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Track curvature pre-scanning measurement algorithm and spatial lag mechanism analysis

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Abstract

Obtaining the track curvature in real time can provide key input parameters for many active control technologies of railway vehicle. It is an effective way to completely solve the problem of signal time delay to obtain the image of the front track through camera and pre-scanning the curvature. Therefore, a pre-scanning algorithm was proposed to map the track curvature through the lateral offset of the track centre line. Then, the lag mechanism of the measured curvature relative to the curvature at the pre-scanning point was further explored: because the virtual vehicle body formed by the pre-scanning point introduces geometric inertia effect (GIE). Then, the spatial correction equation between the measured curvature and the actual curvature was given. Finally, the above conclusions were verified by SIMPACK and MATLAB. The above research results can provide some theoretical reference for the application of vision technology in the field of track curvature measurement.

Keywords: Track curvature measurement; Pre-scanning; Geometric inertia effect; Spatial correction equation

1 Introduction

The track curvature is a key input parameter for many active control systems of rail vehicle[1], such as active steering control system and active tilting system. Currently it is possible to obtain track curvature by combining electronic maps with vehicle GPS positioning technology, but this method is not very reliable when signals are missing or communication is weak. In contrast, relying on the sensor of the vehicle itself to measure the track curvature obviously has higher reliability. However, this technical scheme is faced with the problem of time delay, which is a mathematical delay caused by signal filtering processing and cannot be completely eliminated[2-4]. With the development of computer vision technology, its feedforward characteristic provides a new solution for this problem[5].

For this purpose, this paper derives a visual pre-scanning-based track curvature measurement algorithm using the lateral offset of the centre line of the front track, and gives the analytical equation for measuring track curvature. Then, by comparing the expressions of the measured curvature and the actual curvature at the pre-scanning point, the spatial lag mechanism of the measured curvature is fully explored. On this basis, the spatial position correction formula between the measured curvature and the actual curvature is given. Finally, the validity of these conclusions is verified by simulation studies.

2 Methods

A model of the track curvature pre-scanning algorithm is developed as shown in Figure 1(a) and (b). Point B indicates the front bogie, and point A indicates the rear bogie, point C is the pre-scanning point. The length of the line BC is the pre-scanning distance. Point C' is the point on the track centre line in the image that has the same vertical coordinates as point C. It is evident that the Point C coincides with point C' when the vehicle is on a straight line. When the vehicle enters the curve, due to the bending of the track centre line, there must be a certain amount of lateral deviation of point C' in the camera view. Therefore, when the camera angle of view is fixed, the distance of line CC' reflect the variation with the track curvature.

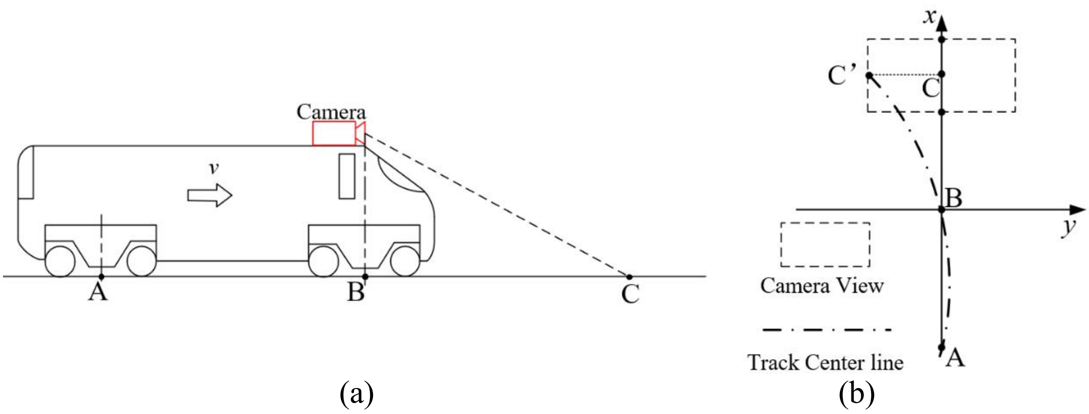
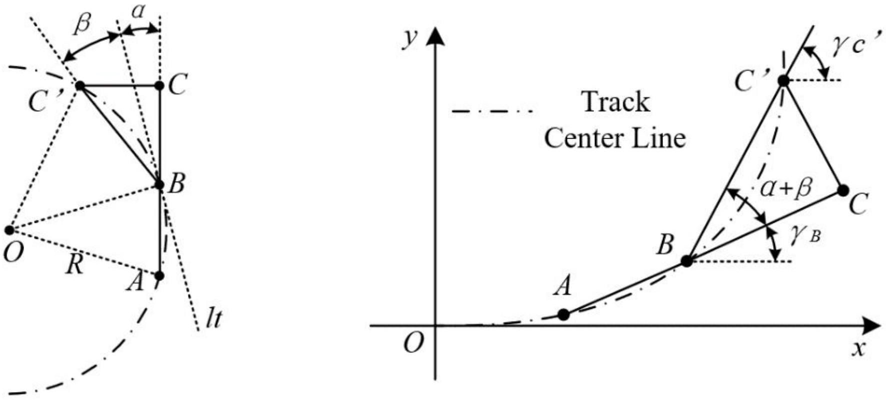


Figure 1 Schematic diagram of the vehicle camera (a) and the track curvature pre-scanning model (b)

According to the model shown in Figure 1 (b), when the pre-scanning point and vehicle are on the circular curve, their geometric relationship with the track is shown in Figure 2 (a). when the pre-scanning point and vehicle are on the transition curve, their geometric relationship with the track can be expressed in Figure 2 (b).



(a) (b)

Figure 2 The geometric relationship between pre-scanning point, bogie, car body on circular curve (a), transition curve(b).

In Figure 2(a), l_t is the tangent through point B, α is the centre angle corresponding to the distance between bogie pivot, β is the centre angle corresponding to the pre-scanning distance.

In Figure 2(b),the track center line satisfies the equation $y = x^3/6Rl$ [6], where R is the curve radius, l is the length of transition curve. $\gamma_{C'}$, γ_B is the tangent angle of line BC' and AB respectively.

In order to verify the accuracy of the proposed equations, the simulation model is established in SIMPACK shown in Figure 3, and the video image of the front track is recorded by using the built-in online simulation and video recording function in SIMPACK. Then, each frame of the video is read in MATLAB and the lateral offset of the pre-scanning point is obtained from it.

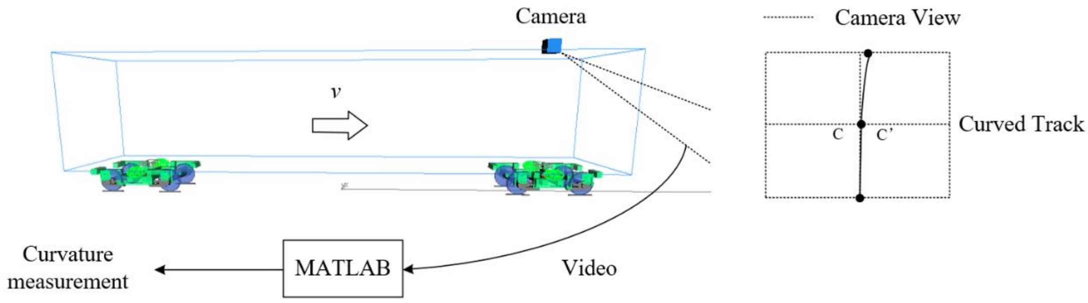


Figure 3 Simualtion Model

Parameters	Track-A	Track-B
Curve radius	500 m	800 m
Length of circular curve	200 m	
Length of transition curve	100 m	
Distance between bogie pivot	15.7 m	

Table 1 Key Parameters

3 Results

In Figure 2 (a), because the curve radius is much bigger than l_{AB}, $l_{BC'}$ and l_{BC}, Equation (1) can be deduced according to the geometric relationship shown in Figure 2(a).

$$\begin{cases} l_{CC'} = l_{BC} \cdot (\alpha + \beta) \\ \alpha = l_{AB} / 2R \\ \beta = l_{BC'} / 2R \end{cases} \tag{1}$$

Then, it can be deduced that the curvature ρ of the track meets equation (2). This Equation shows that the curvature of the pre-scanning point can be calculated by obtaining the lateral offset $l_{CC'}$ in real time.

$$\rho = \frac{1}{R} = \frac{2l_{CC'}}{l_{BC}\left(l_{AB} + l_{BC'}\right)} \tag{2}$$

For the same reason that R is big enough, we can obtain $l_{BC} \approx l_{BC'}$, and Equation (3) can be obtained from Equation (1),

$$\rho = \frac{2(\alpha + \beta)}{l_{AB} + l_{BC}} \tag{3}$$

This equation shows that $(\alpha + \beta)$ can be regarded as the return angle between two car bodies (virtual car body and actual car body), in which the length of virtual car body is l_{BC} and the length of actual car body is l_{AB}.

According to the model in Figure 2 (b), the curvature calculation Equation (4) of the pre-scanning point can be deduced as follows, where *s* is the running distance of the vehicle, *R* is the radius, and *l* is the length of the transition curve, and we define $l_{BC} = c_l l_{AB}$.

$$\rho = \frac{3s + (c_l + 2) l_{AB}}{3Rl} \tag{4}$$

Since point C' is on the transition curve, the curvature at this point can be calculated by the following Equation (5),

$$\rho_{C'} = \frac{s + (c_l + 1) l_{AB}}{Rl} \tag{5}$$

Combining Equation (4) with Equation (5) shows that the measured curvature ρ is not equal to the curvature at point C', and the difference between the two is shown by equation (6),

$$\Delta\rho = \rho_{C'} - \rho = \frac{2c_l + 1}{3} \cdot \frac{l_{AB}}{Rl} \tag{6}$$

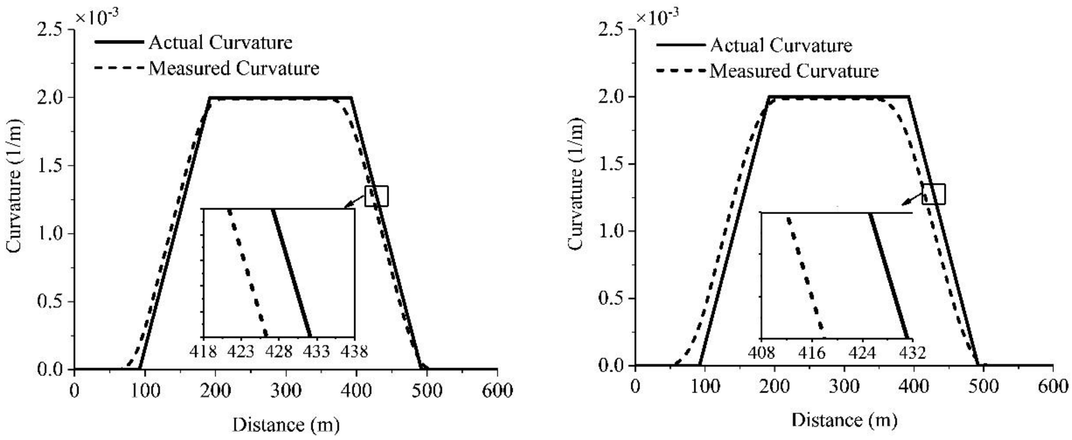
This shows that the measured curvature lags behind the real curvature of the pre-scanning point. In addition, since the change rate of the track curvature curve is $1/RL$[6], the lag distance between the measured curvature and the actual curvature can be calculated by Equation (7),

$$l_{delay} = \frac{2c_l + 1}{3} \cdot l_{AB} \tag{7}$$

Therefore, the actual advance distance l_{pre} of the track curvature obtained based on pre-scanning relative to point B can be calculated by Equation (8),

$$l_{pre} = l_{BC} - l_{delay} = l_{AB}\left(\frac{c_l - 1}{3}\right) \tag{8}$$

The simulation results based on SIMPACK and MATLAB are shown in the Figure 4 and Table 2. The solid line in the figure is the actual curvature of point B and the dotted line is the measured curvature of pre-scanning point C. It is evident that the advance distance is far less than the pre-scanning distance. The theoretical results show the same pattern as the simulation results, the underlying reason being the geometric inertia effect (GIE)[7] introduced by the virtual vehicle body formed by the visual pre-scanning point.



(a) (b)

Figure 4 Simulation results of case A-1(a) and A-2(b)

Case	Pre-Scanning Distances	Theoretical values	Simulation values
Track-A-1	30m	4.77m	5.46m
Track-A-2	50m	11.43m	12.85m
Track-B-1	30m	4.77m	4.86m
Track-B-2	50m	11.43m	13.01m

Table 2 Advance distance of pre-scanning

4 Conclusions and Contributions

1) In this study, an algorithm is proposed to measure the curvature of the forward track through the lateral offset of the track centre line. This algorithm has the same mechanism as the method of measuring curvature through two car body rotation angle. Because, the pre-scanning point can be regarded as a virtual bogie, and the distance between the pre-scanning point and the camera can be regarded as a virtual vehicle body.

2) The curvature value obtained by pre-scanning lags behind the actual curvature of pre-scanning point in space. The fundamental reason for the above lag is that the virtual car body formed by visual pre-scanning introduces geometric inertia effect (GIE). On this basis, the spatial position correction equation between the measured curvature and the actual curvature of the vehicle position is given.

3) The simulation results show that the curvature pre-scanning algorithms presented in this paper have high calculation accuracy. The spatial position correction equation also better describes the advance of the measured curvature relative to the vehicle position.

4) Therefore, when pre-scanning the front track curvature by machine vision, the measured curvature must be corrected by the spatial position according to the correction equation, and then the accurate curvature can be obtained.

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References

[1] Bruni S, Goodall R, Mei TX, et al. Control and monitoring for railway vehicle dynamics. Veh Syst Dyn. 2007;45(7–8):743–779.

[2] Wang XM, Ni WB, Li F. Research on gyroscope platform based tilting train railway line information inspection system. China Railw Sci. 2004;25(1):41–45.

[3] Sim KS, Hur HM, Song HS, et al. Study of the active radial steering of a railway vehicle using the curvature measuring method. J Mech Sci Technol. 2014;28(11):4583–4591.

[4] Tian S, Luo X, Ren L, et al. Active radial system of railway vehicles based on secondary suspension rotation angle sensing. Veh Syst Dyn. 2021;59(5):765–784.

[5] Berg A, Öfjäll K, Ahlberg J, et al. Detecting Rails and Obstacles Using a Train-Mounted Thermal Camera. Proceedings of the 19th Scandinavian Conference on Image Analysis, Copenhagen,2015,6.

[6] Lou P. A general method for determining transition curve equations by means of the curvature of transition curve. J China Railw Soc. 2003;25(03):104–106.

[7] Tian S, Luo X, Xiao C, et al. Real time measurement of track curvature based on vehicle attitude perception. Veh Syst Dyn. 2022, DOI:10.1080/00423114.2022.2047211