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Gauge point positioning method based on computer vision

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Abstract. A new effective gauge point positioning is proposed in the paper, which is very crucial from the viewpoint of the safety and reliability of railway transportation. Firstly, framework of the computer vision based track geometric deformation detection system is proposed. In particular, the visual inspection system is made up of four modules, that is, 1) Sensing system, 2) Light source system, 3) Image acquisition system, and 4) Image processing system. Secondly, to tackle the gauge point positioning problem, two conversions should be done in advance, including 1) world coordinate system to camera coordinate system, and 2) camera coordinate system to image coordinate system. Thirdly, in order to accurately position gauge points, a weighted least square based curve fitting algorithm is exploited to choose an appropriate type of curve to fit the observed data. Finally, from the simulation results, it can be observed that the proposed method is able to position gauge points using computer vision.

Key words. Gauge point positioning, computer vision, curve fitting, surface defect repair.

1. Introduction

As the backbone of modern transportation system, railway plays an important role in promoting the development of social economy and improving the utilization of social resources [1], [2]. In recent years, with the rapid development of railway construction, the passenger and freight volume increase rapidly [3]. Particularly, after China comprehensively promoting the construction of high-speed railway passenger and freight traffic, traffic density significantly develops than ever. Furthermore, together with the high quality demand of the railway line, the requirements of track parameter standardization improve as well [4], [5].

Track irregularity mainly contains track longitudinal level, along-track, track level, track twist irregularity, gauge, and so on. In all track parameters, gauge refers to one of the basic rail parameter and it has always been one of the necessary ones which should be measured [6], [7]. However, if the gauge cannot be detected precisely, it will lead to weighty rail hidden trouble. Moreover, when gauge is out of range, not only the stability of vehicle's moving and the comfort of passengers will

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be affected, but also the relationships between wheel and rail may cause security risks of climbing out of track [8]. In order to detect gauge points precisely, high efficiently, and non-contact, there are many difficult problem we should solve [9], [10]. Particularly, to satisfy to the need of speediness and over loading and guarantee the train running safely, it is of great importance to propose an effective gauge point positioning method [11].

The rest of the paper is organized as follows. We illustrate the computer vision based track geometric deformation detection system in section 2. In Section 3, we explain the proposed gauge point positioning method. To test the effectiveness of the proposed method, simulations are conducted to prove the effectiveness of our method in section 4. Finally, section 5 concludes this paper in detail.

2. Computer vision based track geometric deformation detection system

Computer vision products can obtain object information through the image acquisition system, and then convert them into digital signals, which can be widely used in image processing system, image processing system, and so on. After a series of operations and processing steps, the target characteristic information of the position and contour can be obtained. Finally, equipment actions are controlled according to test results. Thus, the visual inspection system is made up by the following parts:

1. Sensing system—relies on various types of sensors to collect information, and then build detection devices.
2. Light source system—provides the linear light source through the light source controller for the detection system.
3. Image acquisition system—contains video camera, image acquisition card, and so on.
4. Image processing system—contains a variety of image processing algorithms, and image processing software.

Early track geometric deformation detection mostly used the contact measurement mode. However, this kind of method mainly depends on the rolling wheel rail contact to obtain valid data. Therefore, measurement accuracy and reliability of are not very ideal. At present, with the rapid development of high-speed railway technology, gauge detection becomes more and more important to track the geometric deformation. In track geometric deformation detection, the geometrical parameters selection is a crucial problem. Particularly, gauge point positioning should be solved in advance. Framework of the computer vision based track geometric deformation detection system is shown in Fig. 1.

The detection system based on machine vision has been widely used in track geometric deformation detection due to its powerful function of perception, analysis and processing of data. Therefore, considering various factors, in this paper, we

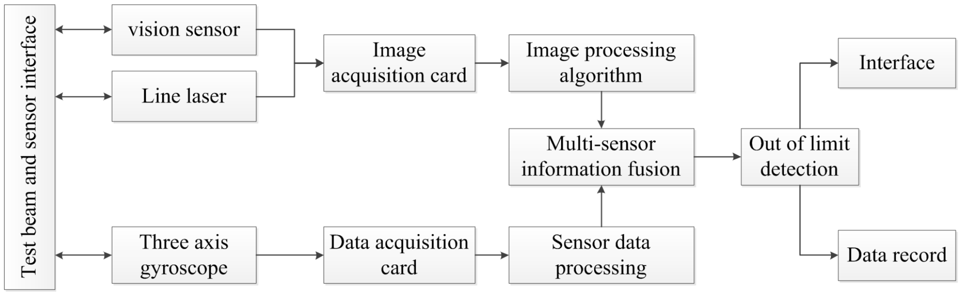

Fig. 1. Framework of the computer vision based track geometric deformation detection system

will use the detection system based on machine vision to realize the track geometry deformation gauge positioning algorithm. Diagram of gauge and gauge point is shown in Fig. 2.

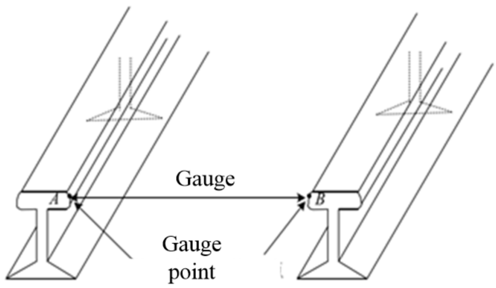

Fig. 2. Diagram of gauge and gauge point

As is shown in Fig. 2, the gauge point is located at the top of the vertical downward 16 mm position, and points A, B denote two gauge points which are corresponding to the left and right rails, respectively. According to the railway gauge corresponding with the international standard in China, the distance between two gauge points is 1435 mm.

3. The proposed gauge point positioning method

For the gauge point positioning problem, we should solve the coordinate system conversion issue. World coordinate system can be converted to the camera coordinate system by the equation

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0^{\mathrm{T}} & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{1}$$

where R is the rotation matrix, which is computed as follows

$$R = \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) & 0 \\ \sin(\varphi) & \cos(\varphi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \sin(\theta) \end{bmatrix} \cdot$$

$$\cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix}, \tag{2}$$

where symbols φ, θ, ϕ denote the angle between the three axes of the camera and the corresponding world coordinate system, and $T\{t_x, t_y, t_z\}$ refers to the displacement between two different coordinate systems.

Next, we will discuss how to convert the camera coordinate system to the image coordinate system. Suppose that a point of camera coordinate system is represented as $P(x, y, z)$, and the corresponding image coordinate is represented as $p(X, Y)$. The point $P(x, y, z)$ can be converted to $p(X, Y)$ as follows

$$\begin{cases} X = fx/z \\ Y = fy/z \end{cases}. \tag{3}$$

Then, the following equation should be satisfied.

$$z \begin{bmatrix} X \\ T \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & f & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}. \tag{4}$$

To effectively position gauge points, we utilize curve fitting algorithm to select the appropriate type of curve to fit the observed data. For x, y, the discrete array is represented as(x_i, y_i), and curve fitting process aims to find a function $y = f(x, c)$. Particularly, we choose the weighted least square method [12–14] to solve the curve fitting problem.

4. Experiment simulation

In this section, we test the performance of the method is by simulations. Particularly, parameters of Laser transmitter, CCD camera, and Image acquisition card, and the detailed experimental settings are shown in Table 1.

For the laser light rail profile image with top surface defects, in order to achieve precise positioning of the gauge point, we should repair defects of the top laser light. To solve this problem we utilize the curve fitting technology to repair surface defects at the top of track. Rail profile image is processed by several steps, such as grayscale, binarization, filtering, contour extraction, camera calibration, image correction, and so on. Next, Matlab is used to extract single pixel laser stripe coordinate. Curve fitting results are shown in Figs. 3 and 4.

Table 1. Experimental settings

Item	Index name	Value
laser transmitter	light source color	red
	angle of sector	eight degrees
	shape	planar array
CCD camera	resolving power	752×582
	working temperature	−9°C to 45 °C
	frame rate	80 fps
image acquisition card	interface number	five
	interface type	CoaXPress

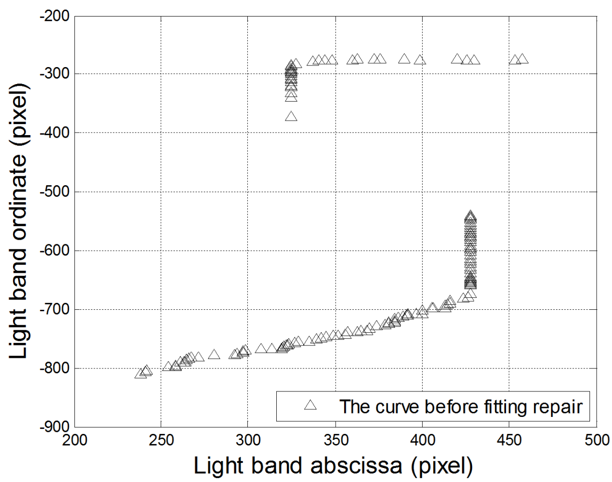

Fig. 3. Diagram of gauge and gauge point

It can be observed from Figs. 3 and 4 that the surface defect at the top of track can be repaired very well, and then the utilization rate of data acquisition can be promoted significantly. Based on the surface defect repair results, accuracy of the gauge point positioning can be enhanced obviously.

5. Conclusion

In this paper, we discuss how to locate gauge points with higher accuracy. The framework of the computer vision based track geometric deformation detection system is proposed at first. To solve the gauge point positioning issue, we explain how to convert world coordinate system to camera coordinate system, and how to convert camera coordinate system to image coordinate system. Based on the above steps, a weighted least square based curve fitting algorithm is exploited locate gauge

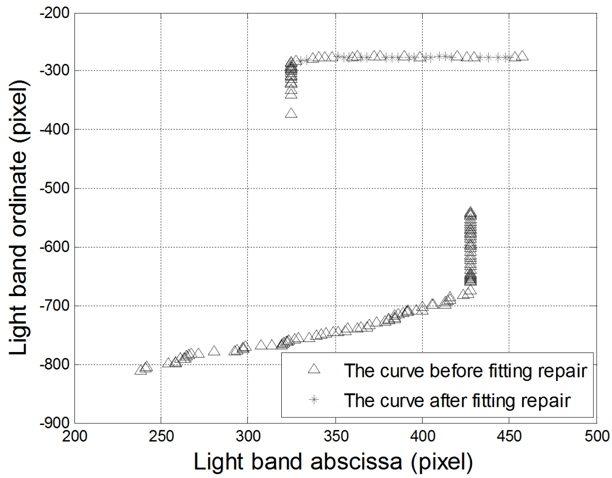

Fig. 4. Repair curve of surface defect at the top of track

points. In the end, experimental results demonstrate the effectiveness of our proposed method.

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