Research on Track Irregularity Based on K Nearest Neighbor Algorithm

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Abstract. Aiming at the safety and comfort of urban rail transit operation, a machine learning KNN algorithm is proposed to predict the degree of track irregularity. There are many fundamental factors that cause the track to be uneven, mainly reflected in the lateral irregularity of the track and the vertical irregularity. In this paper, the inertial navigation system is used to realize the acquisition of the orbital dynamic acceleration data, and the secondary displacement of the acceleration can obtain the relevant displacement information. The measurement of the gauge distance can be achieved by using a laser displacement sensor. By extracting the different displacement feature data of the same position at the same time and calculating the distance between the feature values, the purpose of predicting the degree of track damage can be achieved.

1. Introduction

Urban rail transit has been vigorously developed due to its large volume and speed. While vigorously developing and popularizing, passengers have put forward higher requirements for the safety of urban rail transit operations and the comfort of riding. The smoothness of the track has a crucial impact on safety and comfort. It is usually detected by a large-scale rail car, and the gauge and level are statically detected. Large-scale track inspection vehicles are comprehensive and accurate, but costly. Although the static detection is cheap and easy to operate, it is inefficient and inaccurate [1]. The above detection methods can only determine the damage point of the track through the multi-number detection data, and the early warning cannot be performed in advance. This subject is equipped with an inertial navigation system on the track inspection vehicle that has been built to collect the horizontal and vertical irregularities of the track. The laser displacement sensor is equipped to measure the gauge [2]. By extracting the eigenvalues from the collected data, a reasonable prediction of the degree of damage to the unknown point can be achieved. Through the K-nearest neighbor algorithm, the track damage point can be early warning, which improves the reliability of the track running environment.

2. Theoretical research

2.1. Inertial Navigation System Overview

The inertial navigation system (abbreviation: inertial navigation system) is mainly composed of two parts: gyroscope and accelerometer. The schematic diagram of the inertial navigation system is shown in Figure 1. The dual inertial navigation system is fixed on the dedicated inertial navigation platform
of the track detection car, and the gyroscope outputs angular velocity information. The angular velocity signal output by the gyroscope is used to perform the attitude matrix of the carrier. Live Update. The accelerometer outputs acceleration information. The acceleration signal outputted by the accelerometer is transformed into the geographic coordinate system through the attitude matrix [3]; the displacement information of the carrier in the geographic coordinate system can be obtained by performing two integral operations on the acceleration signal.

Figure 1. Schematic diagram of inertial navigation system.

When the track detection car is traveling on the track, the track irregularity information will be transmitted to the inertial navigation system through the two wheels on the front side of the track inspection vehicle. The schematic diagram of the track irregularity detection is shown in Figure 2. The curve x, the curve y, and the curve z are projections of the track line on the longitudinal, horizontal and vertical planes, respectively. By repeatedly measuring the same section of the road and repeatedly comparing the measured results, the irregularity information along the track direction, the gauge distance and the vertical direction of the track can be reflected.

Figure 2. Schematic diagram of track irregularity detection.

2.2. Laser Displacement Sensor Overview

The laser displacement sensor uses a contactless triangulation method. When the laser diode emits laser light onto the surface of the object to be measured, the laser will reflect back to the CCD linear sensing element with a certain reflection angle [4]. At this point the integrated circuit of the sensor processes the optical displacement data and outputs the digital quantity in the form of an analog signal. The measurement principle is shown in Figure 3. The laser displacement sensors are respectively mounted on both ends of the track inspection vehicle inspection beam, and are symmetric about the center line, and the installation angle is a. The distance between the two sensor installation centers is C, and the lengths of the two dotted lines are respectively and, and are equidistant, just calculate, which is calculated by the following formula:

$$C = \sqrt{2 \cdot \text{and}^2 - \text{and}^2}$$
The gauge \( d \) can be calculated by the trigonometric function calculation rule. \( d \) can be calculated by the following formula:

\[
d = C + 2l_i \cos(a + \arctan \frac{x}{y})
\]

(2)

Figure 3. Schematic diagram of gauge measurement.

2.3. Overview of algorithm theory

The K-nearest neighbor algorithm performs prediction by using the method of measuring the distance between feature values of different displacement information [5]. In the actual track irregularity data acquisition, the wheel unevenness and the transmission system will have a certain impact on the detection data, resulting in the occurrence of abnormal values. The advantages of using the K-nearest neighbor algorithm are high precision and insensitivity to outliers, and no data input assumptions. The lateral unevenness of the left and right rails at the same point is specified. The vertical and horizontal irregularities of the left and right rails and the gauge are normalized to \( A \), \( B \) and \( C \) respectively, and the values of the respective position points are set as coordinates, and \( i=1, 2, 3... \). According to the Euclidean distance calculation formula, the distance between two points can be obtained:

\[
d = \sqrt{(A_i - A_{i+1})^2 + (B_i - B_{i+1})^2 + (C_i - C_{i+1})^2}
\]

(3)

After calculating the distance between all the points, sort them in ascending order. Determine the main classification of the top K distance minimum elements. The degree of track irregularity is divided into three categories, which are normal, slight and severe.

3. Data analysis results

3.1. Overall analysis of data

In the actual measurement, a length of the track is selected for multiple measurements, and the same point of multiple measurements is averaged. And the orbital points are tagged, that is, normal, slight, and severely positioned 1, 2, and 3 respectively. Part of the data is organized as follows:

Table 1. Track irregularity data.

| Left and right rail lateral difference/mm | Left and right rail vertical difference/mm | gauge/mm | degree |
|------------------------------------------|------------------------------------------|----------|--------|
| 0.071                                    | -0.026                                   | 0.274    | 2      |
| 0.023                                    | 0.014                                    | -0.067   | 1      |
| ...                                      | ...                                      | ...      | ...    |
| 0.034                                    | 0.023                                   | -0.052   | 3      |
| -0.041                                   | 0.022                                   | -0.076   | 1      |
3.2. Normalization and visualization of output information
Since the resulting track irregularities have different values, larger data information will have a large impact on the calculation results. The lateral irregularity of the track, the vertical irregularity, and the weight of the track are not the same as the influence of the track irregularity. Therefore, it is necessary to normalize the measured values to generate a scatter heat map. The following table:

Figure 4. Track gauge and track data scatter plot.

It can be seen from Fig. 4 that there are fewer data points of the track damage degree in this section, and the gauge value has the greatest influence on the degree of track damage. It can be considered that in the gauge value and the rail value, the gauge value has a larger weight.

Figure 5. Track vertical and orbital data scatter plot.

It can be seen from Fig. 5 that the serious damage points of the track are concentrated in the lower right half. Explain that the orbital data value track damage has the greatest impact.
Figure 6. Trajectory of horizontal and vertical data of the track.

It can be seen from Fig. 6 that the distribution of track damage points is relatively average, indicating that the horizontal and vertical values of the track irregularity have the same weight for the damage degree.

Through the above data analysis and algorithm training, when a new set of data is obtained, the data damage can be quickly determined by simply substituting the data into the algorithm. The maintenance time of the staff is greatly saved, and the maintenance and repair of the serious damage points of the track are facilitated.

4. Conclusion
(1) The system adopts the inertial navigation system to collect the horizontal, vertical and gauge data of the track, which improves the detection efficiency;
(2) The laser displacement sensor can work in conjunction with the inertial navigation system to improve the accuracy of the detection;
(3) The KNN algorithm can be used to visualize the detection data. The scatter thermal map can be used to evaluate the three factors affecting the track irregularity, and the weight of the gauge value is the largest.
(4) The unlabeled data points of the track can be predicted and classified, and the algorithm correct rate is greater than 98.95%.

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