Exploring the practicality of hybrid ranging method RSSI and TOF in practical environments

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Abstract: Due to its low cost and low complexity, RSSI ranging technology in wireless ranging is widely used in positioning systems. In this paper, when the TOF ranging accuracy of the hardware cannot meet the requirements, the RSSI is proposed as an auxiliary ranging method to correct the TOF ranging distance. On this basis, Gaussian filtering is proposed to optimize fingerprint database information and WKNN algorithm to improve the accuracy of RSSI. Finally, based on the ranging, a one-dimensional positioning algorithm is used and the final positioning result is tested. After verification, it was found that the positioning accuracy can meet the actual requirements. The positioning algorithm in the positioning system can be divided into two categories according to whether or not ranging, one is based on ranging positioning algorithm, and the other is based on non-ranging positioning algorithm. When discussing the precise positioning algorithm, the non-ranging positioning algorithm has low positioning accuracy and does not meet the requirements. Therefore, the positioning algorithm based on ranging is discussed here. The technical means of ranging are roughly divided into the following categories: TOA, AOA, RSSI, etc. RSSI is widely used due to its low cost and low complexity. However, due to the limitations of the RSSI itself, in the actual situation, the RSSI's ranging accuracy is the strongest at 0-20m, which can reach 0.76m/db and reach 5.7m/db in the range of 20m-100m. The RSSI resolution that can be achieved by the RSSI outside the range of 100m is lower and cannot be used as an auxiliary means for correcting TOF ranging, so it is no longer used. Therefore, this paper only studies the positioning accuracy problem in the range of 0-40m. The experimental hardware uses the sx1280-based beacon card and positioning terminal independently designed by Zhengzhou Xinlibotong. Because the error of TOF in the actual measurement is large within 0-40m, and the RSSI is self-contained on the hardware. Therefore, it is considered to use RSSI to assist the ranging, and to correct the situation that the TOF has a large ranging error.
Keywords: Ranging, RSSI, TOA.

1. RSSI ranging principle

The theoretical source of RSSI ranging: wireless signals will have losses in transmission, which is related to distance. Thus, as long as there is a theoretical model, the distance between the two points can be obtained according to the theoretical model. The theoretical models that are commonly used today are:

\[
PL(d) = PL(d_0) - 10n\log\left(\frac{d}{d_0}\right) + X
\]  

In the above formula, \(d\) is the distance between the receiving end and the transmitting end, which is a reference distance, which is generally 1 m. \(X\) is the received signal power from the location at the transmission point. \(X\) is a Gaussian random variable with a mean of 0, which represents the change in received signal power when the distance is constant. \(n\) is the path loss index, which is related to the actual environment in the mine. According to the above formula, the distance between two points can be calculated from the obtained data in practice. However, in practice, the external environment changes complexly, and it is necessary to correct the theoretical model according to the external environment to obtain more accurate data.

The values obtained by RSSI ranging are not stable because they are easily affected by environmental noise and multipath effects, especially in the case of mines, the shape of the roadway (bending, tilting, horizontal), the roughness of the road surface, metal equipment And so on have an impact on the wireless signal attenuation law. In the mine, along the wireless signal transmission process, the two points of the wavelength difference, due to the multipath effect in the mine, the power of the received signal may differ by about 30-40dB. Therefore, it is obvious that the accuracy of RSSI ranging is low.

In order to solve the problem of low RSSI ranging accuracy, many scholars have done a lot of research work to improve the ranging accuracy of RSSI positioning. For example, Zhu Minghui's research on the RSSI-based indoor ranging model [2], which combines the theoretical model with the actual ones, gives an emphasis on the actual model: That is, the influence of the occlusion factor on the RSSI is not counted, and the influence of the RSSI in the actual environment is the most non-line-of-sight. Wherein, the radio frequency parameter \(A\) is defined as the absolute value of the average energy received by the transmitter 1 m in dBm, that is, the received signal strength at 1 m from the transmitting node; \(n\) is the signal transmission constant, which is related to the signal transmission environment; \(d\) is the distance from the transmitting node. Both \(A\) and \(n\) are related to the actual environment. Next, linear regression is used again to get the most suitable \(A\) and \(n\) values in the current
environment. At this point, it can be guaranteed that the error is basically within 2m. In the ZIGBEE-based RSSI ranging study [3], Zhang Jianwu proposed to correct the theoretical model to filter out the unstable RSSI value. The calibration models are: statistical mean model, correction model based on the distance between fixed nodes, Gaussian model. The filtering effects of the three correction models are compared. In the distance of 20m, the statistical mean model has the worst ranging error of 3.2m, and the Gaussian model has the best ranging error, less than 2m. However, the research on RSSI is based on short-range ranging, that is, placing multiple base stations for ranging, and the cost is exchanged for ranging accuracy, so it is not desirable. Next, the ranging resolution of RSSI and TOA will be compared. The RSSI theoretical model refers to Equation 1, and n is 2.

![Figure 1 Ranging resolution of RSSI and TOA](image)

It can be clearly seen from the figure that the ranging resolution of RSSI is rapidly decreasing as the distance increases. When the receiving point and the transmitting point are close, the RSSI ranging resolution is relatively large and the change is obvious. When the receiving point and the transmitting point are far away, the RSSI ranging resolution is small and the change is not obvious. When the RSSI is in the 0-20m interval, the RSSI is reduced by 23db, that is, the ranging resolution can reach 0.76m/db in this interval, which can meet the precise positioning requirements. In the 20-100m interval, the RSSI is reduced by 7db, and the ranging resolution at this time is 5.7m/db. In the 100-1000m interval, the RSSI is reduced by 10db, and the ranging resolution at this time is 45m/db, which cannot meet the ranging requirements. In theory, the RSSI-based ranging technology reduces the accuracy of the ranging when the ranging distance increases, and the accuracy is larger when the ranging distance...
is closer. The RSSI cannot meet the purpose of accurate ranging under the control of cost.

Compared with TOA, TOA's ranging resolution is independent of ranging distance, and ranging accuracy is only related to TOA's time resolution, but semtech's sx1280 has been able to provide m-level ranging accuracy. The positioning accuracy can be met under the control of cost.

![Figure 2 Ranging schematic](image)

### 2 TOA's principle of ranging

The essence of the TOA measurement distance is to measure the wireless signal transmission time $t$ between the receiving point and the transmitting point. The TOA needs to know the time $t_1$ at which the transmitting point transmits the signal, and the time $t_2$ at which the receiving point receives the signal, according to the distance between the two points. Where $C$ is the propagation rate of electromagnetic waves in vacuum. According to the theory of electromagnetic waves, electromagnetic waves are not affected by the underground environment when they propagate downhole. Therefore, it can meet the needs of precise positioning of coal mines. However, if the distance is calculated according to formula (2), the time synchronization requirement for the transceiver device is very high, because once the microsecond error occurs, the error of the measurement distance is 100 meters. To achieve precise synchronization of transceivers, the cost is very large. At this point, a method of two-way ranging is proposed.

$$d = c(t_2 - t_1)$$  \hspace{1cm} (2)

The sending point A first sends a ranging request at the time $T_1$. After receiving the
received point, the receiving point sends a feedback to the sending point after treplyB, and the current time is recorded after the sending point is received. According to this, according to: $d = \frac{1}{2} c(T_2 - T_1 - t_{\text{replyB}})$, the distance between the two points is obtained, and time synchronization is not required at this time, and the achievability is greatly improved.

3 Positioning method for long straight roadway

3.1 Long straight roadway positioning algorithm dimension

Due to its small space, underground mines are distributed along strips or chains, with a large span, usually several kilometers. However, the height of the mine is limited, and it is basically within 8m. Taking the ordinary mine road height of 5m and width of 4m as an example, the proportion of the length and width of the mine track increases with the increase of the length as shown in the figure:

As can be seen from the above figure, when the length of the roadway increases continuously, the aspect ratio and height-to-length ratio of the roadway gradually approach zero. It can be clearly seen that the length of the roadway is the main reason when positioning the long roadway. Therefore, when the lane length satisfies a certain reason, the positioning algorithm can ignore the height and length. In the literature [4], it is proposed to adopt a three-dimensional positioning algorithm based on AOA and TDOA in the mine. The implementation of this algorithm requires a large number of dense nodes and is expensive. In the literature [5], a three-dimensional algorithm for wireless network nodes based on particle swarm optimization is proposed. This algorithm is complex and requires a large number of dense nodes, so it is not available in practice. From the above figure, when the aspect ratio of the length of the roadway and the aspect ratio of the aspect ratio are less than 0.01, the height direction and the width direction are neglected when the length exceeds 30 m. It is more appropriate to carry out one-dimensional positioning. When the length does not
exceed 30 m, it is necessary to consider the influence of the high direction and the
wide direction, and it is more suitable to perform three-dimensional positioning at this
time.

3.2 Long straight roadway projection positioning method
The wireless positioning of the mine channel obtains the distance between the
reference point and the mobile node through the TOA. The following figure is a top
view of the positioning environment of the mine roadway. In this positioning method,
two-point positioning (ie, two reference points) is selected, and reference points B1
and B2 are located on the same roadway wall, and the roadway direction is the x-axis,
and the roadway width is the y-axis, and a plane coordinate system is established.

![Figure 4 Plane coordinate system](image)

The graph is analyzed, taking the mobile node R_P2 as an example, and d1 and d2
are the distances of the point to the two reference points B1, B2. However, the value
of this distance is subject to error and is not an accurate value. This will list the
equations for moving points to the reference point:

\[
\begin{align*}
(x - x_1)^2 + (y - y_1)^2 &= d_1^2 \\
(x - x_2)^2 + (y - y_2)^2 &= d_2^2
\end{align*}
\]  

In the equation (3.1), the position coordinates indicating the two reference points B1,
B2 indicate the position of the moving point R_P2, and d1 and d2 are the distances
from the point to the two reference points B1, B2. Solving the equations of (3.1), the
solution point V_P2 is obtained as the measurement estimation point of the moving
point. Since the measurement has a positive error [6], the measurement estimate
often deviates from the mine and falls outside the mine. Obviously such a point is not
actually present, and the measured points are not practical. Therefore, for such a
situation, the roadway is regarded as one-dimensional, and V_P2 is projected to the
roadway, and the projection point can accurately reflect the true position of the R_P2
in the roadway. Therefore, the method converts the two-dimensional positioning into
one-dimensional positioning by projection, which reduces the computational
complexity and improves the positioning accuracy.
4. Ranging experiment

The experimental site selects the long straight corridor of the company building's roadway. As shown in the figure, the long straight corridor is about 3m wide, about 3m high and about 50m long. The transceiver used in the experiment is based on the sx1280 RF chip hardware device, operating frequency 2.4G, this chip contains a variety of physical layers and a variety of modulation methods, such as LORA, FLRC, GFSK. The special modulation and processing method greatly increases the transmission distance of LORA and FLRC modulation, and GFSK modulation is compatible with Bluetooth BLE protocol. Excellent low-power performance, on-chip DC-DC and Time-of-flight make this chip powerful.

In the experimental scene below, the receiving height of the mobile node and the reference point is fixed so that it is located on a horizontal plane, simulating the long straight roadway under the mine. In the experiment, two reference points are used, one reference point is placed on one side of the corridor, one reference point is prevented on the other side, and two reference points of the mobile node are randomly moved.

![Figure 5 Experimental environment](image)

![Figure 6 No positioning method](image)
In the above figure, the symbol "O" represents the true position of the moving point. In order to limit the deviation from the centerline and the centerline of the aisle by 0.5m, that is, the moving point y direction takes only three values, namely 1, 1.5 and 2. The symbol "*" represents the estimated point calculated by the two reference points, and the symbol "+" represents the projection of the estimated point of the ranging plane. Take the projection point on the center line of the roadway, that is, the y coordinate of the projection point is 1.5. It can be clearly seen that the "*" deviates significantly from the "O" due to the ranging error, even on the outside of the aisle region. It shows that the ranging error is more serious. The projection point "+" is closer to the position of the moving point to a greater extent, effectively improving the positioning accuracy.

Table 1 Error Table

<table>
<thead>
<tr>
<th>Positioning method</th>
<th>Average position error/m</th>
<th>Root mean square error/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference point positioning</td>
<td>(0.020,4.765)</td>
<td>7.843</td>
</tr>
<tr>
<td>reference point positioning and projection method</td>
<td>(0.013,0)</td>
<td>1.347</td>
</tr>
</tbody>
</table>

5. Summary

By studying the variation of the range resolution of RSSI and TOA with distance, the accuracy of RSSI and TOA in long straight roadway is compared, and the TOA ranging method is introduced. Furthermore, the spatial characteristics of the long straight roadway are studied. In connection with the actual roadway, it is proposed that the height position information and the width position information can be ignored in the long straight roadway, and the width position information is neglected, so that the positioning algorithm is simplified into a one-dimensional positioning algorithm, which is not only greatly The computational complexity is reduced, and the estimated value
in the x direction is closer to the real value, and the positioning accuracy of the target under the long straight roadway is improved.

References


