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Aircraft Riveting Defect Detection Method Based on Image Processing

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Abstract: *The problems of low manual detection rate, high false detection rate, and high labor intensity are aimed at in the aircraft rivet defects detection. Rivet defects detection is studied in this paper, and a method is proposed based on image processing. In this paper, image processing method is used to detect and identify the defects of rivet surface in the riveting process of aircraft. A dynamic threshold adjustment method is used to determine the threshold of binarization. Compared with other methods to determine the threshold, the method selected in this paper can obtain more accurate defect image in the pre-processing stage. The false detection rate is lower when the defect is identified.*

Keywords: *Image processing, Riveting defect detection system, Scar detection, Dynamic threshold adjustment*

1. Introduction

Image detection and recognition technology is widely used in aircraft riveting defect detection in aerospace industry. During the flight of aircraft, the quality of riveting is one of the problems affecting the safety of aircraft. With the development of society and science and technology, the requirement of riveting quality is getting higher and higher, and the detection of riveting becomes more and more important in the process of aircraft operation. According to Gordon [1], in the daily inspection of aircraft, the vast majority of the inspection is visual inspection, visual inspection is the fastest and most economical way to obtain the operation status of aircraft and its components. Typical defects of aircraft can be found by visual inspection, which can be divided into three categories: cracks, corrosion and degumming. But the subjectivity of human eyes often leads to the problem of low detection rate when we examine defects.

Compared with traditional inspection methods, the riveting defect detection method adopted in this paper can detect rivet surface defects efficiently and accurately. Therefore, this paper uses image processing technology to detect the riveting defects of aircraft, and preprocesses the acquired images by graying and histogram equalization, median filtering, image enhancement and binary image filtering. In the process of image binarization, this paper chooses a dynamic threshold adjustment method. Compared with the method we used in previous experiments to determine the threshold, the image processed by this method has clearer defect contour and lower false detection rate in subsequent processing [2]. Then through the identification of aircraft riveting defects, the final aircraft riveting defects location. This method effectively avoids the problems of low efficiency of manual detection, high error rate and high labor intensity [3-4]. It plays an important role in improving work efficiency and aircraft safety.

2. Literature survey

At present, there are various technologies for surface defect detection. Wei Zhipeng [5] used the method of template matching based on asynchronous scaling to effectively reduce the impact of target deformation in the process of defect detection of flexible printed circuit boards. Cui Ming [6] proposed a spectrum feature analysis method for texture defect of vehicle seat belt surface, which can meet the requirements of real-time detection. Ding Shuming [7] et al. used Hog and support vector machine to detect the surface defects of fabrics. Yang Yanxi [8] et al. proposed a detection algorithm based on

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background difference method for strip surface defects. Wu Shengjin [9] used template matching to locate the target area, then sharpened the target area to get the clear outline of the target. Finally, BP neural network was used to classify the defects. A Data-driven methods usually extract visual features from non-defective and defective areas and apply them to defect classification. Siegel et al. [10] used neural network to classify cracks and erosion. Mumtaz et al. [11] used three methods to distinguish cracks and scratches: neural network, energy calculation based on contour transform and discrete cosine transform (DCT). Rong Z et al. realized the non-contact and high-precision measurement of rivet defects by designing rivet geometry parameter algorithm and using digital image processing technology [12]. Fromme P et al. used the method of structural wave propagation to detect rivet crack defects. KB Kahen et al. proposed eddy current technology based on rivet in-situ detection, which realized the accurate detection of rivet cracks [13].

There are many methods of surface defect detection by image processing. In this paper, the segmentation threshold of rivet surface defect is studied in the process of image processing and recognition, and a more suitable threshold method is found. A large number of experiments show that the method of dynamic threshold adjustment to determine the threshold can improve the situation that different rivet defect images may not get edges or false edges because of different gray changes.

3. Image Processing of Rivet Surface Defects

In order to make the rivet surface scars clear, first of all, it is necessary to preprocess the photographs taken to remove the factors that affect the quality of the images, such as uneven illumination, noise and other interference, in order to highlight the unclear defects in the pictures. Then the image is processed by the defect recognition algorithm, which can determine the location of these defects in the image, and display their characteristic information for staff reference [14-15].

3.1 Pretreatment

The pretreatment stage of this paper is mainly divided into the following steps:

1) Grayscale and histogram equalization: The collected RGB images are converted into gray images, and the unnecessary color information is removed. Then, the contrast of images with small dynamic range of gray values is enhanced by histogram equalization.

2) Image filtering: This paper uses median filtering, which can effectively remove impulse noise and protect the edge details of the image while de-noising.

3) Image enhancement: Contrast enhancement is used to improve the contrast of defective images, so as to improve the overall darkness or brightness of the image due to illumination, mechanical vibration and other factors.

4) Image binarization: Defect image is divided into two parts: background and target by threshold constraints, and the pixels in the threshold are classified as target 1, and the pixels outside the threshold are classified as background 0, so as to achieve the purpose of making the target detection easier and clearer in the later stage.

5) Binary image filtering: The binary image filtering in this paper is mainly the area filtering of the connected area. The noise of small area is removed to filter and denoise [16].

In the process of image processing, the quality of preprocessing has a great influence on the accuracy of subsequent image recognition. In this paper, the key to affect the quality of preprocessing is the selection of thresholds in image binarization. After a lot of experiments, this paper chooses the method of dynamic threshold adjustment to determine the threshold, and the effect is remarkable.

The main step of image binarization is to find the appropriate threshold. The image is prone to degradation or noise interference because of the open location, shooting conditions, background and other factors. Combining the above characteristics, this paper chooses the method of dynamic adjustment of threshold based on Kirsh operator to calculate the threshold.

The basic idea of Kirsh operator is that for each pixel I of defective image, the gray value of eight adjacent points around it is considered, and the difference K(i) is obtained by subtracting the weights of the other five adjacent points from the weights of three adjacent points. Then three adjacent points are shifted around i, and eight differences are calculated by the same method. The maximum of the eight differences is taken as the Kirsh operator.

Assuming that Si is the sum of three adjacent points and Ti is the sum of the other five adjacent points, the Kirsh operator is defined as:

$$\mathrm{K(i)} = \max\{1, \max(5\mathrm{Si} - 3\mathrm{Ti})\} \tag{1}$$

Assuming that the threshold is TH, when $\mathrm{K(i)} > TH$, the pixel I is a step edge point.

Assuming that the size of defective image is $\mathrm{H} \times \mathrm{W}$ pixels, the edge pixels of defective image will not exceed 5H. For the image with defective object, this is a limited value with a large range. In this paper, Kirsh operator is used to take a lower initial threshold TH. For each pixel point i, its Kirsh operator is calculated. If $\mathrm{K(i)} > TH$, i is the edge point, and the edge point N plus 1 (the initial value of N is 0). When the number of edge points exceeds 5H and i is still less than the number of pixels in the defective image, it means that the threshold is too low to detect many non-edge points, so we need to improve the threshold.

In order to adapt to most defective images, the initial threshold TH is set relatively low, so that the image with small difference between defective target and background can also be detected. However, such a result can lead to a large difference between the initial threshold TH and the real threshold of some images. Therefore, it is necessary to find a more appropriate threshold for detection. On the basis of Kirsh operator, this paper adjusts the threshold dynamically. The adjusting steps are as follows:

1)If $\mathrm{K(i)} > TH$, then i is the edge point. We should record the coordinates of point i and the minimum value of $\mathrm{K(i)}$ $K(i)_{min} = \min\{K(i)\}$, N plus 1.

2) When $\mathrm{N} \geq 5\mathrm{H}$, the threshold is adjusted to the minimum value satisfying the minimum edge requirement, $\mathrm{TH} = K(i)_{min}$.

3) Comparing the previous edge points with the new thresholds, selecting the points larger than the new thresholds as the new edge points, and recalculating the $K(i)_{min}$ under the new thresholds to get the new edge points N_{new}.

4) Assigning new edge points to N.

5) Return to the first step. If $\mathrm{N} \geq 5\mathrm{H}$, repeat the second step until $\mathrm{N} < 5\mathrm{H}$.

Figure 1 shows a comparison between the image after binarization using dynamic threshold and the image after binarization in reference [2]. From the comparison results of two methods to determine the threshold, we can find that the top scar on the rivet convex surface in Fig. 1(b) is more obvious than that in Fig. 1(a). From the test results in Ref. [2], we can know that this scar has not been detected, but using the method in this paper, this scar has been detected. At the same time, by comparing the images of 1(c) and 1(d), we can find that the contour of the scar notch is more perfect by using dynamic threshold method.

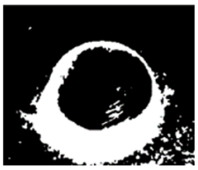

Fig. 1(a) Threshold method of rivet convex surface in reference

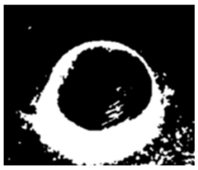

Fig. 1(b) Dynamic threshold adjustment method for rivet convex surface

Fig. 1(c) Threshold method of rivet concave surface in reference

Fig. 1(d) Dynamic threshold adjustment method for rivet concave surface

Figure 1 Binary image

The pre-processing and post-processing images are shown in Figure 2. As can be seen from the images Fig.2(b) and Fig.2(d), the defects of the preprocessed image can be clearly seen. It is easy to locate the defect in the post-processing.

ISSN 2616-5775 Vol. 8, Issue 4: 11-18, DOI: 10.25236/AJCIS.2025.080402

Fig.2(a) Image before preprocessing for rivet convex surface

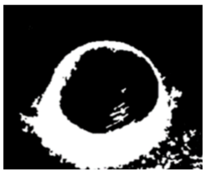

Fig.2(b) Image after preprocessing for rivet convex surface

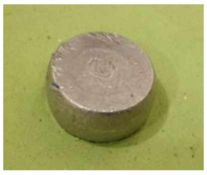

Fig.2(c) Image before preprocessing for rivet concave surface

Fig.2(d) Image after preprocessing for rivet concave surface

Figure 2 Images before and after preprocessing

3.2 Defect Recognition of Rivet Surface

In order to improve the detection rate of defect image, multi-step processing of image is needed. Step by step, finally achieve the purpose of detection and recognition. Figure 3 shows the process of defect image detection and recognition on rivet surface.

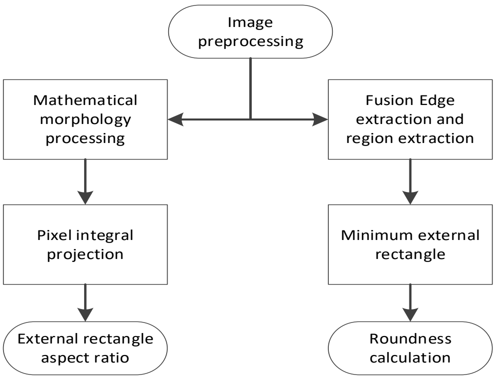

Figure 3 Defect image detection and recognition process of rivet surface

In the stage of wound recognition, because of the difference of the shape of the wound, using the same feature extraction and segmentation method will reduce the accuracy of the wound recognition, and the false detection rate is high. In this paper, different methods are used to extract and recognize the features of the wounds. Mathematical morphology is used to identify the features of the linear wounds, while the fusion edge extraction and region extraction are used to identify the features of the arc wounds.

3.2.1 Linear Defect Recognition

Linear defects can be identified by morphological regional features in the recognition stage. This paper uses digital morphological methods to identify them. Figure 4 shows the image after the mathematical morphology operation.

Figure 4 Preliminary defect recognition based on mathematical morphology

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3.2.2 Arc Defect Recognition

In this paper, the method of fusion edge extraction and region extraction is used for arc defect recognition [17]. Canny operator is used to extract edges. Combining the region growing algorithm with Canny operator can make the contour of arc-shaped defects clearer and improve the recognition accuracy. The recognition image based on the fusion edge extraction and region extraction algorithm is shown in Figure 5.

Figure 5 Image based on edge extraction and region extraction algorithm

3.3 Defect Judgment and Location

Because this paper judges the defects of two different shapes, different methods are chosen to judge and locate them according to their different characteristics.

3.3.1 Linear Defect Judgment and Location

In order to accurately get the region information of defects, this paper divides the defects into rows and columns. The so-called line segmentation method based on pixel integral projection refers to the horizontal pixel integral projection of the defective binary image, and then the line gap is used to segment the defect from the background image. Column segmentation method is to do vertical pixel integral projection on the defective image which has been segmented by rows.

The pixel integral projection used in this paper can be roughly divided into the following steps:

1) Selection of image centers.

For the preprocessed defect image, this paper denotes it as I(i, j), where m and n represent the total number of rows and columns of the image, respectively. In the image, point $\mathrm{C(c1, c2)}$ is taken as the center point, where $\mathrm{c1} = \frac{m}{2}$ and $c2 = \frac{n}{2}$.

2) Pixel integral projection of defect image

$\mathrm{I(i, j)}$ is a defective image, $\mathrm{g(i, j)}$ is a corresponding pixel, n represents the number of columns of the image, then the horizontal pixel integral projection is:

$$\mathrm{H(i)} = \sum_{j=1}^{n} g(i, j) \tag{2}$$

m is the number of rows of the image, and the vertical pixel integral projection is:

$$\mathrm{D(j)} = \sum_{i=1}^{m} g(i, j) \tag{3}$$

3) Determination of defect boundary

The image $\mathrm{I(i, j)}$ is projected horizontally by using formula (2) and scanned upward and downward from point $\mathrm{c1}$. The line gap of the defect is used to determine the integral value of the horizontal pixel integral projection, and the upper and lower boundaries of the defect are determined.

$$(\mathrm{H(i-1)} > \mathrm{h}) \cap (\mathrm{H(i-2)} > \mathrm{h}) \cap \cdots \cap (\mathrm{H(i-r)} > \mathrm{h}) \cap (\mathrm{H(i)} < \mathrm{h}) = 1 \tag{4}$$

$$(\mathrm{H(i+1)} < \mathrm{h}) \cap (\mathrm{H(i+2)} < \mathrm{h}) \cap \cdots \cap (\mathrm{H(i+r)} < \mathrm{h}) \cap (\mathrm{H(i)} > \mathrm{h}) = 1 \tag{5}$$

In the formula, h is the threshold of line segmentation, ideally 0. This paper chooses it as 1 and r as the threshold to distinguish the line gap. This paper fixes on 1.

Similarly, using formula (3) for vertical pixel product projection, from point $\mathrm{c2}$, scanning from left and right directions, the left and right boundaries are obtained. The expressions are as follows:

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$$(\mathrm{D(j-1)} > \mathrm{d}) \cap (\mathrm{D(j-2)} > \mathrm{d}) \cap \cdots \cap (\mathrm{D(j-s)} > \mathrm{d}) \cap (\mathrm{D(j)} < \mathrm{d}) = 1 \tag{6}$$

$$(\mathrm{D(j+1)} < \mathrm{d}) \cap (\mathrm{D(j+2)} < \mathrm{d}) \cap \cdots \cap (\mathrm{D(j+s)} < \mathrm{d}) \cap (\mathrm{D(j)} > \mathrm{d}) = 1 \tag{7}$$

In the formula, d is the threshold of column segmentation. This paper chooses it as 1 and s to distinguish column gaps. In this paper, 25 is fixed.

The projection curves can be drawn by horizontal and vertical pixel integral projections, so as to locate the specific area and parameter information of defects. Figure 6 shows its projection curve.

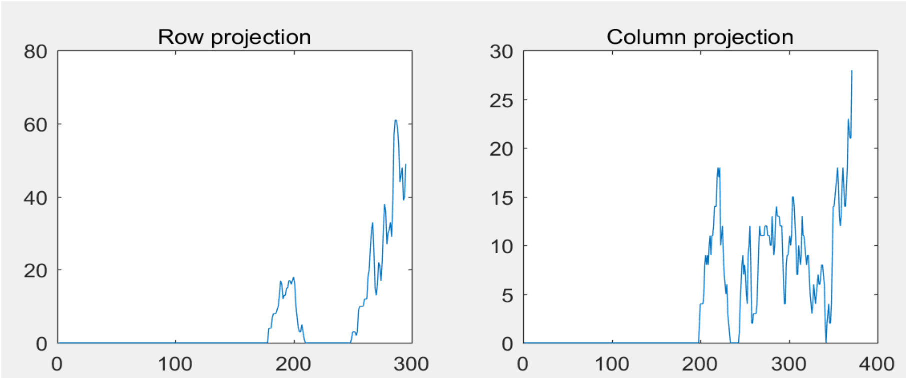

Figure 6 Projection curve of image

Pixel integral projection of image can extract the horizontal and vertical boundary of defects. This paper mainly identifies the vertical and horizontal defects in defects. In order to better judge the direction of defects and get more defect feature information, this paper adopts the simplest and quickest method of defect detection by using the minimum length-width ratio of the outer rectangle. Firstly, the method rotates with an incremental step of 3°in the defect e° range. After each increment is rotated, a set of characteristic parameters information of the outer rectangle is obtained. When comparing all the parameters information, the rectangle area A reaches the minimum, then the rectangle is the smallest outer rectangle. L is the length of the smallest outer rectangle in the connected area and W is the width of the smallest outer rectangle in the connected area. In this paper, the ratio R of rectangular length to width is chosen as the criterion to judge the direction of defects. When the ratio R is greater than 1, it is a transverse defect, otherwise it is a longitudinal defect. The formula is as follows:

$$\mathrm{R} = \frac{L}{\mathrm{W}} = \begin{cases} \text{Transverse defect}, & R > 1 \\ \text{Longitudinal defect}, & Others \end{cases} \tag{8}$$

The processed linear defect image is shown in Figure 7. Compared with the linear defect image in reference [2], it can be found that the defect treated by this method is more perfect, especially the top one. The scar was not identified in reference [2].

Figure 7 Processed linear defect image

3.3.2 Judgment and Location of Arc Defects

In order to extract the geometric features of defect image, the feature parameters of the target area of defect image should be calculated first. In this paper, the minimum outer rectangular model is selected to obtain the information of characteristic parameters, and then the circularity calculation is used to determine whether it is a circular arc defect, finally the defect is located.

The formula for calculating roundness is as follows:

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$$r = \frac{4 \times \pi \times S_n}{C^2} = \begin{cases} Arc\ defect,\ 0.85 \le r \le 1 \\ Non-circular\ arc\ defect, Others \end{cases} \tag{9}$$

Among them, r: defect roundness; S_n: defect area; C: defect area circumference.

After a series of processing, the image of arc defect is shown in Fig. 8. After careful observation of Figure 8, we can find that it is compared with reference [2]. The Defect Outline identified in this paper is more complete, especially the arc defect gap is clearer. It can be concluded that the dynamic threshold method is more suitable for this experiment.

Figure 8 Arc defect image

4. Conclusion

In this paper, a method of defect detection and recognition using image processing on the surface of aircraft rivet is proposed. According to the collected image, the defect detection algorithm is used to determine whether the rivet surface is defective or not, and the defect image is obtained by judging the defect. As shown in Figure 9, compared with the defect image identified in reference [2], the defect identified in this paper is more perfect. In the process of linear defect recognition, this paper can identify the top defect in the defect image. In circular arc defect recognition, the method proposed in this paper can fill in the missing defects in reference [2]. Therefore, the method presented in this paper can effectively overcome the errors and inefficiencies caused by manual detection [18]. In addition, on this basis, we hope that we can add other algorithms, at the same time, we can add neural network for training, and design a perfect system to achieve the purpose of classifying and identifying different defects.

Fig.9 (a) Linear defects identified in reference

Fig.9 (b) Linear defects identified in this paper

Fig.9 (c) Circular arc defects identified in reference [2]

Fig.9 (d) The circular arc defect identified in this paper

Figure 9 Defect recognition contrast image

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