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A Real Time Detection Method of Track Fasteners Missing of Railway based on Machine Vision

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Abstract

Detection of the missing track fasteners is an important part of the daily inspection of the railway, according to the requirement of real-time and self-adaptation of the modern railway to the automatic detection technology. A real-time detection method based on machine vision is proposed. On the basis of the basic principle of machine vision, the image acquisition device with LED auxiliary light source hood is designed. Adaptive image enhancement for fastener edge feature by using switching median filter and improved Canny edge detection method based on image gradient magnitude combined with the stability of the edge profile of fastener, real time detection of missing fastener has realized by template matching based on curve feature projection. After the experiment, the average processing time of each image is 245.61ms, the correct rate of recognition is 85.8%, and the method has a certain degree of adaptability, which supports up to 3.85m/s implementation speed and meets the real-time detection requirements for missing fasteners for actual operation of the real line. Rail damage detection method based on machine vision is often affected by noise interference in the process of image acquisition. In this paper, an improved median filtering algorithm is proposed to solve the problem of noise filtering appearing in the image. The algorithm points out an upper triangular block in the rectangular filter window as the mark point and finds the gray value in the upper triangular block to replace the gray value of the processing point. By the simulation experiment of this algorithm and other algorithms, the results show that the new algorithm is effective and the running time of the algorithm can be reduced effectively.

Keywords: fastener missing detection; image enhancement; template matching; salt and pepper noise; median filter

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1. Introduction

Rail fastener is an important part of the safety of railway transport; its lack will cause serious incidents such as derailment of the running trains. At present, the fastener detection mainly depends on manual inspection, which is a method of labor intensity and low efficiency, especially for high speed railway whose most parts are on viaduct or in closed protected areas, which has been unable to meet the needs of daily inspection. There is an urgent need for fast and efficient automated testing equipment, in order to achieve real-time detection of rail fasteners in the operation of the track [6].

In recent years, major universities have launched the study of railway automatic detection, Guangchun QIAN [11] established a computer vision detection model of missing fastener which focuses on the hardware design, and realizes the positioning of fastener area using the straight-line method; Ling WANG and other [14] completed the detection of the missing fastener nut through the statistics of the specific region of the pixel information to locate the fastener area. Fengying XIE [16] proposed rail and sleeper positioning method based on image gray and gradient distribution characteristic, which achieved precise positioning of the fastener according to the position features of the fastener and the image information; Jianqiao LUO et al. [10] established the nonlinear spatial partial characteristic expression model of the fastener profile, and then combined with the visual relationship between the sub images of the fastener to transform the feature into the semantic

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information vector to carry on the deletion of the fastener. The existing research focuses on the rapid positioning of fastener area in fastener missing detection system. But according to the requirement of system application, it is needed to consider the real-time requirements and adaptive requirements for the detection of complex illumination environment.

Combined with basic requirements of the detection system, this paper presents a visual detection method of track fastener loss. Hood and LED auxiliary light source provides stable light environment for image acquisition and ensures access to high quality image. Image enhancement algorithm removes the interference of image impulse noise, and combines the histogram concavity analysis to solve the self-adaptive problem of double threshold selection in edge detection to ensure the adaptability of the system to the complex environment. The algorithm can reduce the computation of template matching, select the similar measurement based on curve feature, and realize the fast and accurate identification of the missing fastener through the direct edge contour search.

2. Fastener Missing Detection System

According to the basic principle of machine vision, defect detection model of track fastener is established, which includes three parts: image acquisition, image enhancement and image recognition. In order to reduce the influence of the external complex illumination condition on the flaw detection system of the fastener, the shading device is designed. At the same time, the auxiliary LED light source is added to provide a stable light environment for image capture, as shown in Figure 1. Image enhancement and image recognition is achieved by using NI image processing module and LabVIEW programming software.

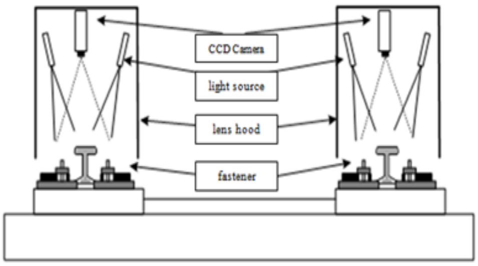

Figure 1. Schematic diagram of vision inspection system with missing fastener

3. Fastener Area Image Enhancement

3.1. Switching Median Filter

There is a large amount of impulse noise in image of fastener area, which has great influence on the result of edge detection. The traditional Gauss filter, mean filter and median filter cannot restrain the noise. In this paper, a switching median filtering method is used to remove the noise points by using Laplace operator to judge the noise points, and combining the results of median filter. This method can preserve the continuity of image edge direction, and has a good effect on the impulse noise suppression [19].

Laplace operator K1, K2, K3 and K4 are the switching median filter detection operators; their direction is shown in Figure 2.

$$K_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -1 & -1 & 4 & -1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad K_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(a) 0° direction **(b) 45° direction**

$$K_3 = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \end{bmatrix} \qquad K_4 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{bmatrix}$$

(c) 90° direction **(d) 135° direction**

Figure 2. Four directions Laplacian operator

Assuming the gray value of each pixel in the image is *f(x, y)*, the discriminant operator *r(x, y)* is:

$$r_{(x,y)} = \min\left\{\left| f(x,y) \otimes K_p \right|\right\}, p \in 1,2,3,4 \tag{1}$$

where $\left| f(x,y) \otimes K_p \right|$ represents the absolute value of the pth convolution at the pixel point (x, y). Assuming the gray value is $f'(x,y)$, $f_{\text{med}}(x,y)$ at image point (x, y) after filtering, decision parameter is T, then:

$$f'(x,y) = \begin{cases} f_{\text{med}}(x,y) & r_{\min(x,y)} > T \\ f(x,y) & r_{\min(x,y)} \le T \end{cases} \tag{2}$$

If $r_{\min(x,y)} > T$, the current pixel is noise, and the gray value of the pixel is replaced by the median filter; if $r_{\min(x,y)} \le T$, the current pixel is the signal, and its gray value is unchanged. According to the experimental analysis from literature [19], the value of T can be chosen.

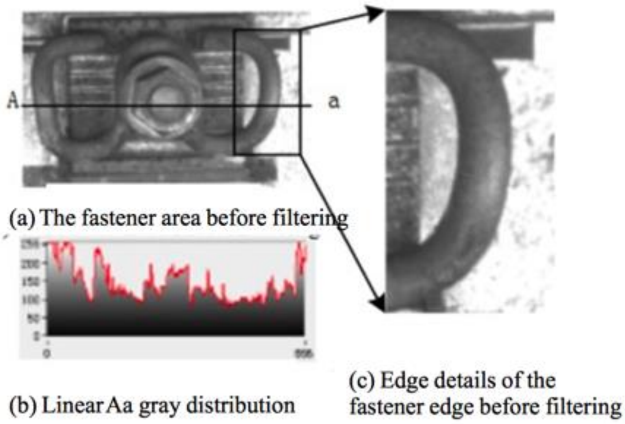

Figure 3. Image filtering edge details

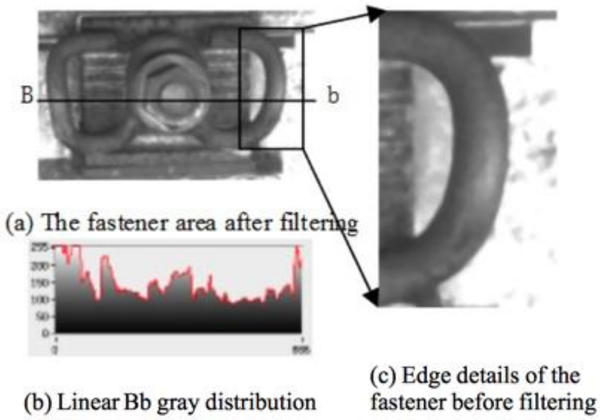

Figure 4. Image filtering edge details

After switching median filter processing, contrast of the fastener area before and after filtering is shown in Figure 3 (a) and 4 (a). Extracting the line Aa and Bb at the same location of the fasteners before and after filtering respectively, the straight line is extracted and its gray level distribution map is drawn, as shown in Figure 3 (b) and 4 (b). It is found that the burr in the curve is basically cleared, but the shape of the curve is all reserved. This shows that the impulse noise in the image is well suppressed, but the image edge information is all preserved. Contrast fastener edge before and after filtering can confirm this statement as shown in Figure 3 (c) and 4 (C). It is obvious that the edge of the fastener is preserved, and the noise is effectively eliminated.

3.2. Edge Extraction Based on Image Gradient

The edge of the image can be characterized as the position of the sharp change of the gray value, which can be calculated by the image function in the neighborhood of the pixel. The edge magnitude is the gradient magnitude, and the edge direction is the direction of the gradient direction of rotation -90°. The gradient magnitude and $|\nabla f(x,y)|$ and direction α as shown in formula 3 and 4:

$$|\nabla f(x,y)| = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \tag{3}$$

$$\alpha = \arg(\frac{\partial g}{\partial x}, \frac{\partial g}{\partial y}) \tag{4}$$

Canny edge detection has a certain adaptive adjustment ability to the non-maxima suppression of amplitude and the extraction process of the double threshold method, and the method has a good noise suppression effect. But, the double threshold fails for the traditional Canny edge detection when the noise density suddenly increases that causes missing or false detection. In order to solve this kind of emergency situation, this paper uses image gradient method based on histogram concavity to realize fastener edge contour extraction [20], in order to improve the adaptability of the algorithm in complex environment. The edge extraction process is described as follows:

(1) Extract the gradient magnitude histogram *h(i)* of image I, and record non zero starting point $(i_0, h(i_0))$, non-zero end point $(i_n, h(i_n))$.

(2) Calculate the slope of each gradient, as shown in formula 5, to find the corresponding slope of the maximum gradient magnitude. The point is defined as the salient point of the histogram, and N bumps are obtained by searching different gradient magnitude:

$$s(i) = \frac{h(i) - h(i_0)}{i - i_0}, i_0 < i < i_n \tag{5}$$

where i represents the gradient magnitude, *s(i)* indicates the slope of the gradient magnitude.

(3) Connect non zero starting point $(i_0, h(i_0))$, non-zero end point $(i_n, h(i_n))$ and N bumps to form the minimum convex polygon $\bar{h}(i)$ of the envelope histogram *h(i)*.

(4) Calculate the residual error *c(i)* using formula 6. When the concave residual is the maximum value, the corresponding gradient amplitude is high threshold T_h.

$$c(i) = \bar{h}(i) - h(i) \tag{6}$$

(5) Calculate the cumulative histogram of the image gradient, and account the ratio t of strong edge pixels among total image pixels. According to literature [18], the low threshold value is $T_l = 0.4T_h$.

Using the above method, the edge of the fastener area image is extracted, and the effect is shown in Figure 5.

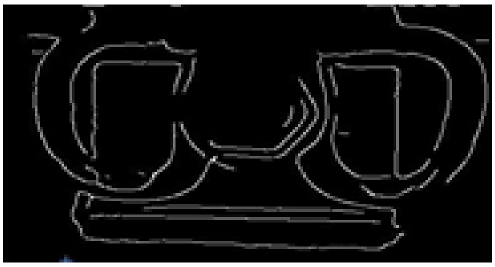

Figure 5. Image edge extraction

4. Missing Fastener Identification

Template matching is a process of similarity retrieval and matching by using the approximation measurement of image feature vectors. Missing fasteners identification can be achieved by direct template matching for the extracted fastener edge image, whose search scope is small and characteristic is obvious [17].

4.1. Basic model of missing fastener identification

The basic principle of template matching carries out the identification of missing fastener. Knowing input image S(W, H), template T(m, n), the comparison of template information value and the corresponding value of the image carries out the search of discrimination through template to perform slide searching in the original image, as shown in Figure 6.

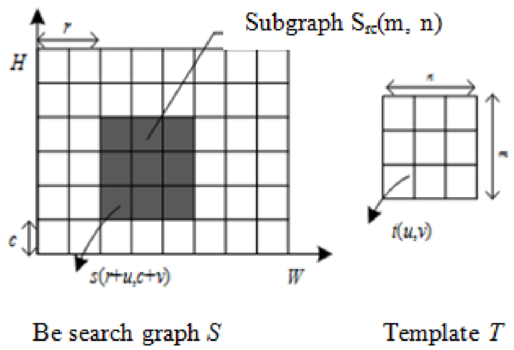

Figure 6. Schematic diagram of image pattern matching

(1) Starting from the left corner (*0, 0*) of the input image to extract a block of temporary image $S_{(0,0)}(m, n)$ from (*0, 0*) to (*m, n*).

(2) Establish the similarity measurement between the template *T(m, n)* and the temporary image $S_{(0,0)}(m, n)$:

$$sad(r,c) = \frac{1}{n} \sum_{(u,v)\in T} \left| t(u,v) - f(r+u,c+v) \right| \tag{7}$$

$$ssd(r,c) = \frac{1}{n} \sum_{(u,v)\in T} \left| t(u,v) - f(r+u,c+v) \right|^2 \tag{8}$$

According to formula (7) and (8), compare the relationship between the temporary image and the template, and record the comparing results c at the starting point (0, 0).

(3) Slide the template to (0, 1) and extract a block of temporary image $S_{(0,1)}(m, n)$ from (0, 1) to (*m*, *n+1*). Repeat step (2).

(4) According to a certain way to carry out image searching, repeat step (1) ~ (3) until the image searching is complete.

It can be seen that the performance is determined by the selection of the similarity measurement and selecting the features that can reflect the target accurately and stably. The similarity measurement can be used to perform identification when the external light environment changes; at the same time, the calculation of template matching is mainly determined by the product of the calculation of the correlation algorithm and the number of search positions. It is needed to set search location to improve the detection efficiency.

4.2. Template Matching Based on Curve Projection

Considering real time detection requirement of fastener loss, the comparison of fastening strip and the background gravel is obvious [2,13]. The rule of edge feature is easy to distinguish and the characteristic of curve is obvious under different illumination conditions. To be the matching template, choose the edge of the elastic fastener on both sides of the fastener. The elastic strip edge template is obtained in the same shooting condition and the same acquisition device to reduce the large number of operations caused by the position and pose transformation, image affine transformation and so on [1,12]. A template matching method based on curve feature projection is adopted in this paper; this method uses the integrity of the edge curve of the projectile (reflecting the integrity of the relative template of the curve), the expected value of the relative model offset (reflecting the degree of deviation from the template) and offset variance (reflecting the degree of dispersion of the curve with respect to the template) as the similarity measurement of the template matching [3,7].

Assume a given curve template C, length of L, width of W; template matching similarity measure S can be defined as:

$$\begin{cases} S = \dfrac{w_1 I + w_2(1-O) + w_3(1-V)}{w_1 + w_2 + w_3} \\ I = \dfrac{l_p}{L} \\ O = \left| \dfrac{1}{w l_p} \int_p 2h ds \right| \\ V = \dfrac{1}{w^2 l_p} \int_p \left(2|h| - wO\right)^2 \mathrm{d}s \end{cases} \quad (9)$$

where, I is the integrity of the curve, O is the normalized offset expectation, V is the normalized offset variance, $w1$, $w2$, $w3$ are the weight, l_p is the projection length of the edge on the template, h is the offset of the curve point with respect to the template, as shown in Figure 7.

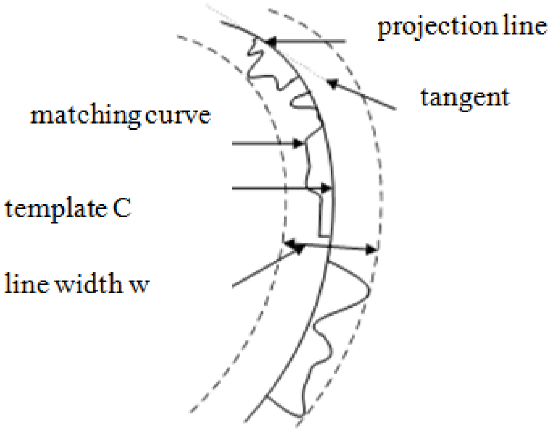

Figure 7. Sketch of curve feature projection

Search along the curve of the template for the matching of the outline of the bullet, greatly reducing the search range of the original template matching, while improving the matching speed. According to the similarity measure of the curve feature, the template offset caused by the noise points can still be correctly reflected by the similarity degree between the template and the image; the matching results are shown in Figure 8. According to the model theory, it is assumed that the loss of matching images will not cause the increase of the matching error; that is, there is no corresponding matching point. Therefore, the lack of edge information can be solved, and the matching point is not found.

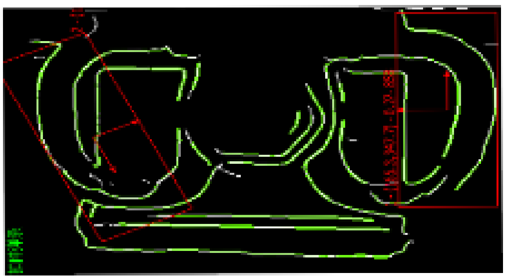

Figure 8. Missing fastener identification

5. Experimental Results and Analysis

There is very little circumstance in the actual line of the continuous lack of fasteners; in the field experiment, the detection is mostly carried out under the existing state of the fastener. In this paper, the system verification experiment is re-designed: 250 pieces of fastener pictures has been captured in the actual line, fastener missing images has been increased to 100 pieces by using of artificial synthesis. Fastener pictures has been selected randomly and divided into 5 groups with each group of 50. The defect pictures has been selected 5 times randomly with each time of 50 pictures, which has been disrupted the order and added into the 5 groups of fasteners pictures, in order to ensure the randomness of testing. 5 sets of test results were recorded to obtain the correct rate of the final identification of the missing fastener, and record the time of each test; the specific data is shown in table 1.

Table 1. Fastener missing detection results

Group No.	Identification correct rate (%)	Average identification correct rate (%)	Detection times (ms)	Average detection time of each picture (ms)
1	89		23317.41	
2	92		25536.73	
3	86	85.8	22479.31	245.61
4	78		23862.46	
5	84		24608.34	

From the experimental data, we can see that the real-time tracking algorithm proposed can reach speeds up to 245.61ms per frame image. The maximum speed of real-time detection of the portable track defect vision inspection system is 3.82m/s; the average correct rate is 85.8%.

6. Improved Image Preprocessing Algorithm for Visual Inspection

The salt and pepper noise has a lot of white or black spots on the image noise; their gray value is about 0 or 255. In order to get the image as clear as possible, the algorithm uses the filtering window to update the gray value of the pixel points before updating the gray value of the pixels. When the gray value of the pixel point is located within the set threshold value, the gray value of the pixel is kept constant; otherwise, the gray value of the pixel is updated by using the filtering window. The gray value of each pixel G meets n≤G≤m [5,9,15]; the gray value of the pixel keeps unchanged. Among them, n and m were the two threshold values. The filtering effect of the algorithm can be evaluated by comparing the improvement factor R of the ratio of signal to noise [4,8]; the signal to noise ratio improvement factor R is defined as:

$$R = 10\log\frac{\frac{1}{KL}\sum_{i=1}^{K}\sum_{j=1}^{L}(y(i,j)-s(i,j))^2}{\frac{1}{KL}\sum_{i=1}^{K}\sum_{j=1}^{L}(x(i,j)-s(i,j))^2} \tag{10}$$

where, L and K represent the length and width of the image respectively. t is the image after filtering, which is a standard image and a noise image. If the R is negative, the filtered noise is suppressed; the lower the R, the better the filtering effect. In order to achieve the best filtering effect, according to the characteristics of salt and pepper noise, a simulation experiment has been conducted for the situation of n∈ (1,5) and m∈ (249,254). The simulation results are shown in table 2.

Table 2. n, m value simulation results table

n	m	R
1	250	-38.658
1	251	-39.721
1	252	-39.189
1	253	-38.083
1	254	-33.469
2	250	-41.880
2	251	-39.809
2	252	-39.116
2	253	-38.353
2	254	-39.142
3	250	-37.609
3	251	-39.652
3	252	-38.353

3	253	-40.088
3	254	-40.775
4	250	-37.941
4	251	-41.199
4	252	-40.563
4	253	-38.740
4	254	-38.249
5	250	-40.414
5	251	-40.167
5	252	-40.898
5	253	-40.217
5	254	-40.373

It can be obtained from table 2 that when n=2 and m=250, R value is the smallest, which is where the filtering effect is the best.

For the filtering window, take the image point which points to the center of the filter window as the mark point figure out the upper triangular block of the shadow part, as shown in Figure 9.

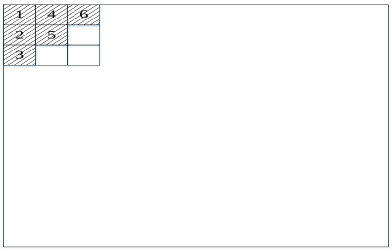

Figure 9. Upper triangular block

There are 5 steps in the algorithm, which are shown in Figure 10.

f(v-1,w-1)	f(v-1,w)	f(v-1,w+1)
f(v,w-1)		
f(v+1,w-1)		

Figure 10. Gray value of pixels in the window

6.1. Simulation Experiment and Result Analysis

In order to test the filtering effect of the improved algorithm, this paper uses 100 images of rail image and fastener image as the initial image. During the simulation test, we added strength of 0.05 of salt and pepper noise to the initial image to obtain the noise image for the experiment. The average signal to noise ratio improvement factor R of the 100 experiments of each algorithm is shown in Figure 13. (Due to the limitation of the space, Figure 11 and Figure 12 are given partially of the filtering results of each algorithm). Simulation experimental platform is Windows7, 32 bit system, a computer with the CPU of Core Intel (TM) 2 2.93GHz and 4GB memory.

From the point of view of filtering effect, Figure 11 and 12 show the results obtained by the mean median filtering algorithm. The algorithm has little differences compared to our algorithm; all can filter the salt and pepper noise in the image, but the filter image obtained by using median filter is relatively poor. The column figure of Figure 13 also confirms the conclusion obtained from the filtered image.

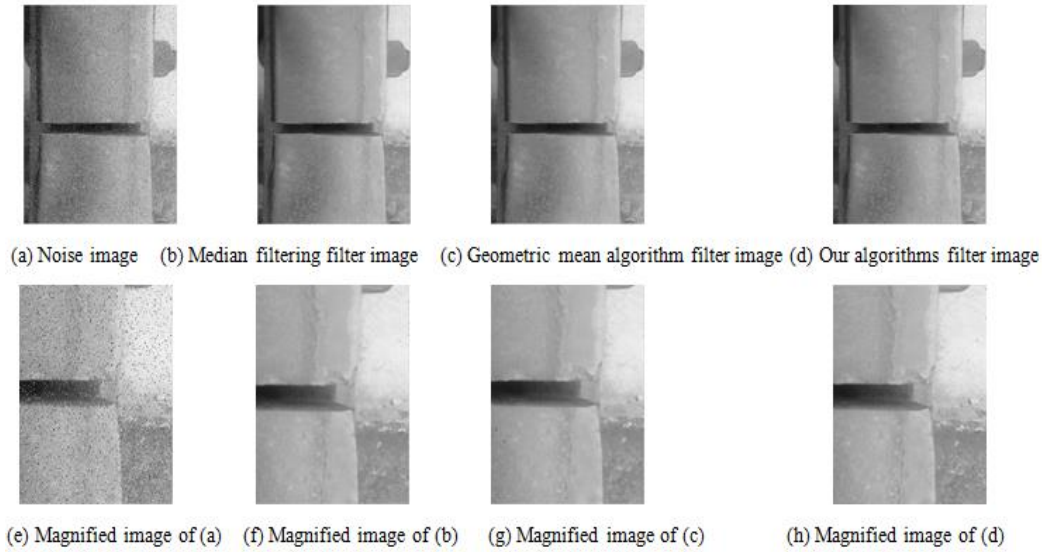

Figure 11. Rail image filtering effect diagram

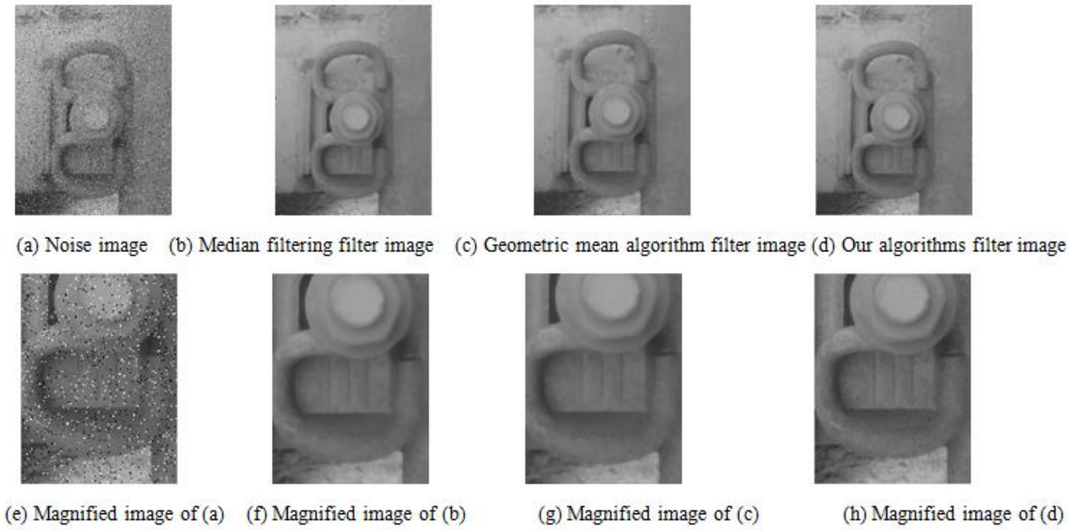

Figure 12. Fastener image filtering effect chart

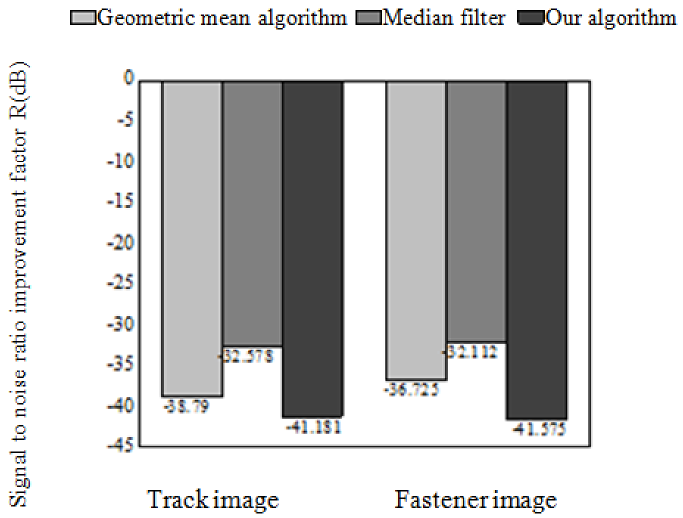

Figure 13. Result chart of Signal to noise ratio improvement factor of different algorithms

7. Conclusions

This paper presents a real-time detection method for visual fastener missing, mainly using the fastening elastic bar at the edge of the curve characteristics, at the same time of image denoising as far as possible to retain the edge features. In order to overcome the dynamic change of illumination intensity, the Canny edge detection based on double threshold adaptive selection is carried out. At the same time, the fast template matching based on curve projection ensures that the missing of the fastener can meet the requirement of real-time detection. Experimental results show that the average processing time of the method is 245.61ms, the detection accuracy is 86%, and the method is adaptive. It can be used in real time detection of rail inspection car. The method that detects the condition of the fastener is too single; further analysis is needed to solve the problem of the rapid identification of the occlusion and the injury of the fastener. Furthermore, this paper uses the characteristic of gray value of salt and pepper noise in image located near 0 or 255. The threshold range is set up through the simulation experiment, and the gray value of the pixels in the threshold range is adjusted to improve the running speed of the algorithm, which is beneficial to improve the overall image clarity. Through the simulation experiment, we can see that using this improved algorithm to filter the image containing noise can obtain a good filtering effect, and shorten the running time of the algorithm, which is conducive to the application in the field of rail detection based on machine vision.

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