On the detection of defects on smooth free metallic paint surfaces

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Abstract—In view of the difficulty of automatic detection of defects on smooth free metallic paint surfaces, a simple and effective automatic detection system based on deflection principle is proposed in this paper. This system consists of cameras and a set of striped lights. A series of images can be acquired at a certain frequency by camera. And the detection algorithm is divided into three steps. In the first step, the square-difference fusion method and minimum fusion method are used to fuse a group of the standard images to obtain two fusion images, which are used to extract the ROI and partial template. In the second step, partial template is used to perform template matching and correction on the fusion images. In the last step, extraction of mask, extraction of defects, and screening of defects are performed on the corrected fusion image to extract defects. To detect complex metallic paint surfaces of the car, the experimental results demonstrate that the defects detection accuracy can reach 85% and the defect recognition size can reach 0.1mm.

1. INTRODUCTION
Currently, the requirements for surface quality inspection in industrial inspection are getting higher and higher, and the need for a method for quickly and accurately detecting surface defects is more urgent. Defect detection of some planes and simple curved surfaces has made great progress, and has achieved high-precision, high accuracy, and efficient detection, such as large-caliber precision optical components [1], PCBs [2], etc., and has been well applied in production lines.

However, in practical applications, many industrial products need a defect detection of their smooth free metallic paint surfaces. And most of the industries still use manual visual inspection to detect defects on smooth free metallic paint surfaces [3], but manual inspection cannot accurately distinguish the small differences in defects on paint surfaces, and has the disadvantages of taking too long, being inefficient, being affected by human factors and so on.

Therefore, the defect detection of smooth free metallic paint surfaces is an urgent problem. Aiming
at this problem, a simple and effective automatic detection system is proposed in this paper. In the system, the metallic paint surface is scanned by the streak structured light, and the camera acquires a group of images at a certain frequency. This group of images are merged into an image highlights the defect features. Finally, the fusion image is processed to extract defects.

2. DETECTION PRINCIPLE AND DETECTION SYSTEM
The principle of defect detection used in this paper is the deflection principle [4], which has proven to be a reliable and accurate method for detecting defects in metallic paint surface. As shown in Fig. 1, the streak structured light is composed of bright and dark bands crossing. Using the method of retroactive light tracing, it is assumed that the light is emitted from the center of the camera. When there is no defect, the light is reflected on the dark band. When there is a defect, the defect changes the direction of light reflection and the light reflects on the bright band. Similarly, if the light is normally reflected on the bright band, when there is a defect, the light will be reflected on the dark band. Therefore, as shown in the right images in Fig. 1, the defect appears as a bright spot in a dark area or as a dark spot in bright areas in the image acquired by the camera. At the same time, the closer the light transition position (the junction of the bright and dark bands) to the defect location, the closer the defect is in the image to the size of the object [5]. Based on this, the detection system consists of cameras and a set of striped lights. The metallic painted surface is scanned by striped lights, and the camera acquires a set of original images at a certain frequency during the scanning process. Then, the original images are processed by an algorithm to obtain the defect information of the metallic paint surface. In this paper, the outer metallic paint surface of the car is used as the test surfaces and partial original images of a part of the car are shown in Fig. 2.

3. DETECTION ALGORITHM
Aiming at the defect detection of metallic paint surface, an image detection algorithm based on the above detection system is proposed in this paper. Its flow chat is shown in Fig. 3.
3.1. Minimum Fusion
As shown in Fig. 2, due to the interference of light streaks, a partial contour template of the metallic paint surface cannot be extracted. So an image showing the metallic paint surface clearly needs to be obtained. Because the stripe is used to scan the painted surface, there will be a moment when the painted surface is not illuminated by the bright band. At this moment, the gray value of the position is the smallest and can reflect the contour information of the position. Base on this, a fusion method, named the minimum fusion method, is proposed in this paper to get an image which shows the metallic paint surface clearly, as follows:

\[ I_{\text{Min}} = \min(i_k), k = 1, \ldots, m \]  

Where \( i_k \) is the k-th frame of the images, m is the total number of images.

According to (1), a minimum fusion image \( I_{\text{Min}} \), which clearly reflects the contour information of the metallic paint surface, can be obtained, as shown in Fig. 4.

3.2. Square-difference Fusion
The images collected by the camera are a set of images at different moments. We need to fuse the defect information in the images at different moments into one image. In the fusion process, we must try to highlight the image defect information and reduce the impact of diffuse reflection and environment. Therefore, the square-difference fusion method is proposed in this paper, which is as follows:
\[ I_k = (i_{k+n} - i_k)^2, k = 1, \ldots, m - n \]  
(2)

\[ I_s = \max(I_k), k = 1, \ldots, m - n \]  
(3)

Where, \( i_{k+n} \) is the \((k+n)\)-th frame of the images and \( i_k \) is the \(k\)-th frame of the images, \( n \) is the interval between subtracting two images, its value is related to the stripe scanning speed and the stripe width and it is set to 6 in this paper, \( m \) is the total number of images.

First of all, according to (2), it can effectively reduce the effect of diffuse reflection and environment by calculating the difference between two images with an interval of \( n \). On the other hand, with the square of this difference, it can maximize the effect of the contrast between low and high levels of pixel intensity. And then according to (3), the image defect information can be highlighted in the fused image.

According to the above fusion method, a square-difference fusion image \( I_s \), in which defects will be highlighted, can be obtained, as shown in the Fig. 5.

![Figure 5. Square-difference fusion image \( I_s \)](image)

### 3.3. Create ROI and Template Matching

The purpose of this process is to extract the detection area roughly and is to perform rotation and translation correction on the square-difference fusion image to ensure that its position is basically consistent with the standard square-difference fusion image. First of all, a group of standard images needs to be acquired in advance. The above two fusion methods are used to fuse this group of images to obtain a standard square-difference fusion image \( I_{StdDiff} \) and a standard minimum fusion image \( I_{StdMin} \).

The image \( I_{StdMin} \) is used to extract the partial contour template and image \( I_{StdDiff} \) is used to extract the ROI, which needs to ensure the area of the detection area is the largest. Finally, the extracted partial contour template is used to perform template matching [6] on the image \( I_{Min} \) to generate a correction matrix, which is used to correct image \( I_s \) to get image \( I_R \).

### 3.4. Extraction of Mask

The detection method used in this paper is to scan the metallic paint surface with fringe light, which will necessarily scan the irrelevant areas. In the process of defect detection, misjudgment is often caused by interference from irrelevant areas. Therefore, it is necessary to generate an accurate mask.

Before extracting the mask, we need to use the created ROI to roughly extract the detection area image \( I_o \) from the corrected image \( I_R \). It reveals that the gray value of the area to be inspected is close and its area is the largest by analyzing the extracted image \( I_o \). Base on this, mask can be accurately extracted by using the gray histogram.
Therefore, the extraction algorithm of mask proposed in this paper is: first, we need to calculate gray histogram of the image $I_o$, as shown in Fig. 6(b). Second, the corresponding gray values of all the valleys can be obtained from the histogram which needs to be smoothed with a Gaussian filter. A region will be divided between adjacent valleys by using these gray values do threshold segmentation. Then, we need to compute connected components and filter these components by area to remove non-detected regions. Finally, we need to perform hole-filling and morphological operations on the extracted region to generate a mask, as shown in the Fig. 6(c).

Figure 6. Image segmentation process

3.5. Extraction and Screening of Defects

First of all, the image $I_e$, in which the defects are enhanced, can be obtained by performing black hat operation on the image $I_o$. Then the technique of Hysteresis Thresholding [7] is used to extract all suspicious defects from image $I_e$. And we need to use the created mask to remove the extracted suspicious defects outside the detection area. Finally, we need to screen for real defects from remaining suspicious defects based on image pattern recognition. Comparing with the information of pixels of standard defects, the real defects can be screened out and sort out.

4. EXPERIMENTAL RESULTS AND ANALYSIS

In this paper, the exterior paint face of the car is used to verify the above system. The main experimental results obtained by the above algorithm are shown in the Fig. 6, Fig. 7, Fig. 8, and Fig. 9. First, form Fig. 6 to Fig. 7, it shows that the mask of detection area can be accurately generated. Then, from Fig. 8 to Fig. 9, we can find that compared with the original image, the defects are more easily distinguished in the square-difference fusion image. And after black hat operation, the difference between the defect and the background is more obvious, as shown in the Fig. 8(c) and Fig. 9(c). Finally, all the suspicious defects can be extracted by the threshold segmentation. And after screening by using mask and comparing with the information of pixels of standard defects, defects can be detected well by above system. as shown in the Fig. 8(b) and Fig. 9(b).
The minimum scale of the defects required for testing on the paint face of the car is 0.3mm. In the actual experiment, the defect recognition size can reach 0.1mm through the above algorithm and the defects detection accuracy can reach 85%.

5. CONCLUSION
Aiming at the difficulties in the defects detection of smooth free metallic paint surfaces for industrial assembly line production, a detection system based on the above detection principle is proposed in this paper. This system can achieve a variety of defects detection of metal paint surface just by simple hardware for image acquisition and a robust detection algorithm. It has a strong applicability and can be used as a general method on defects detection for similar object.

In addition, although the algorithm proposed in this paper can satisfy the high defects detection rate, the accuracy of classification and degree judgment is still to be improved. Future work can be focused on the short-cutting of adjusting the artificial parameters, which will mainly depend on the use of machine learning and deep learning algorithm.
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