

The Method of Train Positioning Based on Digital Track Map Matching

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Abstract. A train positioning method based on GPS and digital rail line matching is proposed. Firstly, the digital track line is generated based on the fitting and interpolation algorithm of train track line. And then the GPS data are corrected by the track line positioning correction method, and the more accurate position estimation of the train is obtained. Finally, the data track line is simulated and analyzed with some measured data from Harbin to Qigihar track line. The analysis results show that cubic spline curve is better than cubic B-spline curve on the establishment of digital track map.

1 Introduction

The railway transportation has the characteristics of strong transportation capacity, fast speed, wide network coverage, and so on. There are many kinds of goods transported, including high value-added goods related to the national politics, military and enterprises, people and other broad interests. It is an increasingly urgent task to improve the safety and capacity of the railway transportation system and to effectively manage the transportation of railway high value-added goods transportation in economy and society.

The existing railway logistics tracking methods are achieved through the positioning and tracking of the train. The main implementation methods include track circuit positioning, response inquiry, train positioning, cross induction loop positioning, speed measurement and positioning, etc. But, these methods have limitations [1].

As a kind of global satellite navigation system, GPS can be used for all-weather and continuous train positioning. It has the advantages of high real-time positioning accuracy, low cost, small size, convenient maintenance and so on. Moreover, accurate location information is essential to train safe and reliable operation [2]. Railway freight transportation and dispatching need more optimized train positioning technology. Therefore, the research on train positioning method based on GPS is of great significance to promote the development of railway transportation.

2 Analysis of Problems

Based on the spatial subordination of train position, the digital track line provides an effective way for mapping the geographical coordinate and one-dimensional orbit coordinate system. At present, map aided localization has formed a variety of different calculation methods,

including line topology analysis, similarity, probability and so on [3].

In the process of train positioning with GPS, the GPS receiver receives the satellite signal in real time and obtains the pseudorange between the satellite and the receiver antenna, and further calculates the state parameters of the train position and speed [4]. The GPS navigation information for train positioning are described, such as shown in formula (1).

$$P_i = \Psi(P_{i-1}) + v_i + D_i \quad (1)$$

Here, the P_i is the train state vector, Ψ is the system equation, v_i is system noise, and D_i is the correction vector.

The train positioning can choose different positioning methods according to the requirements, such as the location of the satellite navigation system alone or by inertia, dead reckoning positioning system and satellite navigation system combination [5]. Either way, the measurement vector eventually needs to be constrained by map matching to the railway track line. In this paper, the non-differential precision observation positioning of GPS and the constraint of digital track line are studied.

GPS non-differential precision positioning observation equation is:

$$\Phi_{ij}(t_r) = \Phi_{ri}(t_r) - \Phi_{sj}(t_r) + N + \varepsilon_{ij}(t_r) \quad (2)$$

Here, t_r is the sampling time of train positioning, $\Phi_{ri}(t_r)$ is the oscillation phase, $\Phi_{sj}(t_r)$ is the carrier phase of satellite j , N is the integer ambiguity of satellite j , $\Phi_{ri}(t_r)$ is the observation noise.

3 Digital Track Map

The conventional track diagram consists of discrete measuring points along track and related information. The measuring points of railway track can be divided

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into low precision and high precision according to the precision. The measuring point with low precision can generate approximate track line, and the line diagram is composed of single line. The track lines generated by high precision measuring points can distinguish double track tracks and switches.

Track lines are usually approximated by straight lines connected to discrete points one by one. The discrete points can be obtained from the measured points by a certain algorithm. The distance between discrete points is different, and the accuracy of the track curve is different.

When the line is used in the geographic information system, it needs to be transformed from the CGCS2000 coordinate system of GPS to the Descartes coordinate system in the map. In this paper, the common Gauss-Kruger projection method is used to transform the coordinate, but the transformation of coordinate system will introduce some error and reduce the precision.

The rail transit line consists of straight lines, circular curves and transition curves connecting straight lines and circular curves [6-7]. A segment of railway is represented by a line between two nodes. The accuracy of the line diagram depends on the distance between the nodes in the line.

3.1 Fitting Method of Track Line

When the measuring point of the track is low precision, there is a large measurement error in the measured point data, and the track line can be generated by curve fitting method. Considering the characteristic of curve section of railway track, cubic spline curve fitting is adopted [8].

In order to ensure the effect of curve fitting, we need coordinate X monotonicity. The railway track line is a curve from the departure station to the terminal station, which can generally guarantee the X monotony through coordinate rotation. The coordinate rotation matrix equation is:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ 1 \end{bmatrix} \quad (3)$$

Here, θ is the rotation angle, x_0, y_0 is the original coordinate value.

3.2 Interpolation Method of Track Line

When the horizontal accuracy is better than that of 0.5m, the original track data can be regarded as the true value point, and when the track line is generated, the line curve passes through the measuring point. In order to reduce the computation amount, there's no need to rotate coordinates. In this paper, the non-uniform cubic B-spline interpolation method is used to generate the track line, in which the back calculation of the curve control point is the focus of the algorithm.

The problem is to find a set of characteristic polygon vertices P_i corresponding to the data points $Q_i(x_i, y_i)$ so that the cubic B-spline curve $P_i(t)$ takes $Q_i(x_i, y_i)$ as

the node. The parameter value t corresponding to each measuring point is estimated with the accumulated chord length parameter method.

Because the curve need C^2 grade continuous, we use the endpoint interpolation method to reverse the control point. Suppose the i -th cubic B-spline curve is:

$$P_i(t) = \sum_{i=1}^{n+1} P_i N_{i,4}(t), \quad t \in [0,1] \quad (4)$$

Here, $P_i, i = 1, 2, \dots, n+1$ is the control point, $N_{i,4}(t)$ is the primary function of cubic B-spline curve.

According to the property of the cubic B-spline curve, it can be obtained [9]:

$$P_{i-1} + 4P_i + P_{i+1} = 6Q_i, \quad i = 1, 2, \dots, n \quad (5)$$

The equations set have n equations and $n+2$ unknowns, so it is necessary to add 2 boundary conditions to solve them with the tangent vectors of the end points. The supplementary boundary conditions are as follows:

$$\begin{cases} P_{n+1} = P_n \\ P_0 = P_1 \end{cases} \quad (6)$$

Through the equation 5 and 6, the control point can be obtained with the chasing method.

Finally, according to the control point and the known data point, the cubic B-spline interpolation is completed by De Boor recursive method. The curves are close to the actual curve, and have good shape preserving and smoothness, which can satisfy the demand of high precision track line in theory.

4 Map Matching Method

The basic idea of digital rail line auxiliary train positioning firstly is to match the train track of satellite positioning with the digital track map. Secondly, to find the current roughly moving position of the train. Finally, the current positioning point of the train is corrected.

4.1 Projection Correction Method

When the train runs in the straight line, the position of the positioning point can be corrected by projection method, thus the positioning accuracy is improved. The curve segment can be approximately considered to be connected by a shorter line segment [10].

Assuming that the train runs at point P between the two points of the straight track L_0L_1 at a certain moment, the receiver obtains the train at the point M outside the track due to the error of the GPS positioning. According to the error circle of the locating point, the line segment L_0L_1 is obtained by searching the line data table, and the distance between the point M and the line L_0L_1 is the smallest. The MM' is perpendicular to the track heading L_0L_1 , and the current position of the train is evaluated at M' points, as shown in Figure 1.

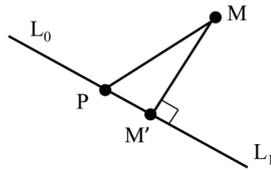


Figure 1. Sketch map of satellite positioning correction.

In the graph, the equations of line L_0L_1 and MM' are respectively:

$$\frac{x - x_a}{x_b - x_a} = \frac{y - y_a}{y_b - y_a} \quad (7)$$

$$\frac{x - x_{p0}}{x_{p1} - x_{p0}} = \frac{y - y_{p0}}{y_{p1} - y_{p0}} \quad (8)$$

Then, the length of MM' is D :

$$D = \frac{x_{p0}(y_a - y_b) - y_{p0}(x_a - x_b) + (x_a y_b - x_b y_a)}{\sqrt{(x_a - x_b)^2 + (y_a - y_b)^2}} \quad (9)$$

In this way, the projective point M' of the point M on the line is approximated as the real point P on the line. As shown in Figure 1, the positioning error is reduced from the original PM to the current PM' .

4.2 Average Distance Method

The track line is usually multi-line parallel, at this time, the pure geometry method of discerning rail line is prone to make mistakes, and the train may swing between different lines. Therefore, it is necessary to use different methods to determine the train running track at this time.

When the satellite positioning error exceeds a certain range, the shortest distance method can't determine the line, the train running line can be determined according to the method of majority decision.

Select the first n positioning points, according to the formula (10) to find the average distance to the line, the minimum distance line is the matching line. The distance average is:

$$\bar{D} = \frac{1}{n} \sum_{i=1}^n D_i \quad (10)$$

The advantage of the average distance method is that it is convenient to calculate and shorten the computation time of distinguishing the line. The disadvantage is that when the distribution of the road is more intensive, the matching point may jump between several lines. If the topology and connectivity of the track network are further considered, the jumping situation can be reduced and the accuracy of line resolution can be improved.

4.3 Grid Matching Method

In this way, the grid table is used to match the location points with the known marked points of the railway. Firstly, it is necessary to establish the spatial index of railway markers, and then calculate the weight matching coefficient. Finally, according to the different matching coefficients from the locating points to different marked points, we finally determine the location of the positioning points.

In the matching process, we first need to determine which marked points can participate in matching. This problem can be solved by partitioning the network on the map. From the left to the right, from the bottom to the top, the electronic map is divided into $M \times N$ mesh areas according to a certain step length. M and N represent the number of rows and columns respectively, and all known marked points must be included in the grid area.

The matching coefficient is calculated as follows:

$$f_p = \omega_d \frac{1}{d} + \omega_\theta \cos(\Delta\theta) \quad (11)$$

Here, ω_d and ω_θ are the weights of distance and directional factors, and $\omega_d + \omega_\theta = 1$. $\Delta\theta$ is the angle difference between the location point and the marked point in the speed direction. d is the distance between the location point and the marked point.

By comparing the matching coefficient, we can get the matching degree between the location points and the marked points. The bigger the matching coefficient is, the higher the matching degree is.

5 Simulation and Analysis

In the train location, we usually make use of the method proposed in the previous section. But these methods rely on relatively accurate digital maps. Therefore, accurate digital map is very necessary. In this section, we compare and analyze the different effects of fitting method and interpolation method on the establishment of digital map. The data come from the measurement of some railway lines from Harbin to Qigihar. The data are divided into two parts: Pa and Pb . One part of data is used for calculation and the other is for verification.

In the simulation, the point set Pa is used for calculation though fitting and interpolation. Figure 2 is the overall track line graph. The error results are shown in Figure 3 and Figure 4.

We evaluate the effect of fitting and interpolation by the three parameters of maximum, minimum and RMSE (Root Mean Square Error). The result of the parameter value is shown in Table 1.

Through the analysis and calculation of the simulation, we can see that fitting and interpolation can basically approximate the railway track. Whether it is fitting or interpolation, the cubic spline is more in line with the actual trajectory.

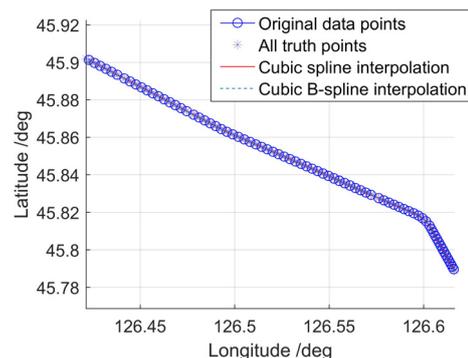


Figure 2. Track line graph.

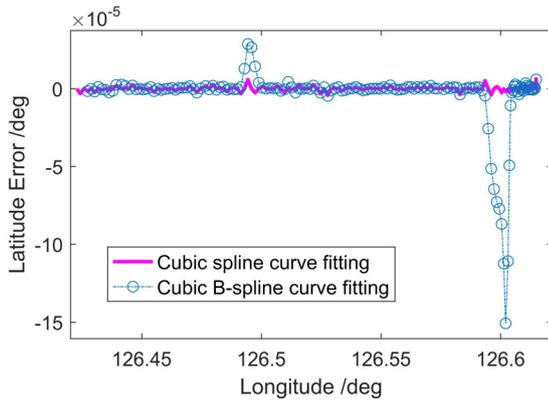


Figure 3. Comparison of fitting error

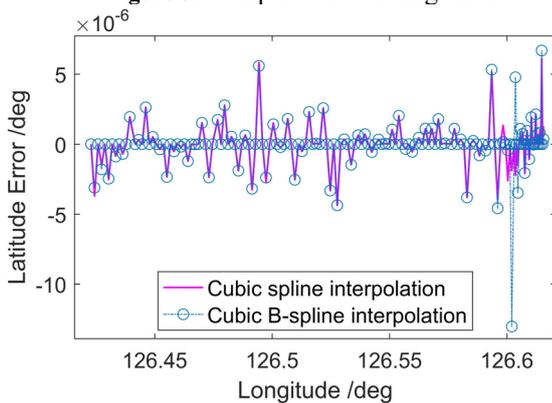


Figure 4. Comparison of interpolation error.

Table 1. Effect comparison.

	Maximum (deg)	Minimum (deg)	RMSE (/deg)
Fitting (cubic spline)	6.315e-06	-4.365e-06	1.436e-06
Fitting (cubic B-spline)	2.86e-05	-1.508e-04	2.25e-06
Interpolation (cubic spline)	6.110e-06	-4.365e-06	1.44e-06
Interpolation (cubic B-spline)	6.69e-06	-1.303e-05	1.82e-06

From Figure 3 and Figure 4, it can be seen that the larger errors appear in the curved line. But the increase of the number of the sampling points can improve the accuracy of the fitting and interpolation. Therefore, it is necessary to increase the sampling frequency of the curved line to improve the accuracy of the track itself, so as to improve the accuracy of the line.

6 Summary and Conclusions

The safety of GPS plays an important role in improving the safety and capacity of railway transportation system, as well as effectively managing the transportation of railway high value-added freight. According to the accuracy of measurement data, the digital track line is constructed by fitting and interpolation, and then the positioning error is corrected by projection correction method and multi-line parallel track discerning method.

According to the partial measurement data of Harbin to Qiqihar railway, the fitting and interpolation models

based on the cubic spline curve and the cubic B-spline curve are established respectively. The simulation results show that fitting and interpolation can basically approximate the railway track, and the cubic spline is more in line with the actual trajectory.

The method used in this paper can effectively create railway track map. The GPS can improve the accuracy of train positioning with map. So the method has practical significance to improve the reliability and safety of freight train, and it is suitable for the control and management of railway transportation.

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