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Center Line Coordinates Survey for Existing Railway by 3-D Constraints Method

Hui Wei[1,2], Hongtao Zhu*[1],Zhiyong Wang[1,3],Weijun Wu[1,3]
1. Sch. of Mech. Eng., Nanchang Univ.,
No.999, Xuefu Av., Nanchang City, Jiangxi Prov., P.R.C,Tel: +86-79183969625
2. Sch. of Automotive Eng., Jiangxi Univ. of Tech.
No.115, Ziyang Av., Nanchang City, Jiangxi Prov., P.R.C,Tel: +86-79188138784
3. Everbright Railway Equipment Develop Co.,Ltd.
No. 966, Gaoxin 5th Road, Nanchang City, Jiangxi Prov., P.R.C,Tel: +86-79188197837
First Author, e-mail: weihui@163.com
*Corresponding Author, e-mail: honey62@163.com

Abstract

Since the maintenance of HSR depends both on inner geometries and outer geometries information of track, it's necessary that the survey technologies could measure the smoothness and coordinates of track in a high-density manner. But the existing technologies for track survey are either inaccurate or inefficient for HSR maintenance, the problem about track survey arises with the rapid development of high-speed rail (HSR) in China. To meet the demands on track smoothness survey of existing line, a method denoted as 3-D Constraints Method is introduced in this paper. The general principle of the method is obtaining center line locus with location information by means of survey trolley and CP-□ stakes. By measuring the distances between trolley and CP-□ stakes, the boundary condition could be determined. So, the problem of center line calculation is transformed into the problem of definite integral for FOG signals. Accordingly, an algorithm of coordinate calculation is given. With the constraints form CP-□ stakes, the coordinates of center line could be obtained in a defined accuracy. Finally, the simulation result shows that the method is effective.

Keywords: *3-D constraints method, maintenance benchmark, track geometries measuring trolley, center line survey*

1. Introduction

As one of the primary technical facilities for rail, track plays a fundamental role for railway operation. Track is composed with rails, sleepers, bed, fastenings, anti-creepers, etc. Its functions are leading the operation of rolling stock, sustaining the axle load and conducting it to subgrades or bridges and tunnels structure. The geometries of track are of paramount importance to the railroad industry. So it is reasonable that the track must be sturdy, steady, and keep in correct geometries to ensure travel safety [1-3].

Recently, high-speed rail (HSR) technologies have developed rapidly in China. By the end of July 2012, there is more than 6,894km HSR in operation and 18,000km under construction. Due to the higher traveling speed, the track must be higher smoothness [4]. In recent years, all departments concerned have invested large amount of money to promote the facilities. Nevertheless, with the accumulation of plastic deformation caused by repetitive trainloads, track irregularities gradually deteriorate and finally endanger travel safety. Consequently, for railway engineering, one of the most important tasks is to keep the track geometries in acceptable status.

Track survey is the precondition of track maintenance. The measurements are used to assess the condition of the rail, and schedule any maintenance that may be needed. To ensure the operation safety and riding comfort, it is necessary to measure the geometries of track in a high-accuracy, high- density, and high-efficiency manner. There are two methods for survey the smoothness of track. One is static survey by means of chord, Track Geometries Measuring Trolley, Electronic Total Station (ETS), etc. The other is dynamic survey using track recording car. Despite that the track quality assessment is mainly through dynamic survey in railway administration level, track maintenance depots are more concerned with the deviations from

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design values in daily maintenance rather than the dynamic responds of Train-Track Coupling system. In consideration of the facts mentioned, a complete track geometries information include absolute coordinates is demanded to ensure the smoothness of HSR.

2. Existing Technologies of Static Survey

In general, there are 3 kind of static survey technologies in track geometries survey, including manual survey, relative survey and absolute survey. Traditional static survey includes manual survey, the principle of which is to measuring the irregularities by means of manual tools e.g. measuring chord, graduation ruler, track gauge, etc. Obviously, the survey data are rough and cannot meet the demands of HSR maintenance. Consequently, the track geometries measuring trolley was developed. It is able to measure the inner geometries of track, e.g. the level, gauge, twist, profile and alignment irregularities, in a defined accuracy, by the sensors and gyroscopes mounted on the trolley. But it is also a relative method in essence since there is no benchmark for measuring, thus the trolley could not collect the track information of outer geometries. Furthermore, this disadvantage will lead to intolerable errors with the increase of mileage.

In recent years, a technology denoted as 3-D precise measurement is wildly applied in the construction of HSR, which equipped with ETS and could get the absolute coordinates of rail in a defined accuracy e.g. the azimuth measurement accuracy is less than ±1″and the distance measurement accuracy is less than $\pm(1+1\times10^{-6})$ mm. Since the ETS could measure the outer geometries of track by means of CP-□ stakes measuring, it is a kind of absolute survey and is suitable for rail construction. Whereas, using optical instruments, 3-D precise measurement must take much of time to tracing, locating, adjusting, stabilizing for each survey point, so it is difficult to consecutively survey the location per sleeper during the possessive interval in existing line [5].In short, this method is inefficient for existing line maintenance.

Relative survey technology based on irregularity inspection and absolute survey technology based on ETS is both applied in HSR smoothness survey. However, the relative survey technology is poor in accuracy as a result of it shorts of the outer geometries information and ETS is quite uneconomic and inefficient for daily maintenance, we need a new method to survey the track geometries that combined with outer geometries and inner geometries measurement. Taking into account that the technology of relative irregularity survey is fairly mature and CP-□ (Control Point □) intersection network has been built, we investigated a method with 3-D constraints by means of outer sensors(e.g. string sensor) and track geometries measuring trolley. Through the fusion of CP-□ coordinates and inertial locus of trolley, the center line of track could be calculated.

3. Main Idea of 3-D Constraints Survey

3.1. The Principle of 3-D Constraints Method

In China, Ministry of Railways (MOR) has established precise survey network for survey control, construction control and operational maintenance control in which CP-□ stakes remained contains the absolute coordinate information. Combined with ETS, a precise coordinate of rails can be obtained. However, the operation mode and operation condition of ETS determined that the survey is inefficient. Survey trolley is able to describe the rail locus well with certain efficiency, but it lost the information of positions due to its measure principle of relative survey. And with increasing of mileage, the error of locus should increase rapidly for the bias drift, angle random walk, bias flicker noise, etc. Mere relative survey cannot match up with the demands of HSR maintenance.

In this subsection, we present the main idea of 3-D constraints survey. For described completely the track geometries, a model is assumed that including 3 aspects information: trolley attitude, rail locus and benchmark coordinate. Trolley attitude reflects the irregularity of level and gauge. Track profile and alignment locus is described by trolley mileage and deflection angle. To avoid accumulated errors of center line measurement, CP-□ stakes are set in order to get the absolute coordinates (as shown in

Figure. 1) which are arranged on subgrade shoulders according to a pair per 60m in general.

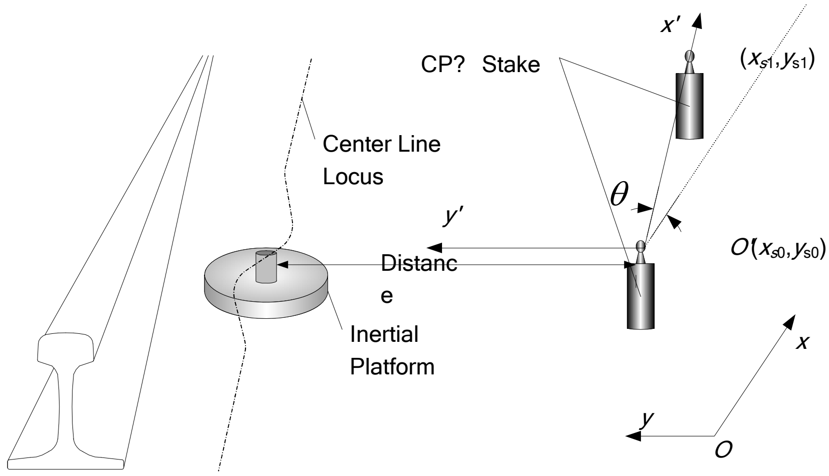

Figure. 1 Scheme of 3-D constraints

In order to calculate the absolute coordinates of center line, a relative coordinate system {*O*';*x*', *y*'} with the origin at (x_0,y_0)(the CP-III stake) is defined, where the *x*' axes fixed on two adjacent stakes. Accordingly, the y' axes oriented perpendicular to the *x*' axes and pointed to track.

The relationship between relative coordinate system {*O*';*x*', *y*'} and absolute coordinate system {*O*;*x*, *y*} is therefore

$$\begin{cases} \theta = \arctan \dfrac{y_{s1} - y_{s0}}{x_{s1} - x_{s0}} \\ x = x' \cos\theta - y' \sin\theta + x_{s0} \\ y = x' \sin\theta + y' \cos\theta + y_{s0} \end{cases} \tag{1}$$

where:
θ: Angle between *x* axes and *x*' axes, in radian;
x_{s0}, y_{s0}: Coordinate of initial CP-□ stake in absolute coordinate system, in meter;
x_{s1}, y_{s1}: Coordinate of adjacent CP-□ stake in absolute coordinate system, in meter.

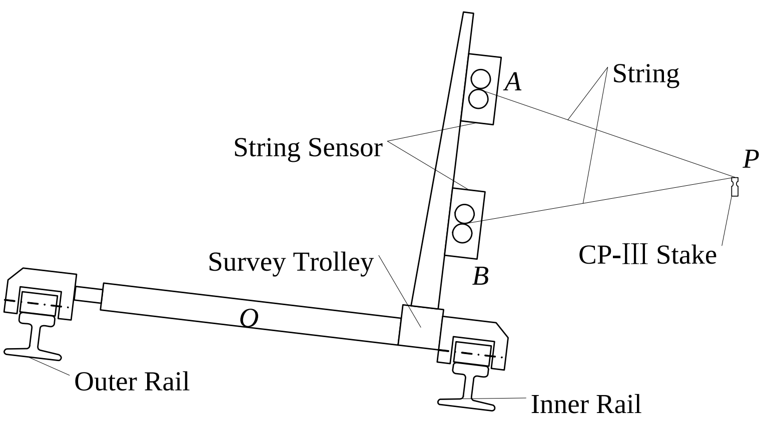

Figure. 2 3-D constraints survey device of the trolley

The absolute coordinate of point (x'_0,y'_0) can be calculated with 3-D constraints. The calculation procedures are as follows: Firstly, the coordinate of point P (x_0,y_0)(the CP-Ⅲ stake) can be gotten from project As-Built documents. Then, draw the string to point P. The distances of AP, BP can be calculated with string sensors. (As shown in

Figure. 2) Finally, with the defined relationship of triangle ΔABP, the distance of *PO* can be determinate. Ignored the deformation of line form, the actual coordinate of (x'_0,y'_0) can be calculated with the constraints of other stakes.

Nevertheless, ignored the errors of point (x'_0,y'_0) in {O';x', y'} coordinate system (As shown in

Figure. 1) , the coordinates of center line locus can be calculated. (The further discussions of locus calculation will be elaborated in subsection 3.2.)

3.2. Reconstruction of Center Line Locus

A reconstruction method of rail geometries has been explored by W.C. Iverson [6]. Iverson pointed out that the rail locus can be described by means of curvature integration. Although a complete model of chord-displacement method has been investigated, practical application is difficult due to the survey data of offsets (versine) is vulnerable to interference, especially for the flow of rail head. Taking account to that the technology of FOG (Fiber Optic Gyroscope) has been successfully applied in survey trolley, we developed a method to reconstruct the center line which simplified the calculation. This subsection briefly explains the mathematical model for the reconstruction by FOG signals, while a more detailed treatment can be found in [**Error! Bookmark not defined.**].

The basic concept of FOG is based on the Sagnac interferometer [7-8]. For a rotating optical fiber coil, two lights traveling in opposite directions in the coil experience different lengths, which results in a phase difference in the two optical waves. The phase difference $\Delta\Phi$ is given by

$$\Delta\Phi = \frac{8\pi N}{\lambda c} A \cdot \omega \tag{2}$$

Where *N* is the number of coil turns, λ is the wavelength in vacuum, *c* is the speed of light in vacuum, *A* is the area vector of the fiber coil, and ω is the rotating rate (angular frequency) vector. By measuring the phase difference $\Delta\Phi$, instantaneous deflection angle can be calculated.

The relationship of deflection angle ϕ and coordinate value (x',y') is illustrated in

Figure. 3, where the coordinate system {O';x', y'} is the relative coordinate fixed on CP-□ stakes. Assumed s is the distance along the rail, then a small increment *ds* in rail length causes small increments in x' and y' given by (3)

$$\begin{cases} dx'/ds = \cos\phi \\ dy'/ds = \sin\phi \end{cases} \tag{3}$$

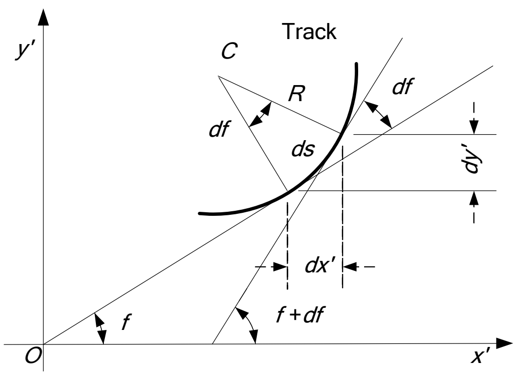

Figure. 3 Relationship of deflection angle and coordinate values

Investigating the relationship of deflection angle and (x',y'), and assumed that the initial values (x'_0,y'_0) and ϕ_0 have been specified, the center line can be calculated with trapezoidal rule [9]. Recurrence formulas are shown in(4).

$$\begin{cases} x'_i = x'_{i-1} + \Delta s \cos\frac{1}{2}(\phi_i + \phi_{i-1}) \\ y'_i = y'_{i-1} + \Delta s \sin\frac{1}{2}(\phi_i + \phi_{i-1}) \end{cases} \tag{4}$$

where i is the number of survey spot, Δs is the sampling interval, in another word, step size.

Formula (4) explicitly shows the relationship between (x',y') and ϕ. Combined with (1), the center line in absolute coordinate system is given as:

$$\begin{cases} \theta = \arctan\frac{y_{s1} - y_{s0}}{x_{s1} - x_{s0}} \\ x_i = x_{i-1} + \Delta s \cos[\theta + \frac{1}{2}(\phi_i + \phi_{i-1})] \\ y_i = y_{i-1} + \Delta s \sin[\theta + \frac{1}{2}(\phi_i + \phi_{i-1})] \end{cases} \tag{5}$$

where i is the number of survey spot, i=1,2,3,…;Δs is the sampling interval in meter; θ is angle between x axes and x' axes, in radian; x_{s0}, y_{s0} is coordinate of initial CP-III stake in absolute coordinate system, in meter; x_{s1}, y_{s1} is coordinate of adjacent CP-III stake in absolute coordinate system, in meter.

4. Simulation of Center Line Coordinates Reconstruction

The preceding algorithms will be simulated by means of MATLAB. To simplify the calculation, the process will be discussed for error-free curvature measurements.

Assumed the route location on paper as that: coordinate system is NE coordinate system; deflection angle is -14.59457°; Deflection point lies in (2945380.71395, 491560.5006); initial mileage is 216034.407m; terminal mileage is 217884.786; length of transition curve is 280m; radius of curve is 6000m; initial location of curve lies in (491558.0255, 2946310.4821); length of curve is 929.77218m. The result of simulation (as shown in

Figure. 4) suggests that 3-D constrains method could reconstruct the center line of track well.

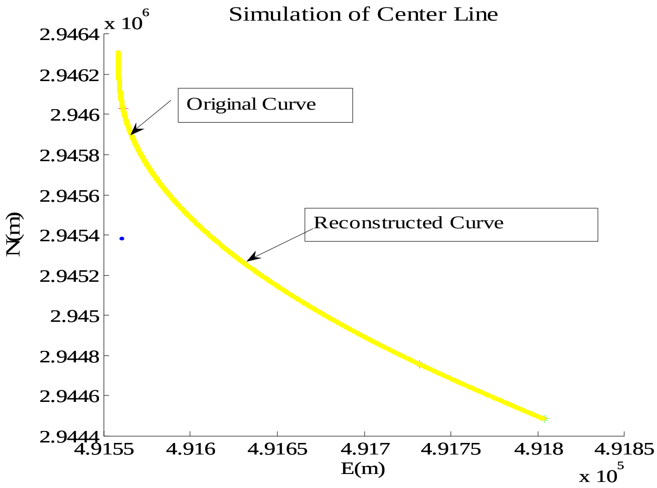

Figure. 4 Simulation of center line reconstruction

5. Conclusions

In this paper, the relationship of relative coordinate system and absolute coordinate system has been analyzed. As a result, the following conclusions can be drawn.

With the constraints of CP-III stakes, the coordinates of center line could be reconstructed by means of deflection angle which could be collected by FOG. This reconstructed center line describes complete geometries information of track, e.g. the profile and alignment irregularities. Using the coordinate information, the maintenance for HSR is practicable. Since it is not necessary to repeatedly tracing, locating, adjusting, stabilizing for each survey point, so this method is more efficient the ETS.

The results of simulation suggested that: Accurate reconstruction is possible if there is no error present in the deflection angle measurements. However, since it is inevitably to introduce measured noise for a practical survey process, the accuracy should be obviously degraded with errors [**Error! Bookmark not defined.**]. For that there is adjustment function of redundant observation, the 3-D constraints method could achieve higher accuracy compared with relative survey.

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References

[1] Hao Ying. *Railway Engineering* (in Chinese). Beijing:China Railway Publishing House. 2002: 46-65.
[2] XIAO Hong, GAO Liang, WU Kaiwei, et al. Dynamic Characteristics Analysis of Mats of Ballasted Track on Bridge. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(7): 1779-1784.
[3] Gore C. Railway noise: principles for an EU policy–the CER view. *Journal of Sound and Vibration.* 1996; (193): 397–401.
[4] Luo Lin. High Smoothness, a Must for the High-speed Railway (in Chinese). *Chinese Railways*. 2000; (9): 8-11.
[5] Zhu Hongtao, Xu Rong. Research on the 3D Precise Measurement Technology for Existing Railway Line (in Chinese). *Journal of Railway Engineering Society*. 2009; (1): 49-51.
[6] WC Iverson, Analysis of the Reconstruction of Rail Geometry from Curvature Data. *IEEE Trans. Industry Applications*, 1974; IA(10): 368-379.
[7] B Lee. Review of the present status of optical fiber sensors. *Optical Fiber Technology*. 2003; (9): 57-79.
[8] Yanran Wang, Hai Zhang, Qifan Zhou. Adaptive Integrated Navigation Filtering Based on Accelerometer Calibration. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(7): 1869-1878.
[9] Jeffrey A, Advanced Engineering Mathematics. San Diego: Harcourt/Academic Press. 2002: 1065-1068.