An improved non-contact geometric parameter detection method for high-speed railway catenary

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Abstract. In order to improve the accuracy and anti-interference of non-contact geometric parameter detection of high-speed railway catenary, the geometric detection algorithm is modified, and an improved non-contact geometric parameter detection method of catenary is proposed. The image edge enhancement and noise filtering are realized by using the enhancement method based on curve transformation, and the image edge is accurately extracted by using SUSAN algorithm. At the same time, considering the influence of vehicle vibration, the vehicle vibration compensation correction is added to improve the accuracy of geometric parameter detection. The results shows that compared with the traditional geometric detection method, the anti-interference and accuracy of the improved algorithm have been improved, which has good practical application value.

1. Introduction

With the rapid development of Chinese high-speed railway, the railway transportation capacity is significantly improved. In the new era, new requirements are put forward to the safe and stable railway transportation. As an important power supply equipment of high-speed railway traction power supply system, the operation status of catenary directly affects the safety and reliability of railway operation [1-2]. As an important index to reflect the operation state of catenary system, the geometric parameters of catenary can better characterize the current collection quality of pantograph catenary system [3]. It should be ensured that it is in a reasonable interval for a long time, which is very important for the safe operation of high-speed railway.

In recent years, scholars at home and abroad have done a lot of research on the detection of geometric parameters of high-speed railway catenary [4-8]. These methods have obtained good application cases, but there are still some shortcomings. First of all, because the contact line is mostly located in the field, the geographical and natural environment is more complex, it is easy to make the collected image have complex background. Therefore, improving the anti-interference performance of the detection algorithm is worth research. Secondly, during the operation, the vibration of the vehicle in different directions will affect the accuracy of the detection results and the clarity of the collected images to a certain extent. It will affect the accuracy of the detection results and the clarity of the collected image to a certain extent that the vibration of the vehicle in different directions. In order to solve the above problems, the geometric detection algorithm is modified in many aspects, and an improved non-contact geometric parameter detection method is proposed.
2. Algorithm design

2.1. Image enhancement
In the process of catenary geometric parameters detection, affected by the actual scene factors such as lack of light, locomotive vibration and weather, the image collected by the detection vehicle contains large noise interference and low image contrast. In order to improve the feature contrast of the image to be measured, it is necessary to use the image enhancement method to process it. In this study, the FDCT-WARP method was used to process the image. Firstly, curvelet transform is performed on the detected image to obtain the curvelet coefficients of each pixel. Secondly, according to the different frequencies, the high and low frequency subbands of the image is obtained, and the enhancement processing is carried out according to their respective characteristics.

2.2. Edge detection
After the enhancement of the image to be measured, the edge of the object in the image needs to be extracted. The traditional edge detection algorithm has the situation of edge direction information loss, while Susan edge detection algorithm does not need to solve its directional derivative by comparing the gray similarity, which reduces the sensitivity to noise and has a good suppression effect on noise.

2.3. Vehicle vibration compensation device
In terms of dynamics, the high-speed railway can be regarded as a spring suspension device, which will vibrate with multiple degrees of freedom in actual operation. In the non-contact geometry detection of catenary, the non-contact geometry parameter detection device is installed on the roof, and the car body coordinate system is taken as the basic coordinate system. When the train runs at different speeds, the vibration amplitude of the car body is also different, which will cause the different detection data of the same pillar. Therefore, it is necessary to install a vehicle vibration compensation device on the bottom of the detection vehicle and map the detection parameters to the rail coordinate system to improve the detection accuracy.

The vehicle vibration compensation device consists of laser camera sensor, detection inertial package, acceleration sensor and other components. Because of rigid connection between the detection device and the vehicle body, its coordinate system can be regarded as the vehicle body coordinate system. Considering that the vehicle body vibration detection plane coincides with the geometric parameter detection plane, the transformation of its spatial coordinate system degenerates into two-dimensional, and the relationship between the vehicle body coordinate system and the rail coordinate system. The system is shown in Figure 1. By detecting the rail's yaw, roll and heave, the detection results are recorded as \( x_0 \), \( y_0 \) and \( \theta \) respectively. Set the space position of the contact line as point \( S \), which track coordinate system is \( (x_c, y_c) \) and car body coordinate system is \( (x_g, y_g) \). Complete the transformation of car body rail coordinate system according to formula (1).

\[
\begin{align*}
x_g &= (x_c \cos \theta - y_c \sin \theta) + x_0 \\
y_g &= (x_c \cos \theta - y_c \sin \theta) + y_0
\end{align*}
\] (1)
3. Model construction

3.1. Modified model
There are two ways to hang the contact wire which are equal height and non equal height. Because of the vibration in rolling and sinking direction of the car body, the accuracy of the measured line height curve is not very high. In order to solve the above problems, combining with the mathematical model of non equal height suspension curve shown in equation (2), a MS particle filter height correction model is established.

\[ y = D - \frac{h}{l} x - \frac{4F_x (l-x)}{l^2} \]  

(2)

3.2. State model
In equation (2), \( D \) and \( y \) are the basic height and conductor height of contact line suspension point respectively, \( x \) is the horizontal position of train operation, \( xoy \) coordinate system coincides with \( X_W \) and \( Z_W \) planes of world coordinate system, and origin \( o \) is the projection point of contact line suspension point at the starting point of rail plane.

The state model is shown in equation (3):

\[ X_k = AX_{k-1} + BU_k \]  

(3)

In order to accurately evaluate the state model, the mean shift (MS) and particle filter algorithm are combined to modify the state model:
- Initialization. Randomly collect N particles in the target area.
- Importance sampling. The particles are brought into equation (3) and transferred to obtain a new particle set.
- Clustering & mean shift.
- Update particle set and weight calculation.
- State estimation.

4. Effect analysis

4.1. Contrast of enhancement effect
In order to test the effectiveness of the proposed algorithm, for the original image collected by the detection system which is shown in Figure 2, the commonly used wavelet fractional order enhancement and the proposed method are used to enhance it respectively. The effect pictures are shown in Figure 3 and Figure 4 respectively. The contrast improvement index is selected to measure the enhancement effect and the results are shown in Table 1.
Figure 2. Original image

Figure 3. Effect picture of wavelet fractional order enhancement

Figure 4. This algorithm enhances the effect of the picture

Table 1. Improvement index of each method

|                      | Wavelet fractional order | This improved algorithm |
|----------------------|--------------------------|-------------------------|
| Comparative improvement index | 0.8721                  | 1.0748                  |

As can be seen from table 1, compared with the traditional wavelet fractional order enhancement algorithm, the contrast improvement index of this algorithm is 1.0748, which has a significant improvement in contrast.

4.2. Comparison of detection results

Similarly, in order to test the edge detection effect of this paper, a frame image is selected as the test image, and the classical Canny operator and the edge detection algorithm are used to process it respectively, and the detection results in Fig. 5 and Fig. 6 are obtained. At the same time, the quality factor is used to evaluate it, and the results are shown in Table 2.
According to Table 2, the edge detection quality factor of this algorithm is 0.0547 higher than that of the traditional Canny operator. The higher quality factor and the more accurate the edge extraction indicate that the edge detection effect of this algorithm is better.

5. Conclusion
In order to improve the anti-interference and accuracy of high-speed railway catenary contact geometry parameter detection, an improved catenary non-contact geometry parameter detection method is proposed in this paper. Specifically, combined with the current image processing technology, the enhancement method based on curve transformation and Susan edge detection algorithm are used to preprocess the detected image, considering the influence of car body vibration, through the car body. Finally, the pull-out value and guiding height value of the catenary are obtained. The results show that the contrast of the image is greatly improved, the anti-interference of the detection is improved, and the detection accuracy is good. The next step of the research can be considered through the actual high-speed railway line for many tests, in the line section of the catenary geometric parameters repeatability test and manual detection test, to calculate the pull-out value and guide height value of the detection error, in order to verify the accuracy of the improved algorithm.

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