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Printed circuit board defect visual detection based on wavelet denoising

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Abstract. In order to realize automatic inspection of printed circuit board (PCB) surface defects, the PCB defect automatic recognition technologies based on image processing and machine vision were studied. Firstly, the detected PCB color image and the standard PCB color image were grayed, and the visual effect of the detected image was improved by wavelet denoising and histogram equalization enhancement techniques. Secondly, the detected image and the standard image were calibrated, and the defects were extracted through the differential processing between them. Thirdly, the defect images were processed by the Otsu image segmentation and morphological method to get the binary images. The defect features were extracted and marked on the images. Finally, the type of the defects was determined according to the defect characteristics and its neighboring image. Five defects such as short circuit, open circuit, sag, bulge and hole, were detected and identified. Experimental results showed that the detectable rate of defects was 100%, and the recognition rate was over 90%, which can meet the need of real-time detection of industrial production lines.

1. Introduction

At present, the printed circuit board (PCB) industry has achieved rapid growth. In 2017, the global PCB market was nearly 60 billion US dollars. Correspondingly, it is necessary to detect these PCB to ensure the qualified rate. The traditional PCB defect detection method is manual detection, however, it has the disadvantages of high human detection costs, low detection efficiency, and inability to meet the shortcomings of high-speed and high-precision inspection requirements in the production line. It is an inevitable trend to replace manual detection by machines.

With the rapid development of electronics and computer technology, machine vision has developed into an important method for PCB surface defect detection [1]. Many common defects of PCBs such as solder joints [2], solder pastes [3], and welds [4], can be found in the literature. The detection algorithm is one of core technologies to detect PCB detection. The earliest developed PCB inspection algorithm is known as template-matching technique as proposed by Akiyarnai et al. [5]. At present, many algorithms including neural networks [4][6], fuzzy reasoning [7], adaptive iterative threshold selection algorithm [8], were proposed for PCB defects inspection.

This paper studies the PCB defect visual inspection technology based on wavelet denoising and feature extraction for rapid detection and identification of PCB defects.

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2. PCB defect detection

The PCB defect detection system is mainly composed of linear array CCD camera, lens, light source, control unit, image acquisition card, industrial computer and image processing software. When PCB defects are detected, the software sends the instructions to the PLC through the serial port to start the pipeline. The detected PCBs are placed on the pipeline. When the detection machine is entered, the camera photoelectric sensor is triggered, and the PC machine controls the CCD camera to take an accurate picture of PCB. The special image acquisition card is transmitted to the PC machine to get the digitized information of the image. PCB defect information is obtained through digital image processing and analysis technology. The built PCB defect detection experimental system used Daheng's true color linear CCD camera and LED line light source. The resolution of the CCD is 1024×1024 pixel, the pixel size is 10 μm×10 μm, the focal distance is 50 mm. The light wavelength of LED line light source is 388~758 nm.

3. PCB image preprocessing

3.1. PCB image grayscale

Grayscale images, like color images, still reflect the distribution and characteristics of the overall and local color and brightness levels of the entire image. However, due to the large amount of color image data, the overhead on the storage is large and the processing speed is slow, so it often turns the color image into a gray image. The basic method is to replace each component by averaging the three components of each pixel in the image.

3.2. Wavelet denoising of PCB image

Wavelet transform is a time scale analysis method, and it has good localization characteristics in time domain and frequency domain, which made it often used in image enhancement, denoising and coding. The practical wavelet transform is usually discrete wavelet transform. Discrete wavelet transform is one of the most used methods.

For two-dimensional discrete signal f (x, y), the basic idea of wavelet transform is to decompose it based on wavelet function. H and g are the low-pass and high-pass filters of the wavelet function respectively. Its two-dimensional wavelet transform decomposition formula is as follows:

$$f_i(m,n) = \sum_{k_1,k_2\in z} h(k_1-2m)h(k_2-2n)f_{j-1}(k_1,k_2) \tag{1}$$

$$W_j^1 f(m,n) = \sum_{k_1,k_2\in z} g(k_1-2m)h(k_2-2n)f_{j-1}(k_1,k_2) \tag{2}$$

$$W_j^2 f(m,n) = \sum_{k_1,k_2\in z} h(k_1-2m)g(k_2-2n)f_{j-1}(k_1,k_2) \tag{3}$$

$$W_j^3 f(m,n) = \sum_{k_1,k_2\in z} g(k_1-2m)g(k_2-2n)f_{j-1}(k_1,k_2) \tag{4}$$

Where, $f_0(m,n)$ is the original two-dimensional discrete digital signal. $f_j(m,n)(j>0)$ represents the low-frequency information of the original signal in horizontal and vertical directions at different scales. $W_j^1 f(m,n)$ represents the details along the diagonal direction. $W_j^2 f(m,n)$ represents vertical and horizontal low frequency information. $W_j^3 f(m,n)$ represents the details along the diagonal direction. After the image is decomposed by wavelet, the four channel wavelet signal is obtained. After the image is decomposed by wavelet, four-channel wavelet signals are obtained: low frequency, horizontal high frequency, vertical high frequency and diagonal high frequency. Each channel corresponds to the information of the original image in the same scale and direction.

Wavelet transform mainly has the characteristics of low entropy, multi-resolution characteristics, decorrelation and flexibility of selecting basis function. Wavelet domain denoising transforms the noisy image signal into multi-scale wavelet transform. At each scale, the wavelet transform of the

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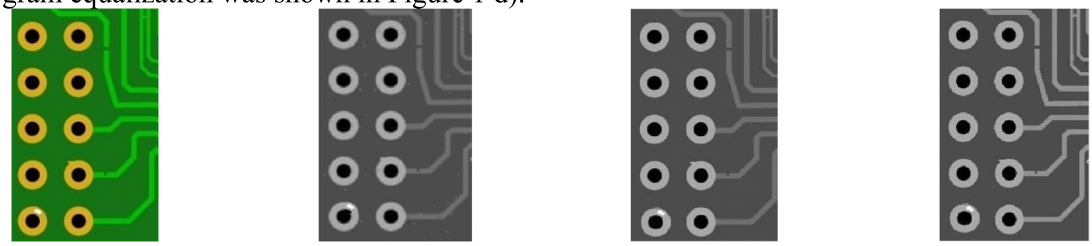
signal is separated from the wavelet transform of noise, the transform coefficient of noise is discarded, and the de-noising signal is changed from the remainder transform coefficient.

PCB image preprocessing results were shown in Figure 1. Figure 1 a) was the initial image including defects and noise. The result of wavelet denoising was shown in Figure 1 b).

3.3. PCB image enhancement

The purpose of image enhancement is to facilitate the analysis and processing of images by human or computer. The methods of image enhancement mainly include spatial domain processing and frequency domain processing. Image spatial domain processing mainly includes gray scale transformation and histogram equalization. The basic idea of histogram equalization is to broaden the number of pixels in the image, and reduce the gray level of the number of pixels. This article adopts histogram equalization method for image enhancement. The result of the image enhancement based on histogram equalization was shown in Figure 1 d).



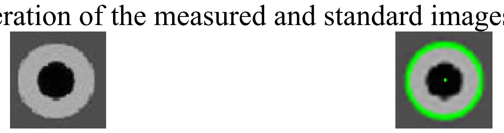
a) b) c) d)

Figure 1. PCB image preprocessing, a) PCB color image, b) Grayscale image, c) Wavelet denoising, d) image enhancement

3.4. Image registration and differential image detection

Image is very important and directly related to the effect of defect extraction. The measured and standard images registration is needed precisely before difference operation. Image registration is the process of matching and superposing images of different times, different sensors or different conditions. The main registration algorithms include Hough transformation, template matching and Harris corner feature, etc.

Hough transform method has good anti-interference performance and the positioning marks on the PCB are simple, so the Hough transform was selected to position the PCB board. The coordinate position of the center point of the positioning hole was used as the feature point of the image matching. Figure 2 showed the results of image registration using Hough transform. The defect image was obtained by the difference operation of the measured and standard images.



a) b)

Figure 2. image registration based on Hough transform, a) positioning circle, b) Hough transform

4. PCB image defect extraction

The defect extraction of PCB images mainly includes the binary segmentation and morphological processing of differential image, and binary defect images are obtained for feature extraction and recognition.

4.1. PCB defect threshold method segmentation

The Otsu method is one of the methods for automatically determining the threshold value, and has the features of simple and fast processing. The criterion for determining the optimal threshold by the Otsu method is to minimize the intra-class variance or the inter-class variance of each pixel class after the threshold segmentation.

It is assumed that the total number of pixels of the image is N, the total number of gray scales is L, and the number of pixels of gray value i is N_i. $\omega(k)=\sum_{i=0}^{k}\frac{N_i}{N}$ and $\mu(k)=\sum_{i=0}^{k}\frac{i\cdot N_i}{N}$ respectively represent the appearance probability and average gray scale of pixels from gray scale 0 to gray scale k. The total probability of all pixels is $\omega(L-1)=1$, and the average grayscale of the image is $\mu_T=\mu(L-1)$.

The intraclass variance is:

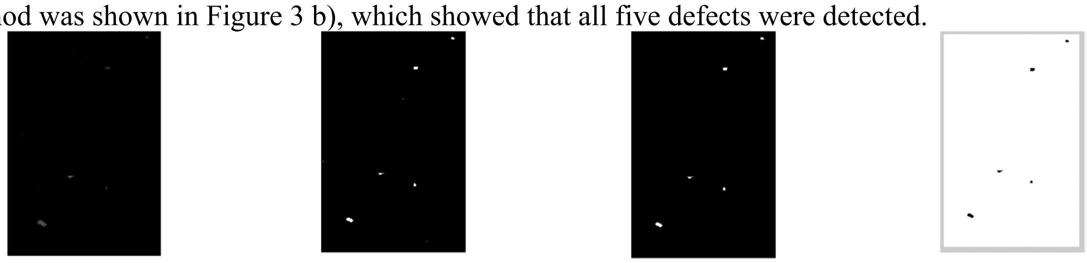
$$\sigma_W^2(t_1,t_2,\ldots,t_{M-1})=\sum_{j=1}^{M}\omega_j*\sigma_j^2 \tag{5}$$

The variance between classes is:

$$\sigma_B^2(t_1,t_2,\ldots,t_{M-1})=\sum_{j=1}^{M}\omega_j*(\mu_j-\mu_T)^2 \tag{6}$$

The threshold group $(t_1,\ t_2,\ldots,\ t_{M-1})$ of minimizing Formula (5) or maximizing Formula (6) is used as the optimal threshold group for M thresholding. If M is taken as 2, that is, divided into 2 categories. The binarization optimal threshold can be obtained by the method.

The Otsu method has a good segmentation effect. The segmentation effect based on the Otsu method was shown in Figure 3 b), which showed that all five defects were detected.



a) b) c) d)

Figure 3. Defect image segmentation and morphological processing, a) Gray scale of defect to be measured, b)Binarization of defect image, c)Morphological processing, d) Image inversion

4.2. Morphological processing

According to the small noise and some discontinuous defect edges in the binary image, it is possible to use the open and closed operations in the morphological operations for denoising and edge connection. Both open and closed operations consist of erosion and dilation operations. The open operation is the operation of using the same structural element to erode the image before it is eroded. The opening operation is usually used when small particle noise needs to be removed and the adhesion between target objects is disconnected. The open operation has the advantage of keep the original size of the target unchanged. The closing operation is used to fill small voids in objects, connect adjacent objects, and smooth their boundaries without significantly changing their area.

In this paper, circular structure elements were used to open and close binary images to remove noise. The processing result was shown in Figure 3 c). In order to better calculate the characteristic information of the image, Figure 3 c) was inverted to Figure 3 d).

5. Feature Extraction and Recognition of PCB Image Defects

5.1. Defect feature extraction and marking

After getting the defect image, each defect needs to be marked the feature values, such as serial number, edge outline, position, and area and so on. In order to identify the defects conveniently, the defects are located in the grayscale image of the PCB, and then the defect type is determined according to the defect characteristics. Figure 4 a) shows the defect number, profile, and area. Figure 4 b) marks the defect information on the gray image.

a) b)

Figure 4. Defect Feature Extraction and Marking, a) Defect Feature Extraction, b) Defect Marker

5.2. Identification of defects

As shown in Figure 5, the major defects in PCBs are short circuits, open circuits, depressions, bumps, and holes, etc. Different defects have different features and have different relationships with neighbouring images, therefore, according to the feature, the types of defects can be determined.

a) b) c) d) e)

Figure 5. Defect Type, a) Short circuit, b) Open circuit, c) Depression, d) Protrusion, e) Hole

The difference between open circuit and short circuit and other defects is that the number of connections is different, so if the number of connections around the defect increases, the inspection result is an open circuit. On the contrary, if the number of connections is reduced, the inspection result in a short circuit. The depressions, bulges and holes can be judged according to the defect area. If the defect area increases, it is a protrusion or a burr. If it decreases, it is a depression or a hole. Hole is created inside the circuit. Depressions are generated at the edges of the circuit. Therefore, the pixel values at the edge of the defect will be different. The pixel value outside the edge of the hole is close, and the pixel value outside the edge of the recess is greatly different. A threshold judgment can be set. The defect with the gray difference greater than the threshold is judged as a recess, and the defect with a value less than the threshold is judged as a hole. By analyzing the above defects characteristics, the defect types can be determined.

The above method was used to detect and identify the defects, such as short circuit, open circuit, depression, bulge, and hole. The test results were shown in Table 1. It can be seen from the table that the defects were completely recognized.

Table 1. Detection results of PCB defects

No.	Position X	Position Y	Area	Defect type
1	40	256	91	Holes
2	78	195	41	Raised
3	125	50	66	Open circuit
4	124	209	26	Depression
5	174	10	33	Short circuit

In this paper, 30 PCB defect images were taken as experimental samples, and the defects were detected and identified by the defect detection method above. The test results were shown in Table 2.

It can be seen from the table that the detectable rate of the five kind of defects was 100%, and the recognition rate was over 90%. All defects were detected and the recognition rate is high. However a hole was misjudged as a short circuit. The analysis showed that the hole boundaries were close to the edge of the circuit due to the large hole area, which caused the misjudgement.

Table 2. Analysis of PCB defect detection and recognition results

Defect type	Defect number	Checkout number	Identification number	Detection rate / recognition rate
Short circuit	12	12	12	100% / 100%
Open circuit	18	18	19	100% / 106%
Depression	22	22	22	100% / 100%
Raised	17	17	17	100% / 100%
Holes	24	24	23	100% / 95.8%

6. Conclusion

This paper mainly studied the PCB defect detection technology based on image processing and computer vision. Five defects including short circuit, open circuit, sag, bulge and hole, were detected and identified. Through the image pre-processing and differential processing, the defects of the images were obtained. The defect features were extracted and marked. Different algorithms were designed to detect and identify defect types based on different characteristics of defects. The results showed that the detectable rate of defects was 100%, and the recognition rate was over 90%, which can meet the need of real-time detection of industrial production lines.

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