A surface defect detection system for railway track based on machine vision

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Abstract. In order to detect rail surface defects more quickly and effectively, a rail surface defect detection system based on machine vision was constructed. A perfect lighting system is built to obtain high quality image information. At the same time, the linear CCD camera is used to collect the rail information, which is uploaded by FPGA, and the image information is processed and analyzed by MATLAB software in the upper computer. Through the methods of image denoising and image enhancement, the image quality is improved, and the image information suitable for operation is obtained; then, the rail positioning is completed by threshold segmentation, gray compensation and image binarization to simplify the image operation; finally, the final positioning of defects is realized through edge detection and feature extraction. By building a test platform on the rail maintenance vehicle, the rail surface defect information collected by the rail maintenance vehicle is analyzed and processed.

1. Introduction
Railway is an important transportation facility in China. With the rapid development of China's economy, the frequency and intensity of track use are increasing. Rail will appear bolt loose, track line deformation, surface wear and other conditions, which will affect the train to complete high-density operation and heavy transportation tasks, so the track department must carry out inspection and maintenance. At present, the mature methods of track detection include manual detection and rail inspection vehicle detection, but the detection accuracy is low and the detection items are limited. With the development of the machine vision detection technology for rail defects, it has been widely used in the rail defect detection industry.

2. Status of track defect detection
In the process of high-frequency use of track line, repeated vibration of load will change the railway line, resulting in bolt loosening, track deformation, surface defects, etc[1]. Therefore, it is necessary to timely carry out maintenance to eliminate hidden dangers. The existing detection methods mainly include manual detection, rail inspection vehicle detection, machine vision based detection and so on.

2.1. Manual detection
Manual detection is the traditional detection method of track detection, which mainly relies on the staff to walk along the railway line with visual inspection and inspection tools. This detection method can effectively detect the surface defects and bolt looseness of the track. However, this method has
some problems such as low sampling rate, low accuracy, low efficiency, high labor intensity, great influence by artificial experience and subjective [2].

2.2. Inspection of track inspection vehicle

Combined with modern sensor technology and computer data processing, the track inspection vehicle realizes the detection of geometric States and irregularities such as the front and rear height of the left and right rails, the track direction and level of the left and right rails, the irregularity of the left and right rails, the superelevation of the outer track of the curve, the radius of the curve, the gauge, the distortion of the line, the horizontal and vertical vibration acceleration of the car body, and the vertical vibration acceleration of the left and right axle boxes.

3. Formatting the text

The system takes computer as the core, applies image processing technology combined with visual sensor to effectively identify defects and realize defect location. The system is mainly composed of image acquisition system, high-speed image acquisition system and image processing system. The schematic diagram is shown in Figure 1.

![Figure 1 System schematic diagram](image1)

The image acquisition system is mainly composed of camera, lamp, photoelectric driver, encoder and GPS. There are mainly two kinds of cameras: rail surface defect acquisition camera and bolt looseness detection acquisition camera, which can obtain the information of the detected object; when the detection system moves relative to the track, the LED lamp and camera are controlled by the optical driver to realize lighting and shooting, and the encoder and GPS can realize the positioning of defects. The high-speed image processing system is used to buffer the photos and save the processed photos. The computer is the core module to realize image processing and position information processing. The structural block diagram of the detection system is shown in Figure 2.

![Figure 2 Machine vision inspection system block diagram](image2)

In order to improve the accuracy of the detection system, we use the gray vision system. After obtaining the image of the object, the system will convert it into a gray image, and then do further processing. White binar...
3.1. Image acquisition system

In the detection system of machine vision, the quality of image directly determines the result and speed of image processing, so it puts forward higher requirements for image acquisition system [3]. The system mainly includes light source, image sensor, baffle and clamping device.

In order to obtain the image with the highest contrast as possible. We use LED linear array light source and linear CCD camera when shooting the orbital plane [4].

The rail with a specification of 50 kg / M is taken as the detection object. The camera lens is 300 mm away from the track surface, and the illumination light is 42 degrees from the vertical line. According to the geometric relationship, the illumination on the rail surface needs about 4600 lux.

3.2. Image analysis and processing system

Image analysis and processing system is the key part of the system. The analysis and processing mainly includes the preprocessing and feature recognition of the acquired image.

3.2.1. Image pre-processing

Image denoising: Due to some interference in the image acquisition process, some image noise will appear on the image [5]. Therefore, image denoising is a necessary part of image preprocessing. The obtained image is represented by the amplitude function $f(x, y)$ of the pixel, and $F$ is the intensity of the coordinate $(x, y)$ pixel. Digital image can be regarded as a finite set of elements obtained by sampling and quantizing continuous analog images. Each element has a specific coordinate and intensity. Then the sampled and quantized digital image can be represented by a $m \times n$ matrix. The representation method is as follows:

$$f(x, y) = \begin{bmatrix}
(0,0) & (0,1) & \cdots & (0,N-1) \\
(1,0) & (1,1) & \cdots & (1,N-1) \\
\vdots & \ddots & \vdots \\
(M-1,0) & \cdots & (M-1,N-1)
\end{bmatrix}$$

The denoising process of the acquired image is mainly to eliminate Gaussian white noise and salt and pepper noise. We use median filter to reduce noise. The output of two-dimensional median filter is as follows:

$$g(x, y) = Med[f(x + i - \frac{m+1}{2}), y + j - \frac{n+1}{2}, (i, j) \in w] \quad (1)$$

The window size $w$ is $m \times n$, and $g(x, y)$ is the value of the central pixel of the filter template after median filtering. After median filtering, objects smaller than the size of median filtering window will be filtered out, while the objects with larger area can be ignored as filtered images.

In order to verify the filtering effect, we select an image, add salt and pepper noise, and then carry out filtering processing. The following is the image before and after filtering.

![Figure 3 Original](image3.png)  ![Figure 4 Add salt and pepper noise (grayscale)](image4.png)  ![Figure 5 Filtered (grayscale)](image5.png)
3.2.2 Rail positioning

**Image enhancement:** The track is easy to be oxidized and rusted during long-term use, which makes the color of the rail close to the road surface at the bottom of the rail, which is not conducive to the recognition of the rail by the machine. Therefore, it is necessary to carry out image enhancement processing.

\[ f_1 = \text{imadjust}(f, [x_1, x_2], [y_1, y_2]); \ldots \ldots x_1 < x_2; y_1 < y_2 \]  

(2)

Where \( f \) is the original image, \( f_1 \) is the transformed image, and \( \text{imadjust} \) is the processing function of gray level transformation. The specific transformation formula is as follows:

\[
x_f = \begin{cases} 
225x_i & \text{if } x < x_1 \\
(y_2 - y_1)(x - x_1)255 + 255y_2 & \text{if } x_1 < x < x_2 \\
225x_2 & \text{if } x > x_2 
\end{cases}
\]

(3)

\( x \) represents the gray value of any point in the picture, \( x_f \) is the gray value of any point in the transformed image. After parameter debugging, we finally determined when \( x_1 = 0.35, x_2 = 0.6, y_1 = 0.1, y_2 = 1 \), the image processing effect is the best. In order to facilitate machine processing, we transform the enhanced color image into a grayscale image.

**Image segmentation:** As can be seen from Figure 10, the rail surface area can now be well distinguished from the non-rail surface area. Next, we extract the rail surface area and remove the non-rail surface area.

Therefore, we do threshold segmentation on the image. We select the segmentation threshold by analyzing the gray histogram [6].

We can find that when the threshold value is 68, it can play a good segmentation effect. The following figure shows the image of several railway track segmentation under the threshold. After the threshold segmentation, the image becomes black and white binary image.

![Figure 6 Rough segmentation of rail images](a) ![Figure 6 Rough segmentation of rail images](b) ![Figure 6 Rough segmentation of rail images](c)

**Rail surface segmentation:** In order to extract the complete track surface, we need to make local gray compensation for the image. Obtain the gray histogram of binary image in the column direction, as shown in the following figure:
We find that the gray value of the rail surface is high and the change of the adjacent area is small, while at the junction of the rail surface and the non-rail surface, the gray level changes sharply, as shown in Figure B and D. Therefore, it can be judged that the rail surface area is between B and D. Suppose the size of Figure 7 is 364 \times 243, calculate the following function in turn

\[ f_j(j) = \sum_{i=0}^{364} f_j(i, j) \]  \hspace{1cm} (4)

And then we find the mutation in \( f_1, f_2, f_3, \ldots \) Points B, C and D in the figure. Find \( j_{\min} \) and \( j_{\max} \). Then calculate \( T = \text{Max}\{f_j(j) | j < j_{\min}, j > j_{\max}\} \). Then do the following calculation:

\[ g_j(i, j) = \begin{cases} 
0, & j < j_{\min} \\
255, & j_{\min} \leq j \leq j_{\max} \\
0, & j > j_{\max}
\end{cases} \]  \hspace{1cm} (5)

**Track surface extraction:** In this paper, a "darkening" algorithm is used to extract the rail surface. The gray image of the rail and the corrected black and white binary image of the rail are calculated as follows. The calculation results are shown in Figure 11 below.

\[ H(x, y) = \text{Min}\{f(x, y), g(x, y) | (x, y) \in A}\} \]  \hspace{1cm} (6)

**3.2.3. Identify and locate defects**

In order to simplify the later algorithm, we cut the image after positioning, as shown in Figure 12. Then the image is compensated by gray level. Finally, defect identification and location are realized.

**Gray compensation:** scan the image line with the upper left corner of Figure 12 as the origin, and perform the following operations:
\[ H_j(j) = \frac{\sum_{i=0}^{N} f(i,j)}{N} \]  
\[ \text{Mean} = \frac{\sum_{j=0}^{M} \sum_{i=0}^{N} f(i,j)}{M \times N} \]  

\( f(i, j) \) is a matrix of size \( M \times N \). Over here \( M = 84; N = 346 \). After processing we get \( \text{Mean} = 203.86 \). The gray projection of the average gray level in the column direction is shown in figure 13.

\[ \gamma(j) = k(j) \cdot \delta(j) \]  
\[ \delta(j) = \frac{\text{Mean}}{H_j(j)} j = 1, 2, \ldots, M \]  
\[ k(j) \cdot \delta(j) \cdot f_j(i, j) \in [0, 255] \]

In this formula, \( k(j) \) is the artificial auxiliary correction coefficient, which is a piecewise function about \( j \) the auxiliary revision is made according to the transformation of \( \delta(j) \). When \( \delta(j) \) is too large, it is used to weaken the compensation effect of \( \delta(j) \). When \( \delta(j) \) is close to 1, the constant 1 is generally taken. The following operations are performed:

\[ G(i, j) = \gamma(j) \times f_j(i, j) \]  

In order to completely eliminate the influence of shadow, we can cycle the image processing for the best effect. The following is the contrast of the image after gray compensation.

**Defect location:** According to the characteristics of pixel data matrix, the defects can be located by coordinates. The image coordinate positioning is composed of absolute coordinates and relative coordinates; the absolute coordinates positioning is based on the positive sequence number of the collected images according to the time series, and the track mileage corresponding to the given image can be obtained through the conversion of the running speed.

4. **Epilogue**

In this paper, a set of rail surface defect detection system based on machine vision is proposed. From the construction of lighting system to image analysis and processing, a complete set of rail surface detection scheme is proposed, which can effectively cooperate with the rail inspection vehicle to complete the rail surface defect detection and surface defect location.
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