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Curvature Detection System of Railway Track Based on Bogie Running Trajectory

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Abstract

An accurate and efficient detection of a railway track curvature can effectively improve the control performance of active control systems for railway vehicles. In this study, aiming to improve the accuracy, real-time performance, and engineering application value of a curvature detection method for railway tracks, a curvature detection system based on a bogie running trajectory is proposed. The system is comprises an angular velocity sensor, speed sensor, and arithmetic unit arranged on the first bogie in the vehicle driving direction. Furthermore, a curvature detection algorithm based on the bogie running trajectory is proposed. The algorithm obtains the bogie running trajectory by measuring the yaw angular velocity and running speed of the bogie, and then calculates the railway track curvature in real time according to the trajectory. On this basis, an engineering prototype of the proposed system is built, and a line test is conducted to verify the effectiveness of the system scheme. During the test, corresponding sensors are installed to measure the running speed and yaw angular velocity of the bogie, and the arithmetic unit (integrated with the curvature detection algorithm) is used to calculate the curvature of the track in real time. The experimental results show that the system can effectively measure the track curvature. In addition, the high-frequency noise in the original signal is filtered out, and the real-time performance of the curvature detection is significantly improved relative to that of a traditional low-pass filter. Moreover, the layout of the system is simple and the algorithm is easy to implement, making it conducive to further engineering applications.

Keywords: railway track, curvature detect, bogie, running trajectory, algorithm, system, railway vehicle.

1 Introduction

A railway track curvature is an important control parameter for many active control systems of railway vehicles, such as active tilting systems and active steering systems. Therefore, realising real-time and accurate detection of railway track curvature is a goal of researchers in related fields. Conventionally, vehicle positioning is realised through external signals such as GPS [1] and ground beacons [2], and track curvature information is accurately obtained using a track database. Nevertheless, this approach requires high reliability and stability in the external signals, and the track database requires frequent maintenance and updates. In contrast, it is evident that a real-time detection of track curvature based on the vehicle itself would be a more appropriate technical route. However, the existing curvature detection methods often have problems such as complex algorithms [3,4,5], requirements for additional sensors [3,4,5], or limited real-time detection [6,7,8,9]; these limitations restrict the further application of these methods.

To further improve the real-time performance and engineering application value of track curvature detection, this study proposes a track curvature detection system based on a bogie running trajectory. Figure 1 illustrates the basic structure of the system. As shown, the system comprises an angular velocity sensor, speed sensor, and arithmetic unit arranged on the first bogie in the driving direction of the vehicle. The system obtains the yaw angular velocity and running speed of the bogie, calculates the bogie running trajectory, and obtains the line curvature in real time according to the trajectory. The system layout is simple, easy to implement, and conducive to further engineering applications.

Based on the above scheme, this study first determined a curvature detection algorithm based on the bogie running trajectory through theoretical analysis. Then an engineering prototype of the curvature detection system was established, and a line test was conducted to verify the effectiveness of the system.

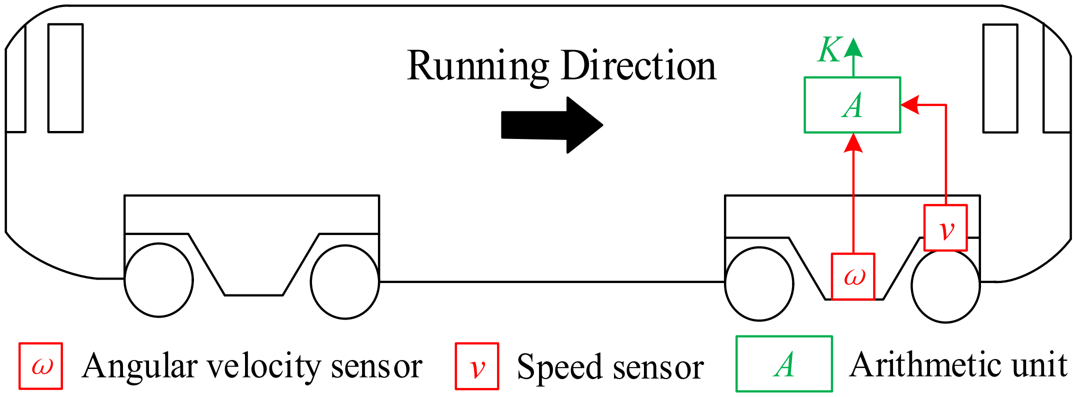


Figure 1: System architecture.

2 Methods

Equation (1) defines the state coordinates of the bogie when it runs on the track. In Equation (1), x and y are the abscissa and ordinate of the bogie centre on the twodimensional plane, respectively; θ is the yaw angle of the bogie; v is the absolute value of the bogie running speed; and ω is the yaw angular velocity of the bogie.

$$P(x, y, \theta, v, \omega) \tag{1}$$

The data window W_j is defined as the set of state coordinate points within a certain mileage with length L, as shown in Formula (2).

$$\begin{aligned} & W_j = \left\{ P_{j(1)}, P_{j(2)}, \ldots, P_{j(n-1)}, P_{j(n)} \right\} \\ & P_{j(i)}(x_{j(i)}, y_{j(i)}, \theta_{j(i)}, v_{j(i)}, \omega_{j(i)}) \\ & \sum_{i=2}^{n} \left[(x_{j(i)} - x_{j(i-1)})^2 + (y_{j(i)} - y_{j(i-1)})^2 \right] = L \end{aligned} \tag{2}$$

It can be easily obtained by basic geometric operations that the relationship between the state quantities of adjacent data points in the data window satisfies Equation (3), where Δt is the integral time constant. It can be seen from Equation (3) that all of the parameters of the state coordinates can be calculated simply by obtaining the running speed v and yaw angular velocity ω of the bogie at each moment.

$$\begin{cases} x_{j(i)} = x_{j(i-1)} + v_{j(i-1)} \cdot \cos(\theta_{j(i-1)}) \cdot \Delta t & (i = 2 \text{ to } n) \\ y_{j(i)} = y_{j(i-1)} + v_{j(i-1)} \cdot \sin(\theta_{j(i-1)}) \cdot \Delta t & (i = 2 \text{ to } n) \\ \theta_{j(i)} = \theta_{j(i-1)} + \omega_{j(i-1)} \cdot \Delta t & (i = 2 \text{ to } n) \end{cases} \tag{3}$$

The coordinates of each point in the data window are transformed according to Equation (4). The essence of this process is to transfer the abscissa and ordinate of each point to the plane rectangular coordinate system with ($x_{j(1)}$,$y_{j(1)}$) as the origin and $\theta_{j(1)}$ as the positive direction of the x-axis.

$$\begin{cases} \theta^T_{j(i)} = \theta_{j(i)} - \theta_{j(1)} & (i = 1 \text{ to } n) \\ x^T_{j(i)} = (x_{j(i)} - x_{j(1)}) \cdot \cos(\theta_{j(1)}) + (y_{j(i)} - y_{j(1)}) \cdot \sin(\theta_{j(1)}) & (i = 1 \text{ to } n) \\ y^T_{j(i)} = (y_{j(i)} - y_{j(1)}) \cdot \cos(\theta_{j(1)}) - (x_{j(i)} - x_{j(1)}) \cdot \sin(\theta_{j(1)}) & (i = 1 \text{ to } n) \end{cases} \tag{4}$$

The above coordinate points are fitted with a cubic polynomial using the least squares method to Equation (5), i.e. the bogie running trajectory in the current data window.

$$y^T_{j(i)} = \mathrm{Y}(x^T_{j(i)}) = a_3 (x^T_{j(i)})^3 + a_2 (x^T_{j(i)})^2 + a_1 (x^T_{j(i)}) + a_0 \tag{5}$$

The curvature at any point of the trajectory can be calculated using Equation (6), where $x^T_{j(i)}$ is the abscissa of the point, as follows:

$$K = \frac{\left| \ddot{\mathrm{Y}}(x^T_{j(i)}) \right|}{(1 + \dot{\mathrm{Y}}^2 (x^T_{j(i)}))^{1.5}} \tag{6}$$

By substituting the abscissa $x^T_{j(n)}$ of the current position of the bogie into Equation (6), the railway track curvature can be obtained using Equation (7), as follows:

$$K = \frac{\left| \ddot{\mathrm{Y}}(x^T_{j(n)}) \right|}{(1 + \dot{\mathrm{Y}}^2 (x^T_{j(n)}))^{1.5}} = \frac{\left| 6 a_3 x^T_{j(n)} + 2 a_2 \right|}{(1 + (3 a_3 (x^T_{j(n)})^2 + 2 a_2 x^T_{j(n)} + a_1)^2)^{1.5}} \tag{7}$$

Evidently, as the data window slides with the bogie running in real time, the calculation result of Equation (7) reflects the curvature of the railway track that the bogie passes through.

3 Results

Based on the above algorithm, the curvature detection system prototype shown in Figure 2 was built for a line operation test. As shown in Figure 2, the speed sensor and angular speed sensor were arranged on the first bogie in the running direction of the vehicle, and a reflector attached to the wheel was illuminated by a photoelectric switch to convert the wheel speed, thus obtaining the running speed of the bogie. The curvature detection algorithm proposed in this study was integrated into the arithmetic unit, which calculated the curvature of the railway track in real time based on the sensor measurement data.

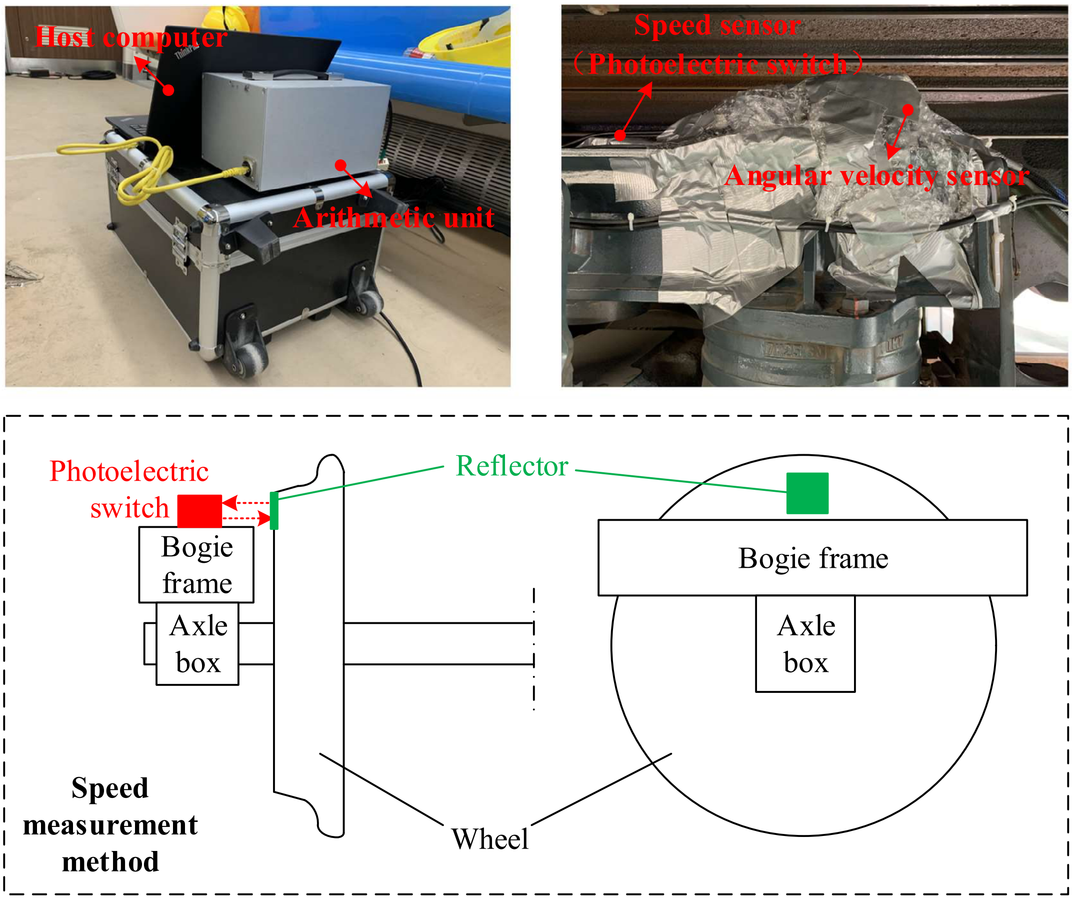
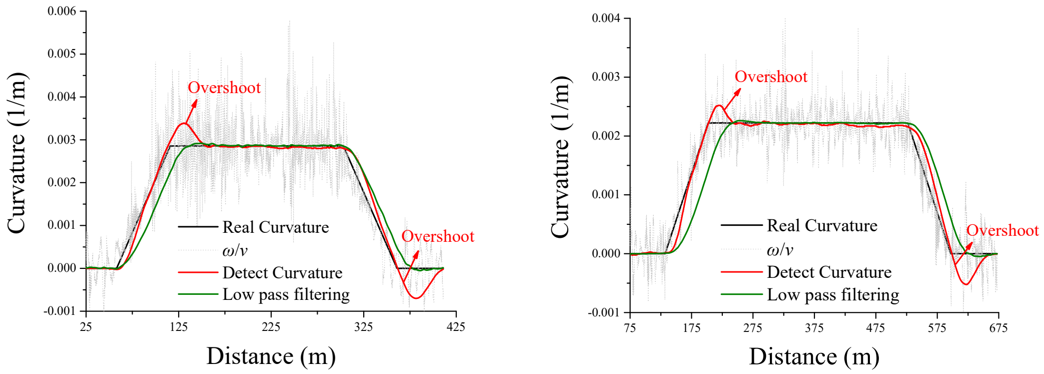


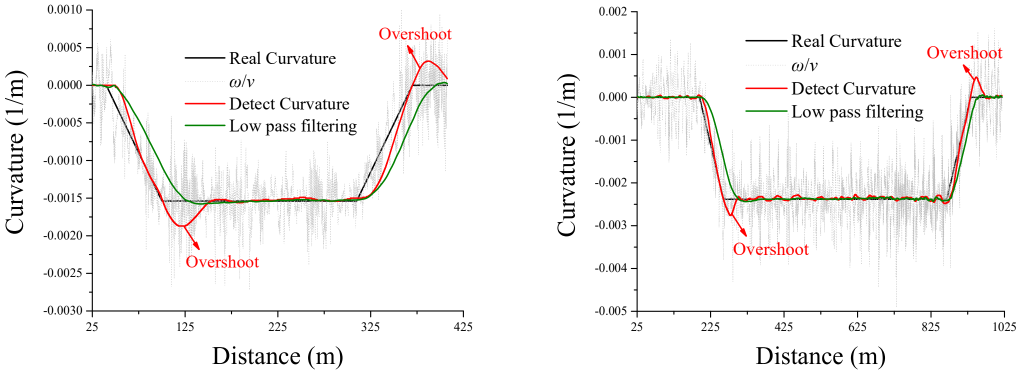
Figure 2: Line test of the system.

Figure 3 shows the real-time detection results from the prototype system during the test. It can be seen that the system can effectively detect the curvature of the railway track. The curvature detection algorithm used in this system can filter the high-frequency noise in the original signal (ω/v) well. Compared with the traditional low-pass filtering method, the spatial hysteresis of the curvature detection is reduced to some extent, especially when the vehicle passes through the transition curve. However, when the bogie enters the circular curve from the transition curve or drives out of the entire curve, the curvature detection results of the proposed system show an evident 'overshoot' phenomenon. This is because when the bogie passes through these junctions (from transition curve to circular curve or from transition curve to straight line), there are two kinds of line trajectory in the data window, which makes it difficult to fit accurately with a unified spline curve. As a result, the curvature detection error is amplified, and will be corrected in further research.



(a) Curve A (Radius 350 m)

(b) Curve B (Radius 450 m)



(c) Curve C (Radius 650 m)

(d) Curve D (Radius 420 m)

Figure 3: Line test results.

4 Conclusions and Contributions

The railway track curvature is an important control parameter for many active control systems of railway vehicles. To achieve more real-time and accurate detection of a railway track curvature, a detection system based on a bogie running trajectory is proposed in this study. The system fits the bogie running trajectory by measuring the running speed and yaw angular velocity of the bogie, and then calculates the railway track curvature.

In addition, a corresponding curvature detection algorithm is proposed. On this basis, an engineering prototype of the curvature detection system is established, and a vehicle running test is conducted to verify the effectiveness of the proposed system. The test results show that the system can effectively detect the railway track curvature. The adopted curvature detection algorithm can filter out high-frequency noise in the original signal well. Compared with traditional low-pass filtering, the real-time performance in curvature detection is improved, especially when the vehicle passes through the transition curve. However, when the bogie enters a circular curve from a transition curve or drives out of the entire curve, there is a certain error in the curvature detection result of the proposed system; this will be corrected in future research.

The layout of the proposed system is simple and easy to implement, making it conducive to further engineering applications.

References

[1] Jin L , Wu W . Train Positioning Technology of Railway And Mass Transit[J]. Urban Mass Transit, 2001(01):30-34.

[2] Cao X. Research on Train Positioning System based on GPS_DR[D]. Southwest Jiaotong University, 2012.

[3] Mei, T.X., Li, H., Goodall, R. Kalman filters applied to actively controlled railway vehicle suspensions[J]. Transactions of the Institute of Measurement and Control.2001, Vol.23 (3), pp.163-181.

[4] Li H. Measuring systems for active steering of railway vehicles[D]. Loughborough: University,2001.

[5] Li H. Non-linear Kalman filter estimation for active steering of profiled rail-wheels[J]. World Congress, 2002,35 (1):91-96.

[6] Wang XM. Research on gyroscope platform based tilting train railway line information inspection system. China Railway Sci. 2004;01:42–46.

[7] Zhou D T. Research on Multi-sensor Information Fusion Based Train Location Method [D]. Beijing Jiaotong University, 2007.

[8] Sim K S , Hur H M , Song H S , et al. Study of the active radial steering of a railway vehicle using the curvature measuring method[J]. Journal of Mechanical Science and Technology, 2014, 28(11):4583-4591.

[9] Tian S, Luo X, Ren L, Xiao C. Active radial system of railway vehicles based on secondary suspension rotation angle sensing [J]. Vehicle System Dynamics, 2020, 1-20.