Efficient rail repair machine based on image recognition technology

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Abstract. In this project, the detecting bolt loosening technology uses the CMOS camera for image acquisition, and the image is extracted by the FPGA combined with the single-chip computer. The author calculates the relative rotation angle of the bolt mark symbol before and after loosening by image analysis technology, through which we can quantify the loose angle of bolt and judge bolt’s loose condition. Then, the author uses the bolt screw maintenance machine to screw the loose bolt, which can achieve the purpose of repairing the loose bolt. This paper is of great significance in providing a theoretical basis for the theoretical design and practical engineering application of the rail maintenance machine.

1. Introduction

After a long working time of the railway track, railway track often appears bolt failure. Usually, bolt failure mainly includes fracture and loosening, among which loosening is the most common problem. At present, there are many methods to detect bolt looseness, such as detecting the change of preloading force, detecting the nonlinear characteristics of connection system and detecting acoustic emission signal. These methods can indeed detect the loosening of bolts, but their operation is often complex and inefficient, which is not conducive to practical production. Moreover, bolt connection, as an important connection mode, has a very large amount of usage, so it is difficult to detect the state of each bolt in the way mentioned above. In the existing maintenance methods, the maintenance workers usually patrol the road to check whether the nut is loose. When the nut is loose, they manually tighten the bolt to increase the pretightening force, which is mainly determined by personal experience. When the preloading force is too large, it will make the bolt in the case of accidental overload plastic deformation and loose, or even pull. When the preloading force is not enough, after using for a period of time, it will cause natural loosening. Human factors will also make the bolt preload inconsistent, leading to each bolt load is not consistent, and result in partial load. Bolts with heavy loads may break in severe cases\cite{1}.

2. Structural Design of Bolt Screw Maintenance Machine

2.1. Overall Structural Design
The overall mechanism of bolt screwing overhaul machine includes bolt screwing and walking mechanism. The main purpose of overhaul machine is to overcome the problems of low efficiency, time consuming, labor consuming, and fatigue misjudgment and so on, which exist in traditional bolt looseness testing. Through image analysis technology, the relative angle of mark symbol on bolt before and after loosening is calculated, and the angle of loosening of bolt is quantified. That provides a fast and accurate method for the detection and maintenance of bolt connection state. The function of the overhaul machine mainly includes two parts: bolt looseness detection and bolt rotation. The mechanical structure diagram of the bolt screw maintenance machine is shown in Figure 1[2].

2.2. Bolt Screw Mechanism Design
Bolt screw twist mechanism function is mainly to rotary screw loose bolts. Bolt screw part is mainly composed of vertical motion components of screw, bearing plate, X - Y adjustment platform, sleeve, torque controller and guiding device. Figure 2 is bolt screw mechanism structure.

![Figure 1. Screw repair machine.](image1)

![Figure 2. Bolt screw mechanism structure.](image2)

During screwing the bolt, the motor drives the lead screw to rotate, which makes the platform equipped with screw device drop the preset distance value L and stop moving. During the falling process of the platform, the guide ring at the bottom of the universal sleeve can ensure a smooth connection and transition between the sleeve and the bolt. When the upper surface of the bolt touches the elastic cylinder inside the sleeve, the cylinder retracts to realize adaptive bolt shape. At this time, multiple friction pairs are formed on the side surface of the bolt and the side of the elastic cylinder to cooperate with the motor above the universal sleeve, so as to provide enough driving power of rotation[3].

The optic-axis slider platform realizes the centering function in the bolt screw module. After the bolt is positioned initially by the maintenance machine, the screwing device drops and the guiding device gradually contacts the outer hexagon nut. The optic-axis slider platform adjusts freely in the X and Y directions to achieve the accurate centering effect. Figure 3 is X-Y adjustment platform structure.

![Figure 3. X-Y adjustment platform structure.](image3)

2.3. Design of Walking Mechanism
The walking mechanism is composed of four walking wheels, motor, bevel gear, etc. It drives the bevel gear to rotate through the vertical motor to realize the walking of the wheel, so as to realize the walking of the machine on the track. Figure 4 is the walking mechanism structure.
3. Use Image Recognition to Identify Bolts That Are Loose
The traditional method of checking bolts mainly uses lines to mark the tightening state of bolts and nuts respectively after the first tightening, and only needs to check whether the lines on the bolts and nuts are aligned. If not, tighten them to make their marks aligned. This method is called the marking method. The marking method is easy for workers to cause visual fatigue after testing a large number of bolts, leading to wrong inspection and missed inspection, especially for the high-speed train which requires workers to complete the inspection of bolts quickly and accurately. In view of the manual marking method, the author proposes to adopt image recognition technology to recognize the mark, which improves the efficiency of recognition and avoids problems such as wrong detection and missed detection[4]. Figure 5 is the flow chart of bolt looseness detection.

Firstly, the author collects images through CMOS camera, and then extracts image features by FPGA and microcontroller. Through image analysis technology, the relative rotation angle of bolt symbols before and after loosening is calculated, and the loosening angle of bolts is quantified to judge the loosening situation. The specific steps are as follows.

(1) Take a picture of the bolt by COMS camera. The picture includes the first mark, the second mark and the complete bolt waiting to be tested.

(2) After the image is taken, FPGA image processing technology is used to identify and process the image and extract the coordinate position of the first and second mark from corresponding data.

(3) According to the coordinate positions of the first mark and the second mark, the relative rotation angle $\alpha$ between the first mark and the second mark is calculated by plane geometry method.

(4) Set the threshold value $\alpha_0$ of relative rotation angle, and compare the relative rotation angle $\alpha$ of step (4) with the threshold value $\alpha_0$. If $\alpha \geq \alpha_0$, tighten the test bolt; if $\alpha < \alpha_0$, detect the next bolt.

Image recognition system includes image processing and image analysis. Image processing refers to the process of optimizing the target objects processed by the system and improving the overall efficiency of image processing. Image analysis is to calculate the processed image by algorithm function, obtain
the required image element information[5], and then process the contour edge information of the image. Figure 6 is the flow chart of the image recognition system.

![Flow chart of image recognition system](image)

**Figure 6.** The flow chart of the image recognition system.

### 3.1. Image Processing

Image processing includes image pre-processing, separation channel and threshold segmentation. Image analysis is carried out after image processing.

#### 3.1.1. Image Pre-processing

In the process of image formation, transmission, reception and processing, there are inevitably some interference, such as imaging sensor noise, photo particle noise and channel transmission error in the process of transmission. So some random, discrete and isolated pixel points appear in the image, named image noise. When collecting images on the spot, the noise is usually gaussian white noise or salt noise, so the denoising process of image acquisition is the process of eliminating these two kinds of noise. In principle, the square wave of low-pass filtering is used to eliminate gaussian white noise or salt-pepper noise, and low-pass filtering will eliminate the useful high-frequency information in the image while eliminating the image noise. Therefore, image denoising is essentially a trade-off between noise removal and the retention of high frequency information.

Median filtering is based on the theory of order statistics which is a nonlinear signal processing technology and can effectively restrain noise. The basic principle of median filtering is to replace the value of a point in the digital image or in the number sequence with the median of other points’ values in the field and make pixel values of the surrounding air close to the real value, thereby eliminating noise isolated points. Its implementation method is to sort pixel values by two-dimensional sliding template, and generate a two-dimensional data sequence that monotonously rises (or falls) [6]. The two-dimensional median filtering output is:

$$g(x, y) = Med\{f(x - k, y - l), (k, l \in W)\}$$ \hspace{1cm} (1)

In the above formula, \(f(x, y)\) and \(g(x, y)\) are the original image and the processed image respectively.

At the same time, affected by environmental factors and lighting changes, the collected target images will have different brightness, which will lead to that some details of the image recognition area can’t be well identified and affecting the accuracy of recognition. Therefore, it is necessary to enhance the contrast of the target image before the next step of recognition.

The author uses STM32 to set the software of CMOS camera driver for the image preprocessing of this link, and compensates the collected images. The image is processed by gamma curve, white balance, saturation, chroma and other basic management as required. Figure 7 is an unprocessed image and figure 8 is a pre-processed image.
3.1.2. Separation Channel. After image pre-processing, images are separated into channels and then transformed into Red, Blue and Green three-channel images. Since the paint of the underlined method is red, threshold segmentation is carried out for the images of Red channel. The specific function is decompose3 (ImageScaled, Red, Green, Blue). Figure 9 is the picture after separating channels.

3.1.3. Threshold Segmentation. The basic idea of threshold segmentation method is to determine a threshold value firstly, and then compare the gray value of each pixel in the image with the threshold value. According to the result of comparison, dividing each pixel into two categories —— foreground or background. Therefore, the selection of threshold value is the most critical, which directly affects the effect of image segmentation and the accuracy of subsequent image description and analysis. The author selects the iterative threshold method as the threshold segmentation method: firstly, a threshold value is selected as the initial threshold value of the image, and usually the grayscale mean of the image is selected as the initial threshold value of the image, and then the optimal threshold value of the image is obtained through the iterative process of image segmentation and threshold modification. The process can be described as follows:

(1) Traversing the gray scale data, the maximum gray scale $Z_{\text{max}}$ and the minimum gray scale $Z_{\text{min}}$ are worked out, and the initial threshold value is set as follow:

$$T = (Z_{\text{max}} + Z_{\text{min}})/2$$  \hspace{1cm} (2)

(2) According to the threshold initial value $T$, the image is split into $R_1$ and $R_2$:

$$R_1 = \{ f(x, y) | 0 \leq f(x, y) \leq T \}$$  \hspace{1cm} (3)

$$R_2 = \{ f(x, y) | 0 \leq f(x, y) \leq T \}$$  \hspace{1cm} (4)

(3) Calculate the average gray value of $\mu_1$ and $\mu_2$ in the region:

$$\mu_1 = \frac{\sum_{f(i,j) \in R_1} f(i,j) \times N(i,j)}{\sum_{f(i,j) \in R_1} N(i,j)}$$  \hspace{1cm} (5)

$$\mu_2 = \frac{\sum_{f(i,j) \in R_2} f(i,j) \times N(i,j)}{\sum_{f(i,j) \in R_2} N(i,j)}$$  \hspace{1cm} (6)

$f(i, j)$ is the gray Value of $(i, j)$ point on the image. And $N(i, j)$ is the weight coefficient of $(i, j)$ point on the image, which generally set to 1. In the iterative calculation process, $T$ is a constant and the optimal threshold[7]. Figure 10 is the image after threshold segmentation, and figure 11 is the image after final processing.
3.2. Image Analysis

After the success of the image processing, the first mark and the second mark are extracted according to the features of the underlined mark, and the marked line is identified by piecewise line fitting based on the least square method. And using the plane geometry method to calculate the relative rotation angle between the first and second marking $\alpha$. The relative rotation angle $\alpha$ is compared with the pre-set threshold value $\alpha_0$ of the relative rotation angle. If $\alpha \geq \alpha_0$, tighten the test bolt; if $\alpha < \alpha_0$, detect the next bolt[8]. The schematic diagram of image analysis is shown in figure 12.

4. Summary

Based on the research of the working principle of the original processing equipment and combining with relevant literature, the project puts forward the basic principle which includes image recognition technology and so on. Through data query and analysis, we can achieve the desired purpose and has its feasibility in practical use by using the basic principle of knowledge. The maintenance machine adopts the idea of mechatronics to realize unmanned and intelligent, which has strong self-adaptation and improves the maintenance frequency. Maintenance machine cost is low, and the market demand is large. So it has a good application prospect.

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