Tracking and Positioning System of Zigbee Shunting Locomotive Based on Geography Information of Stations

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Abstract. In order to solve the problem of inaccurate positioning of shunting locomotives by the shunting subsystem of the marshalling yard, this paper proposed a Zigbee shunting locomotive tracking and positioning system based on geographical information of station yards. The system adopted a modular design. The hardware of the lower computer included a coordinator node, a fixed node (routing node) and a vehicle-mounted collector node. This paper used BP (Back Propagation) neural network to fit the nonlinear function of RSSI (Received Signal Strength Indicator) to transmission distance. The research shows that the positioning system proposed in the paper can control the positioning error within 2m. Combined with the geographical information of the station site, the locomotive running position can be displayed on the map of the station yard. It can be a more complete solution to practical problems and has a certain practical value in the field.

Keywords. Zigbee; geographical information of station yards; tracking and positioning; shunting locomotives.

1. Introduction

With the advancement of science and technology, communication technology is also changing. At present, many large-scale marshalling stations in the country have all established integrated automation and integration systems. These new technologies accelerate the operation efficiency of marshalling stations, and also make the cargo trains basically realize full-scale computer management during the marshalling station decompilation and marshalling operations. However, in the actual operation of the on-site marshalling station, the locomotive dispatcher cannot realize the real-time position supervision of the shunting locomotive at the peak pushing operation and the down-peak finishing operation, and at the large marshalling station, the shunting locomotives operating at the same time are mostly at 8 ~ 10 or more, so that there may be inconsistencies in the shunting plan and the location of the locomotive, shunting locomotives cannot execute the order and other issues in a timely manner. Real-time positioning of the shunting locomotive in the marshalling yard can solve these problems, and can assist the dispatcher to timely demodulate the locomotive’s position information, improve the dispatching...
management personnel’s temporary command capability for the unplanned operation locomotives, and provide the on-site construction workers with real-time security protection, on the basis of improving the marshalling station automation level, accelerates the marshalling station’s marshalling ability.

2. Literature review
In the railway transportation network, the locomotives and vehicles are mainly positioned in four ways: track circuit method, wheel sensor method, electronic shaft recorder method, and speed measurement positioning method [1]. At present, the methods used by various countries for the positioning of railway locomotives are not the same. There are mainly doppler radar positioning, Global Positioning System (GPS) positioning, query/transponder and odometer positioning, and inter-rail cable positioning, in addition to variable-code odometers, split-waveguides, cross-sensing loops, and wireless Spreading and map matching and other positioning methods [2]. The tracking and positioning system for locomotives and vehicles in China is still in its infancy, and there is still a certain gap between the tracking and positioning technology of foreign locomotives and vehicles, and there is no complete positioning system.

3. Methodology
3.1. Overall system design
According to the design drawing system structure shown in Figure 1, the positioning system is mainly composed of two parts, namely Zigbee lower position positioning system and position information processing system.

![Figure 1. System overall design structure](image)

3.2. Positioning System Lower Computer Design
This article uses Zigbee wireless communication technology to adjust the locomotive positioning. The main communication devices in the wireless local area network include network coordinator node, fixed node and vehicle collector node [3].

The hardware design scheme of the network coordinator node and the vehicle collector node of the system is shown in Fig. 2. In the coordinator node, the CC2531 wireless module acts as the master chip of the coordinator and plays the role of establishing and managing the wireless network.
As a part of a wireless communication network, a fixed node mainly completes the transmission of RF (Radio Frequency) signals and functions as a routing function for data transmission in the wireless LAN, and its structure is relatively simple [4]. Since the fixed node has a single function, an RFD device is used. The structure of the RFD device is shown in FIG. 3, and mainly includes a CC2530 master chip, a power supply module, and a debug module.

When wireless communication signals are transmitted in a large number of jamming and complex environments, they are susceptible to reflections, refractions, and scattering effects on the communication signals by surrounding buildings or other devices, so that the signal strength, phase, and delay of the wireless signals received at the signal receiving end are all greatly changed. Therefore, the signal received at the signal receiving end is often not the wireless signal transmitted by the signal transmitting end, but the signal waveform superimposed on the multiple paths [5]. The signal attenuation model of wireless signal transmission under complex communication environment is as follows:

$$RSSI(d) = A - 10 \times n \log(d)$$

Among them, A and n are model undetermined parameters, parameter A represents the average value of signal strength at a distance of 1 m from the signal emission point, and n represents a path loss parameter constrained by the surrounding environment during signal transmission.
When wireless communication signals are transmitted in space, as the signal transmission distance increases, its signal strength also decreases. There is a regular relationship between RSSI(d) and transmission distance d, and the relationship between the two is nonlinear [6]. According to Kolmogorov theorem of BP neural network, any one continuous function can be realized by a three-layer BP network including input layer, hidden layer and output layer [7]. Therefore, it is completely possible to use BP neural network to fit the nonlinear functional relationship between the two.

The BP neural network was trained by a large number of actually measured RSSI and transmission distance values to observe the fitting effect, making the best fitting effect of both. We first fix the number of nodes in each hidden layer to a fixed value. Then we increase the number of hidden layers from the first layer. Observe the fitting effect between the input layer and the output layer to determine the optimal hidden layer with the optimal degree of fit. Through experimental verification, it is found that because the number of neurons at the input and output layers of the system is relatively simple, the hidden layer needs only one layer to meet the fitting requirements, and only one hidden layer can reduce the complexity of training BP neural network and reduce training time. At the same time, the BP neural network Kolmogorov theorem is verified. The BP neural network with three-layer structure of input layer, hidden layer and output layer can be used to fit any continuous function.

3.4. The realization of positioning process
The BP neural network is used to fit the conversion of the RSSI(d) signal receiving end of the locomotive collector node to the signal transmission distance d, and then the least-squares method is used to calculate the real-time position information of the vehicle collector node [8]. The locomotive collector node is fitted to the straight-line distance di to the surrounding fixed nodes (xi, yi) by the BP neural network.

$$\sqrt{(x-x_i)^2+(y-y_i)^2} = d_i, (i = 1, 2,..., N) \quad (2)$$

Among them, xi and yi are the coordinates of the fixed node around the vehicle collector node, and x and y are the position coordinates of the locomotive to be tested.

In the position coordinate calculation process, first select RSSI(d) of 4 fixed nodes that can receive wireless signals around the vehicle collector node:

$$\sqrt{(x-x_i)^2+(y-y_i)^2} = d_i, (i = 1, 2, 3, 4) \quad (3)$$

According to equation (3), four nonlinear equations can be obtained. The first three equations are subtracted from the last three equations of these four equations, and x1, y1, and d1 are eliminated to obtain a linear equation group containing three equations.

$$a_j x + b_j y + c_j d = e_j, (j = 1, 2, 3) \quad (4)$$

Among them, aj, bj, cj and ej are the coefficients of the equation group unknowns.

Make:

$$A = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}, \quad X = \begin{bmatrix} x \\ y \\ d \end{bmatrix}, \quad B = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} \quad (5)$$

Then formula (5) can be abbreviated as:
\[ AX = B \]  

(6)

The least square method is used to solve the final position coordinates:

\[ X^* = (A^T A)^{-1} A^T B \]

(7)

From Equations (3) to (7), a positional coordinate can be obtained when calculating the distance d between four fixed nodes around the vehicle collector node. When using the five fixed node distances d around the vehicle collector node for calculation, through the nonlinear to linear transformation, five solutions can be obtained according to the permutation and combination, that is, five position information. By analogy, more position information can be obtained when the position coordinates are calculated using the transmission distance d of six or more fixed nodes around the vehicle collector node. The paper takes the centre position of the position space geometry for all the calculated position coordinates. If the position coordinate is within the allowable range of positioning error, it is the position coordinates of the shunting locomotive.

4. Results and discussion

4.1. Location algorithm verification

The algorithm fitting error curve is shown in Figure 4. It can be seen that when the transmission distance is 0~20m, the fitting error is close to 0; when the transmission distance is 20m~100m, the fitting error is about 3%. Therefore, by fitting the error results, it can be verified that fitting the RSSI(d) to the transmission distance d through the BP neural network is very ideal, and the fitting accuracy is very high.

![Figure 4. Positioning algorithm error curves](image)

4.2. System test

In the laboratory environment, a single terminal node communicates with the coordinator node to test the communication distance and packet loss rate of the device. The test results are shown in Table 1.
Table 1. Communication test results in a lab environment

| Lab environment       | Coordinator placement | Terminal node placement | Node spacing (m) | Data packet loss rate (%) |
|-----------------------|-----------------------|-------------------------|------------------|---------------------------|
| Between floors        | First floor stairway  | Second floor stairway   | 5                | 0                         |
| First floor stairway  | In the second-floor corridor | In the second-floor corridor | 70              | 20                        |
| In the middle of the first-floor corridor | In the second-floor corridor | 25             | 48                        |
| classroom             | Classroom One Window  | Classroom Three Window  | 70               | 2                         |
| Classroom One Window  | Classroom One Window Sill | 80             | 24                        |
| Classroom Two Central | Classroom Three Window | 20             | 6                         |

As can be seen from Table 1, the communication distance of the terminal node is about 70m, and when the signal penetrates the reinforced concrete wall, the degree of attenuation is relatively large. Therefore, it is best to avoid obstacles when the actual network equipment nodes are arranged.

On the school playground, a simple Zigbee network is formed using a coordinator node, a laptop, and two end nodes A and B. At the same time, the terminal node sends a data packet to the coordinator node one second in turn, and the size of the data packets sent by the two terminal nodes A and B is 1 byte and 2 bytes respectively. The relatively simple Zigbee network tests the packet loss rate during data transmission as shown in Table 2.

Table 2. Simple Zigbee Network Data Transmission Test Table

| Lab environment       | Node A and coordinator node spacing (m) | Node B and coordinator node spacing (m) | Coordinator accepts node A data packet loss rate (%) | Coordinator accepts node B data packet loss rate (%) |
|-----------------------|-----------------------------------------|----------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| School playground     | 35                                      | 35                                     | 0                                                   | 0                                                   |
|                       | 35                                      | 45                                     | 0                                                   | 0                                                   |
|                       | 35                                      | 55                                     | 0                                                   | 1                                                   |
|                       | 35                                      | 65                                     | 0                                                   | 3                                                   |
|                       | 35                                      | 75                                     | 0                                                   | 17                                                  |
|                       | 85                                      | 85                                     | 20                                                  | 25                                                  |
|                       | 75                                      | 35                                     | 15                                                  | 0                                                   |
|                       | 65                                      | 35                                     | 2                                                   | 1                                                   |
|                       | 55                                      | 35                                     | 0                                                   | 0                                                   |
|                       | 45                                      | 35                                     | 0                                                   | 0                                                   |
|                       | 35                                      | 35                                     | 0                                                   | 0                                                   |

The above experimental results can be seen that, within the signal coverage effective distance, the terminal node A and the terminal node B can realize the effective data transmission, and the communication between the nodes does not interfere with each other.

5. Conclusion
This paper presents a Zigbee shunting locomotive tracking and positioning system based on station field geographical information. Considering the complex operating environment of the marshalling station and the cost of the development system, this paper first makes a detailed modular design of the hardware design of the system’s lower computer. Then, the BP neural network in artificial intelligence algorithm is used to fit the nonlinear function relationship between RSSI and transmission distance. Through simulation experiments, the intelligent algorithm significantly improves the positioning accuracy.
Finally, the system is tested in the laboratory. The test results show that the positioning system proposed in the paper can control the positioning error within 2m. Combining the geographical information of the station and the station to show the location of the shunting locomotive on the station field map, it can be a more complete solution to the real problems and has a certain practical value in the field.

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