and $k_{a,f}$ are virtual force coefficients, $k_{r,p} > k_{r,f}, k_{a,p} > k_{a,f}$; $d_{ij}$ is distance between node $i$ and $j$, $r_{th}$ is the distance threshold, and $r_c$ is the radius of one-hop communication. When distance is less than or equal to $r_{th}$, the virtual force is expressed as a repulsive force. When distance is longer than $r_{th}$ and less than or equal to $r_c$, the virtual force is expressed as gravity. When distance is longer than $r_c$, the virtual force is not affected. The resultant force of node $i$ is the vector sum of each virtual force, and its expression is shown in formula (4).

$$
\overline{F}_i = \sum_{j \neq i} \overline{F}_{ij}
$$

After the joint force calculation is completed, the node will move to a new position according to the magnitude and direction of the resultant force. The formula (5) and formula (6) calculate the new coordinates.

$$
x' = \begin{cases} 
    x & \text{if } |F_i| \leq F_{th} \\
    x + \frac{F_i}{|F_i|} \cdot L_{max} & \text{if } |F_i| > F_{th}
\end{cases}
$$
In formula (5) and formula (6), $F_x$ and $F_y$ are the components of the resultant force on the x-axis and the y-axis, $L_{\text{max}}$ is the maximum distance of each movement of the node, and $F_{\text{th}}$ is the virtual force threshold. When the joint force of the node is less than the threshold, the node does not move.

2.4. Moving path strategy of anchor node

Firstly, all unknown nodes are evenly distributed in the regular rectangular area due to the virtual force, and then the length of the area is divided into several rectangles, the length of each rectangle is $d$, which is equal to the communication distance of the moving anchor node.

Then the classic spiral-moving path is the Archimedes spiral, the pitch of the spiral is increasing, and the broadcast step set by the moving path is the communication distance $d$ of the anchor node, which will cause more nodes to be insufficiently covered. The path strategy is based on the equidistant spiral, that is, the pitch is a fixed value, the spiral is composed of multiple semi-circular arcs with fixed angles, and the curves on the upper and lower sides are semi-arc. Because the center of the circle is different, the combination becomes an equidistant arc spiral.

Based on the equidistant spiral, the path strategy of this paper makes the anchor node make dynamic adjustment on the path according to the action of the virtual force. The new position adjusted twice continuously replaces the arc path with a straight path, and finally gets a path based on dynamically adjusting the equidistant spiral.

3. Experiment

Based on the measured RSSI values of multiple sets of Zigbee modules and the corresponding distance values, the fitting effect of the classical loss model and the polynomial loss model is shown in Figure 2. In order to verify the validity of the path strategy, the simulation parameters are as follows: the simulation experiment area is 6*6 square area, 25, 35, 45, 55 unknown nodes are randomly distributed in four times, and the communication radius is 0.6. The node to be located adjusts its position according to the virtual force between the nodes, so that the distribution of nodes in the area tends to be uniform, and the effect is shown in Figure 3. The anchor nodes travel along the equidistant arc spiral path and the dynamic adjustment path from the center of the experimental area. The path strategy effect is shown in Figure 4. When the final anchor node path covers all unknown nodes, stop traveling and calculate the lengths of the two paths for comparison. The result is shown in Figure 5.
According to Figure 2, we can calculate that the average fitting error of the classical loss model is 15.53 cm, while the average fitting error of the polynomial loss model is 6.35 cm, indicating that the fitting accuracy is improved by 59.1%. According to Figure 3 and formula (3), we can calculate that the nodes in the area have reached the virtual force balance, so that the unknown nodes are more evenly distributed in the area. According to Figure 4, we can calculate the closest distance between every point with the path is less than or equal to the maximum communication distance, indicating that the path strategy proposed in this paper can completely cover the effective area. According to Figure 5, the length of path proposed in this paper is shortened by 31.9% compared with the equidistant spiral, indicating that the location strategy proposed in this paper effectively shortens the traversal length of the mobile anchor node.

4. Conclusion
This paper first studies the RSSI loss model and proposes a polynomial loss model. Compared with the classical loss model, the model proposed achieves a better fitting effect. Then the location strategy of mobile anchor nodes in wireless sensor network is mainly studied, and a dynamic adjustment path based on virtual force is proposed. Compared with the equidistant spiral path, the new location strategy shortens the length of the path and can effectively avoid the anchor node traversing the empty area.

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