Research and Implementation of the Localization Algorithm Based on RSSI Technology

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Abstract—The efficiency of sensor localization is a key issue in the Internet of things. There are possibilities for improvements in existing sensor localization systems, such as design complexity, cost. To address these issues, a location algorithm based on Distributed Range-Free Localization (DRFL) is proposed. In our positioning system can be composed by some single species node which can send and receive radio frequency signal, so it reduces the hardware requirements for the system. With this algorithm, system designed by us computes the anchor node weights with the RSSI values of anchor nodes and unknown nodes. Finally, the system acquires the data of unknown node localization with the weights and data of the anchor nodes. In this paper, a prototype was implemented to evaluate the algorithm. The results of experiments were shown that our system was stable. The algorithm, which had a little loss in sensor localization accuracy, had an effect on reducing the account of anchor nodes in the system.

Index Terms—Internet of Things; Sensor Localization; RSSI; Distributed Range-Free Localization

I. INTRODUCTION

The Internet of things (IoT), based on the information such as the Internet, the traditional telecommunication and some other network bearers, make all the ordinary physical objects can be independently addressing connectivity of network as shown in the figure 1. It is the potentialities of the IoT that makes it possible for the development of a huge number of applications, such as transportation and logistics domain, healthcare domain, smart environment (home, office, and plant) domain and personal and social domain [1].

However, the data collected by the sensor without its own location information will have little practical value. Indoor positioning technology is the basis for networking perception layer, it can provide indoor relative location information of the item. By using indoor positioning system, we can realize real-time online indoor items, remote regulation and make the Internet of things the internet have departed from the theoretical concepts to the real world solutions [2-6].

The localization algorithm is the core of the software and its precision determines the system’s use value for a complete set of positioning system. By a certain developments of the current sensor portioning technology, the existing positioning technology is primarily based on the node location estimation system. Generally, positioning algorithm is divided into locating method based on distance (Range - based) positioning and orientation without ranging (Range - free). Locating method, based on distance measurement, measures the distance or Angle point-to-point information between nodes to play the method, such as the RSSI, TOA and TDOA location algorithm [7-8]. Among of them, the method of TOA / TDOA gets some applications because of its excellent positioning accuracy. Such as the articles [9], they present an indoor location algorithm based on cooperate of state matrix and Kalman filter (State-LKalman), and apply it to the time of arrival (TOA) algorithm of the wireless location system. Simulation results show that the State-LKalman has higher accuracy than the cooperative of least square error (LSE) and Kalman filter (LKalman) algorithm [10]. However, method of TOA / TDOA requires specialized equipment
to run, and the specialized equipment is usually relatively expensive. So its prospects will be restricted.

Nevertheless, the methods which mentioned above were built by the complex hardware foundation. This would be difficult to extend in nowadays network. To solve this situation, a kind of Range-free positioning method based on RSSI positioning technology is presented in this paper. This paper was established based on the idea of near distance. When unknown nodes are close to a nearby anchor node, the RSSI values between those will be smaller and the importance of the anchor nodes for unknown node localization will be higher according to the performance characteristics of RSSI. In a limited space, according to the signal characteristics of space area, the influence of the node’s signal strength is similar. So to some extent, the algorithm can overcome the influence of environment on the node signal. In the second part of the article, the proposed position method is described by combine analysis of two methods RSSI-based location technology. The third part describes the derivation of the algorithm. Finally, the actual experiment is listed to test the stability and accuracy of the algorithm.

II. RELATED WORK

Received Signal Strength Indication (RSSI) is an optional part of the radio transmission layer, and it is used to determine the link quality, and whether to increase the strength of the broadcast transmitting. It is a location technology that the distance between the send point and the receive point is measured by detecting the received signal strength between them, and then positioned based on the corresponding data.

The RSSI value was used to represent the energy of the electromagnetic wave in a medium, and it decreases with increasing distance. This measurement value is generally not included in the gain or loss of the antenna transmission system. In general, the RSSI ranging technology was viewed as a coarse ranging technology. The RSSI value, which was measured by the sensor nodes, was associated with the distance information. In the RF embedded devices, RSSI value was expressed as the ratio of the received signal strength and a reference value [13-16]. The following was the RSSI value of the expression:

\[
RSSI = 10 \times \log_{10} \left( \frac{p_{rx}}{p_{ref}} \right)
\]

(1)

where \( p_{rx} \) represented the received signal strength for the reception terminating. \( p_{ref} = 1mW \) . Under ideal conditions \( p_{rx} = p_{rs} \). By Fels free space airwaves formula:

\[
P_{rx} = P_{tx} \cdot G_{n} \cdot G_{r} \cdot \left( \frac{\lambda}{4\pi d_{ij}} \right)^{2}
\]

(2)

where \( P_{tx} \) was the transmission power of the transmitting nodes; \( P_{rx} \) was the reception power of the reception node; \( G_{n}, G_{r} \) for the receiving node and sending node of the signal receive and transmit gain; \( \lambda \) was signal
wavelength and $d_{ij}$ was the distance between the transmitting end and the receiving end. Thus, the RSSI value could be expressed with the relationship of the distance between two nodes.

With the current positioning method based on the RSSI values, range-based algorithms had a good development such as trilateration, triangulation and maximum likelihood estimation method. For example, the figure 4 shown the trilateration method, we used the common radio propagation path loss model to compute the distance between the nodes. The distance between each anchor node and unknown node was obtained by using as the radius and the anchor node as the center, then made three circles around them. By calculating the coordinates of the intersection of three circles, we could get the position information of the unknown nodes [8].

![Figure 4. Trilateration](image)

Using this method seems to be able to get the location information of the node to be positioned. Unfortunately, this approach is too ideal, in practical applications, due to the complex environmental factors and different nodes performance differences, the attenuation of the signal was not only impacted by the distance but also many other factors. The spectral reflections, free space path loss, near & far field effects, multipath fading, diffraction, RF interference and atmospheric conditions also had influenced on the attenuation of the signal. In addition, the formula for RSSI value converted to distance was the empirical calculation model by ideal conditions and it would affect the calculation result for the position information of the unknown node. In order to reduce the impact of the above factors on the positioning result, some others were considered to use the RSSI value in the positioning method base on Range-free algorithms. These methods were regarded as a node in the signal strength “signature.” When the positioning operation was required, the system could be measured for a plurality of nodes in the case of a single feature vector value RSSI, these eigenvectors were called the fingerprint RSS. Due to RSS distribution in the region was relatively stable, so you could advance to create the measured area of each location RSS fingerprints, and then got a map of RSS features for the area. And then we used the measured data to compare with the RSS fingerprint feature map, then we can got position information.

However, there are some flaws in this approach. First of all, RSS eigenvalues was not static in the realistic scenarios, as mentioned above, it could be affected by many factors outside world. The map of RSS features, which was previously prepared, was likely to be failure because of changes in environmental factors. Therefore, in order to obtain relatively accurate positioning results, we needed to frequent calibration RSS map and this workload was enormous. Secondly, in view of its positioning principle, finesse of the RSS maps directly determines the accuracy of the positioning results. In order to get an accurate positioning result, we needed to finesse the RSS maps as precisely as possible. Therefore, the preparatory work of the workload of this approach should not be underestimated. Due to the reality of the wireless communication environment tend to be highly dynamic. For this reason, some scholars have developed some dynamic positioning method in order to overcome this situation by the radio signals. The representative was landmark algorithms. The landmark proposed an idea called "nearest neighbor distance"[12]. As shown in the following figure 5.

![Figure 5. Landmarc Algorithm](image)
The Landmarc Algorithm as an example of LANDMARC layout. In this figure 4, the blue octagon represents a reference label (Ref), green ellipse represent RFID reader (Reader), and the white star indicate carrying RFID tags locate the target (Tag). Reader is constantly transmitting a radio frequency signal to its surrounding. Ref and Tag receive these signals and measures the signal strength, thus obtaining a number of RSS feature vectors for a particular Reader's [12].

In the algorithm, when a tracking tag closed to a reference labels, they also had similar values of the signal intensity obtained for the same reader. Group with this thinking, the method is using a tracking tag with a plurality of different reference tags to the received signal from the reader, and thus generates the corresponding RSS feature vectors. By analyzing their RSSI values, the systems use the formula to calculate the Euclidean distance between these nodes. And then use this distance to establish the weight relationships between them. For a tracking tag, system used the associated reference tags and the value of its weight to calculate the coordinates.

Due to the landmarc algorithm was relied on the reader to detect the other nodes, the position of the readers would impact the accuracy of positioning. Therefore, LANDMARC algorithm reflected some limitations in the practical application. To this end, in this paper we presented the algorithm which used anchor nodes to locate the unknown nodes. In this algorithm, the anchor node acted as a reference tag and reader. The unknown nodes continually radiated radio frequency signal to surrounding environment. When the anchor node received the signal, it would use the correlation equation to converted the signal to the RSSI value and submit to the host. Host computer would select the RSSI value, based on selection criteria, which can be used to locate the unknown node. According to the literature 17, it pointed out that there was a relationship between RSSI value and distance. Therefore, the RSSI value could be measured to the weight relations between the anchor node and the unknown node, so this value could be directly used to calculate the location information of the unknown node.

III. METHOD

According to the requirements mentioned above, in order to make the algorithm have a good practicability, the system would be divided into two parts. The first part was the portion of the system's hardware. By the referred above, the present system consisted of sending and receiving nodes. In this section, the major work was when the anchor node (receiving node) received the signal, the information would be automatically converted into a RSSI value for an unknown node and uploaded to the host acquisition procedures;

The second part was the algorithm described in this article. The algorithm was divided into two blocks.

Block1. Obtained the desired value:

In the system initial, the algorithm would read the coordinates of each anchor node from acquisition procedures \(XY = \{(X_1, Y_1), (X_2, Y_2), (X_3, Y_3), \cdots, (X_n, Y_n)\}\). After acquisition procedure collected RSSI value, the algorithm would be connected to a default excuse and then the value would dump into the algorithm. In accordance with the sequentially of the anchor node serial number \(S_{\text{No}} = \{No_1, No_2, No_3, No_4, No_5, \cdots, No_n\}\), the RSSI value of the anchor node was stored as \(S = \{S_1, S_2, S_3, S_4, S_5, \cdots, S_n\}\). It was stored in the order of \(S_{\text{No}}\). According to requirements screened for positioning anchor nodes, and transferred data to \(St_{\text{No}} = \{No_1, No_2, No_3, No_4, No_5, \cdots, No_n\}\) and \(St = \{St_1, St_2, St_3, St_4, St_5, \cdots, St_n\}\). After this step, the algorithm released of \(S_{\text{No}}\) and \(S\) to saved memory space;

The program summary and flow chart show as followed:

```
procedure Screen_Rec_Sq (S{ })
begin
If(S{}< threshold value) then
St_no{}←I, St{}←S{ };
end
end
```

![Figure 6. Block1. Obtained the desired value:](image)

Block 2. Calculated the unknown node coordinates:

The algorithm used the result, which was obtained by the previous step, to calculate nodes’ weights. According to the literature 1, the Landmarc algorithm used RSSI value for weight anchor node metric, and provided a method for positioning unknown nodes. Through the analysis of the algorithm, the RSSI value was use to calculate Euclidean distance between two points, and weight the anchor node by the distance. To understand this, we needed to know how the RSSI value to calculate the distance between two nodes. The Logarithmic - Normal distribution model was used to calculate the distance between two nodes in the practical applications [16-18]. The formula was as followed.
\[ RSSI = P + G - PL(d) \]  
(3)

where \( P \) was the frequency of emission; \( G \) was the Antenna gain; \( PL(d) \) represented a path loss when the receiving node receives a signal. It was expressed as:

\[ PL(d) = PL(d_0) + 10k\log_{10}(d/d_0) + X_r \]  
(4)

where \( X_r \) was a zero mean Gaussian random number, its standard deviation range from 4 to 10; \( k \) was the path attenuation factor, the range is from 2 to 4; \( PL(d_0) \) was composed by the free space of the radio propagation path loss model obtained in the case of the \( d_0 = 1 \)m. The \( f \) was the signal frequency in the formula followed.

\[ \text{FreeSpacePathLoss} = 32.4 + 10k \log_{10}(f) + 10\log_{10}(d) \]  
(5)

After the anchor node received a signal, the RSSI value was processed as followed. Where the value of \( \text{RSSI \_BASE\_VAL} \) was \(-91dBm\);

\[ \text{RSSI \_SUB} = \text{RSSI \_BASE\_VAL} + 3 \cdot (\text{RSSI} - 1) \]  
(6)

Using this method, the RSSI value, which was used for the positioning calculation, could be obtained. Because the value is negative, so the weight distribution formula of the algorithm was defined as followed:

\[ \omega_n = \frac{1/|\text{RSSI}|}{\sum_{i=1}^{n} 1/|\text{RSSI}|} \]  
(7)

When the weight \( \omega_n = \{\omega_{n_1}, \omega_{n_2}, ..., \omega_{n_m} \} \) was obtained, it uses the formula 8 to calculate the unknown node coordinates. \((X_i, Y_i)\) was the coordinates of the anchor nodes.

\[ xy = \sum_{i=1}^{n} \omega_{n_i} \cdot (X_i, Y_i) \]  
(8)

Based on the above description, the algorithm of the whole process was shown below. In the process, the data which got from block 1 was filtered again to make sure the data could be used in the next step. According to previously mentioned, the RSSI value was extracted by the sequence of St_NO {} from the array of St {}. Then calculated weights Wj {} were according to the formula mentioned previously. Upon completion of the operation to calculate weights, the weights were used by the operation of calculated coordinates which was mentioned above. Then displayed the results of Horizontal and vertical coordinates. The flow diagram of block 2 as fellow.

IV. RESULT

JAVA language was used to programming this algorithm. We designed a single node localization experiment in indoor environment. MX231CB was selected to be used in the experimental. This node was constituted of an ATmega1281v chip and an ATRF231 chip. When the receiving node received signal from the sending node, the signal would be used to calculated a corresponding RSSI value. After that, this value would be transmitted to the host via a gateway. This experiment was carried out in the interior corridors. The test area selected a region, the size of 2.4m * 2.4m, in the corridor.

In experiment 1, we arranged six anchor nodes used in the experimental area as shown in Figure 7. We conducted a total of six experiments, the positioning results were shown in Figure 8 and table1 showed the experimental data.

![Figure 7. Calculate the unknown node coordinates](image)

![Figure 8. The layout of nodes in experiment 1](image)
In the second experiment, we reduced the number of anchor nodes to four and arranged in a manner as shown in Figure 9. The experiments performed three times a typical position, location results were shown in Figure 10, and Table 2 listed the relevant experimental data.

In two experiments, we finished these experiments with the same node in several predetermined locations. The experimental results shown as followed. In the first test, entire test area was delineated by four anchor nodes. In this test, we designed three pilot sites, the average position deviation of the experimental results for 32.976 and average position deviation rate of 0.254. In order to investigate the influence of different anchor nodes arrangement on the performance of the algorithm of positioning, in the second test, we adjusted the anchor node arrangement in the test area. Figure 10 was show for the test results. In the experiment we reduced the anchor node and changed the layout. It can be seen that, from the figure, the arrangement had improved node positioning effect on the regional central. But in other part, there is little effect on the node positioning. The average deviation 26.467cm, positional deviation rate is 0.233. Table 2 lists the second experimental data.

As we see, the circular points delegated the Anchor nodes. The others delegated the Unknown nodes. In the two Figures, the same points delegated an Unknown node’s Actual Position and Calculate Position.

**Table 1. Experimental 1 Results**

<table>
<thead>
<tr>
<th>Experimental 1</th>
<th>Area 240 * 240 Unit: cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>1</td>
</tr>
<tr>
<td>Abscissa</td>
<td></td>
</tr>
<tr>
<td>Coordinate</td>
<td></td>
</tr>
<tr>
<td>Actual Position</td>
<td>120</td>
</tr>
<tr>
<td>Calculate Position</td>
<td>121.57</td>
</tr>
<tr>
<td>Deviation</td>
<td></td>
</tr>
<tr>
<td>Deviation Distance</td>
<td>1.57</td>
</tr>
<tr>
<td>Deviation Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.013</td>
</tr>
<tr>
<td>Ordinate</td>
<td></td>
</tr>
<tr>
<td>Coordinate</td>
<td></td>
</tr>
<tr>
<td>Actual Position</td>
<td>120</td>
</tr>
<tr>
<td>Calculate Position</td>
<td>143.26</td>
</tr>
<tr>
<td>Deviation</td>
<td></td>
</tr>
<tr>
<td>Deviation Distance</td>
<td>23.26</td>
</tr>
<tr>
<td>Deviation Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.194</td>
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<tr>
<td>Position Deviation</td>
<td>23.31</td>
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</table>

**Table 2. Experimental 2 Results**

<table>
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<th>Experimental 1</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Coordinate</td>
<td></td>
</tr>
<tr>
<td>Actual Position</td>
<td>150</td>
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<tr>
<td>Calculate Position</td>
<td>126.87</td>
</tr>
<tr>
<td>Deviation</td>
<td></td>
</tr>
<tr>
<td>Deviation Distance</td>
<td>23.13</td>
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<tr>
<td>Deviation Rate</td>
<td></td>
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<tr>
<td></td>
<td>0.154</td>
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<td>Coordinate</td>
<td></td>
</tr>
<tr>
<td>Actual Position</td>
<td>90</td>
</tr>
<tr>
<td>Calculate Position</td>
<td>118.27</td>
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<tr>
<td>Deviation</td>
<td></td>
</tr>
<tr>
<td>Deviation Distance</td>
<td>28.27</td>
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<tr>
<td>Deviation Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.314</td>
</tr>
<tr>
<td>Position Deviation</td>
<td>36.52</td>
</tr>
</tbody>
</table>
In this paper, referred to RSSI-based positioning technology, we proposed a Range-free localization algorithm based on RSSI technology for the indoor environment. This algorithm took advantage of the information for each node in the network. In the calculation process, using the RSSI valued the weight for each anchor node which would be involved in the positioning calculation. Because of the distance, for the indoor environment, between the anchor node and unknown node was limited, so that we could considered that they had similar jamming environment factor. This algorithm used of this feature to reduce the impact ambient factors to the positioning work.

From the experimental results it could be seen that the present algorithm had better adaptability to the changes in the account of anchor nodes. But the tests conducted for a single node of the experiment, for the positioning of the plurality of nodes had little covered. In next step, according to needs of multiple nodes positioning, we will test the algorithm and improved it. In addition, the algorithm uses two types of receiving and sending node networking mode, which makes equipment performance have a greater impact on the positioning accuracy. For this problem, the next step will be considered to add correction function to the anchor node, so that a corresponding correction work can be performed in the system when an abnormality occurs.

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REFERENCES


