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Geometric Parameters Measurement of Wheel Tread Based on Line Structured Light

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Abstract

In order to develop the geometric parameters measurement technology of wheel tread, it is important to ensure the positioning precision firstly before measurement. In this paper, a new method with no-contact measurement based on line structured light is given to solve this problem. Here the traditional mechanical locating method is used as a rough reference. Then, according to the feature points (particularly, the key points that have not been worn), the precision positioning is adjusted dynamically based on the calculated results of non-contact measurement. With the developed digital image processing techniques, the line structured light on the wheel tread is extracted effectively. Thus the pixels of the extracted line structured light can be transformed to the real geometric dimensions. In this paper, the experiments show that it improves the accuracy of positioning and reduces the factors of measurement errors with the proposed method, and it is possible to implement non-contact measurement of the wheel tread, wheel flange thickness and flange width.

Keywords: non-contact measurement, line structured light, wheelset tread, image segmentation

1. Introduction

With the rapid development of rail traffic, the issues of train safety are becoming prominent more and more. A train wheelset, which is the most important component in each train, bears all the static and dynamic loads from the vehicle. Since it directly contacts with the rail by gradually and inescapably frictions, the wheelset is worn down by the interactions between wheel and rail. It will bring the undermining of critical dimensions. In a long run, the safety and operation quality are seriously affected.[1] In practical applications, it is necessary to measure geometric parameters of train wheelset tread periodically. At present, the wheelset detection method can be roughly classified into the contact and non-contact measurement. The traditional methods still more depend on the special mechanic tools like artificial calipers.[2] Although it is easy to be implemented, there are the problem of high labor intensity, low efficiency and low accuracy. With the development of image processing and camera technology, non-contact measurement gets more and more attention and is widely applied in practical dynamic measurement of various parts.

In this paper, based on line structure light, the experimental model is established and the method with no-contact measurement is developed for the geometric parameters measurement of the train wheel tread. Moreover, the precision of positioning between laser measurement device and wheelset, is studied carefully. The geometric parameters, such as flange height, flange width and wheel diameter etc. are measured using captured images with CCD, processed them with C++ and OpenCV.

Besides the precision of positioning, the accuracy of measurement is also influenced by the extraction precision of line structured light. Hence in the paper, the method of extraction of the feature points and lines is studied too.

2. Experimental principle

Compared with other simple parts measurement, the wheel tread measurement is more complex. This is because multiple dimensions are relative.[2] If there is error in some dimension, the dimensions in other parts are also influenced. In order to explain clearly, here the definition of wheelset's parameters and experimental principle are illustrated firstly.

2.1. *Definition of wheelset's parameters*

Wheel tread is the contacting surface between wheelset and railway. For the measurement of wheel tread, the following wheelset's parameters are necessary to obtained.[3] As shown in Fig. 1, the left side is the medial surface of wheel rim (ostensibly, it is a line in the image).

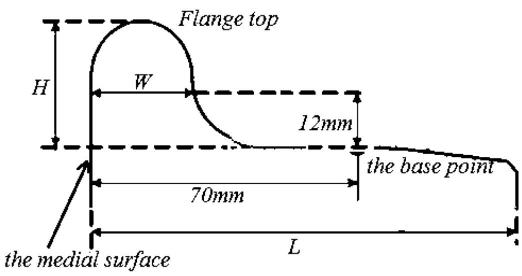

Fig. 1. The critical parameters of wheel tread

Based on this surface, in the horizontal direction, the distance being 70*mm* to the medial surface of wheel rim, there is a point on the tread, and it is customarily called the base point. According to the base point, flange base line is defined with the horizontal line 12*mm* above the base point. Flange thickness W is the horizontal thickness along flange base line intersected with rim. Flange height H is the length between flange base line and flange top. Rim width L is the distance between the medial surface and the lateral surface of wheelset. Moreover, as shown in Fig. 2, the rolling circle is also defined with the circle passing the base point on the tread. Wheel diameter D is the average diameter of rolling circle.

From the definitions, the base point is the key point for the whole measurement. That is, the accurate positioning is the key step to obtain effective measurement results. In this paper, the key parameters H, W and D, are mainly studied to be measured with non-contact measurement method.

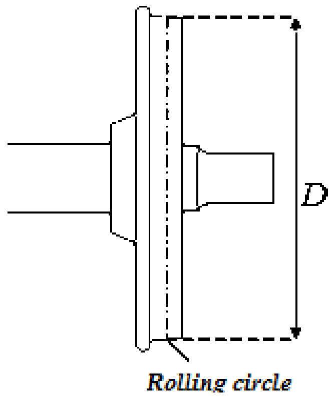

Fig. 2. The rolling circle illustration of one wheel

2.2. *Experimental system and principle*

The structure of the measurement is shown in Fig. 3. There are three cameras and line structure light in the system. The camera A and the camera C, in both ends of the system, are used to accurate positioning. Camera B is used to grab images for tread measurement. Each Laser line and camera are installed with fixed dimensions and calibrated beforehand.

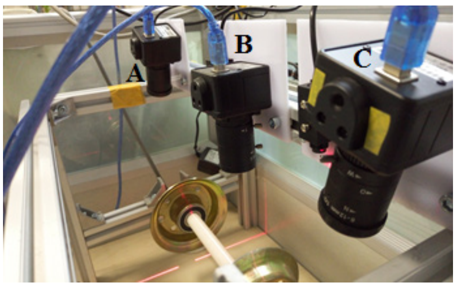

Fig. 3. The illustration of experimental system structure

The non-contact measurement method is shown in Fig.4. Here, we assume the camera view angle in width direction is λx, λy is in the height direction, the length between the lens center and laser center is L, the coordinates of the laser center in image plane is $P(x,y)$, θ is the angle between the lens center line and the vertical line from camera center to the laser center line, the image dimension is $2w\times2h$. Thus we can get the angle β, which is the angle between the line from camera center to $P(x,y)$ and the optical axis of the camera.

$$\beta = \arctan\left(\frac{\tan(\lambda_y)\times(y-h)}{h}\right) \qquad (1)$$

Then the distance between the camera and the object point will be:

$$HY = L\times\tan(\theta-\beta) \qquad (2)$$

After the distance is calculated, the other dimensions can be calculated easily with the pin hole theory.

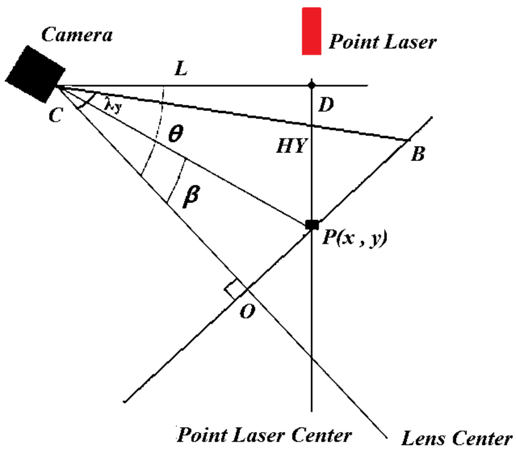

Fig.4. Triangulation measurement principle

The traditional method based on mechanism is difficult to realize accurate positioning directly. The geometric parameters of wheel tread are measured with laser line projected on the surface of work piece. From the previous analysis, it is important to determine the key point accurately, and the laser line must be on the correct region to get accurate measurement. The accurate positioning is required by all of those factors.

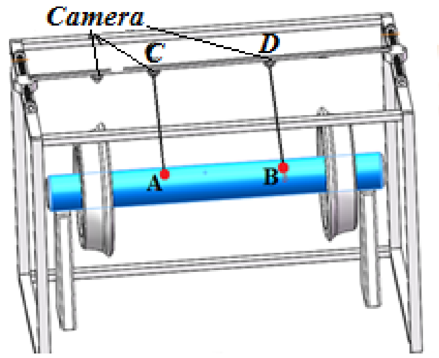

Fig.5. Illustration of accurate positioning

The accurate positioning method is shown in Fig.5. With the non-contact method, the distance between the top point of axis and the optical center of camera can be obtained when the light is perpendicular to the axis. If the distance AC is equal to BD, and line AC and BD in the same plane, it means two axes are parallel. At the same time, the condition of the minimum of AC or BD is considered too. By this way, the accurate positioning can be controlled.

Using the same non-contact measurement method, the tread geometric dimension can be measured. Then the key point and base line can be determined. Parameter H, W can be calculated. As shown in Fig.5, the distance h_1, between the optical center of camera and the center of wheel axis, is fixed by the hardware. When the base point distance h_2 is measured, the wheel diameter D, as shown in Fig.2, can be calculated by Eq. (3):

$$D = 2(h_1 - h_2) \qquad (3)$$

3. Image processing of the laser line

Using the developed system, the image with laser line on tread is captured. As shown in Fig.6, in that image there are lots of non-target objects besides the red laser line. Then the image segmentation is used to extract the laser line. In this paper, the separation algorithm is based on the variation of intensity between the target pixels and the background pixels by a comparison of each pixel intensity value with respect to a threshold. At the same time, a bilateral filtering is used to smooth the extracted target edges. The bilateral filtering formula is given as Eq. (4) and Eq. (5).

$$\tilde{f}(x) = \eta^{-1} \int w(x,y)\phi(f(x), f(y)) f(y) dy \quad (4)$$

where

$$\eta = \int w(x,y)\phi\left(f(x), f(y)\right) dy \quad (5)$$

In the formula, $f(x)$ and $f(y)$ is the intensity of each pixel, $w(x,y)$ measures the geometric proximity between the pixel of target x and neighbor pixel y. Its role is to localize the averaging to a neighborhood of pixel x. Edge-preserving characteristic of bilateral filtering is mainly achieved through combination of spatial function and range of kernel function in the convolution process. The typical kernel function is Gauss distribution function.[4]

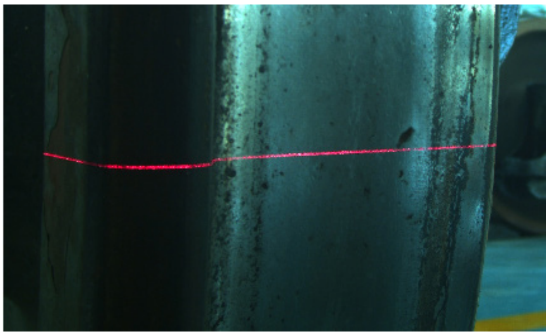

Fig.6. The captured wheel tread image with laser line

With the above processing, the target extract result is shown in the Fig.7. The target character can be controlled effectively.

Fig.7. Laser line extraction with bilateral filtering

After target laser line is extracted, the real three dimension coordinates are calculated for each pixel in the laser line. Then with the definition of wheelset's parameters, the coordinates of point *a, b, c* and *d* can be obtained.[5]

Thus, as shown in Fig.8, flange thickness W and flange height H can be calculated by Eq. (6) and Eq. (7)

$$W = x_b - x_d \quad (6)$$

$$H = y_a - y_c \quad (7)$$

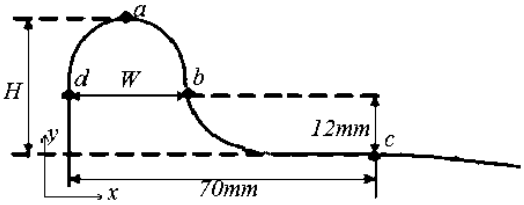

Fig.8. The calculation process of wheel tread parameters

4. Conclusions

The wheelset is important parts for a train. Because its geometric parameters are related, its measure process is more complex than other parts' measurement. In this paper, the non-contact measurement method with laser line is given. In order to improve its measurement accuracy, two steps positioning method is developed:
1) Rough positioning, positioning with tradition method; 2) Accuracy positioning, paralleling the measurement frame to the wheel axis. With this method, the laser line can be projected on the correct section of wheel tread. Moreover, the bilateral filter algorithm is developed to extract the target edge accurately. These algorithms are verified with a wheelset measurement experiment.

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