INSPECTION OF DEFECTIVE PRINTED CIRCUIT BOARDS USING IMAGE PROCESSING

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Abstract

The goal of this paper is to present the inspection of defective Printed Circuit boards with the help of image processing. As Image processing is an important and useful toolbox in these days. Printed circuit boards (PCBs) are the fundamental component of electronic devices. The performance of the electronics product depends on the quality of PCBs. The defects detection (if any) in the first stage of manufacturing process (on bare PCB) reduces the overall manufacturing cost of PCBs. In this paper, defects detection on bare PCB images is presented using different image processing techniques.

Keywords: PCBs; image subtraction; coefficient; histogram; entropy; mean square error; peak signal to noise ratio; similarity structural index measure.

1. Introduction

Image processing is a process of images using different mathematical operations by using one of the forms of signal processing. In this paper, image processing is used with the combination of Printed circuit boards. Printed circuit board (PCB) is a necessary component of many electronic devices such as computers, appliances, and telecommunication [1].It is mechanically supported and electrically connects different components of electronics using conductive tracks, pads and other features from laminated copper sheets on a conductive substrate. In general, they are the substrates that provide the electrical interconnect of the circuit [2].Printed circuit boards have recently been at the heart of this progress due to their small size and functionality ability. There is a [1]high need to ensure proper functioning of PCBs before being used because of the high cost associated with electrical failure.The performance of electronic products depends on the quality of PCBs [1].The quality control at every production stage has been needed by manufacturers [2]. The PCBs must be checked, to achieve the best quality of electronics products [4]. The PCBs can be verified manually by the humans. But there are many drawbacks of human inspection as stated next [1] [5]:

1) More chances of mistakes due to human error
2) Slow
3) Less consistent than automated inspection system.

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4) The circuits on PCBs are becoming much finer and more complex, making human visual inspection a challenge.
5) High labour cost of inspectors.

The above problems increase as the board becomes more complex. For this, we need to develop an efficient automatic inspection system which will detect the defective PCBs. As there is no damage or contamination of the PCBs from the human handling. Thus, the error rate decreases in automatic methods. In this paper, proposes different approaches and techniques for detection of defects in PCB images.

2. Material and Methods

Following material and methods have been used for proposed work:

2.1 Types of Defects

It is important to inspect the PCBs before insertion of components and the soldering process because there are defects which have a range from the hairline to unacceptable enlargements and reductions in line widths to poorly form plated through holes [6]. The defects are classified mainly into two groups: Potential and fatal defects. Fatal defects are those in which the PCB does not meet the objective for which it is designed e.g. short-circuit and open-circuit defects. Potential defects are those which compromise the PCB performance during utilization e.g. breakout, under etch, missing hole [7]. Fig.1 (a) shows the PCB image pattern with no defects and Fig.1 (b) shows an image with a number of defects.

2.2 Methods for PCB Inspection

There are mainly two approaches which are used for visual inspection of PCBs:

2.2.1. Referential method

In the referential method, some features of the printed circuit boards (the PCBs which have to be inspected or tested for defect detection) is compared with reference PCB (PCB with no defects). It is a point to point comparison method.

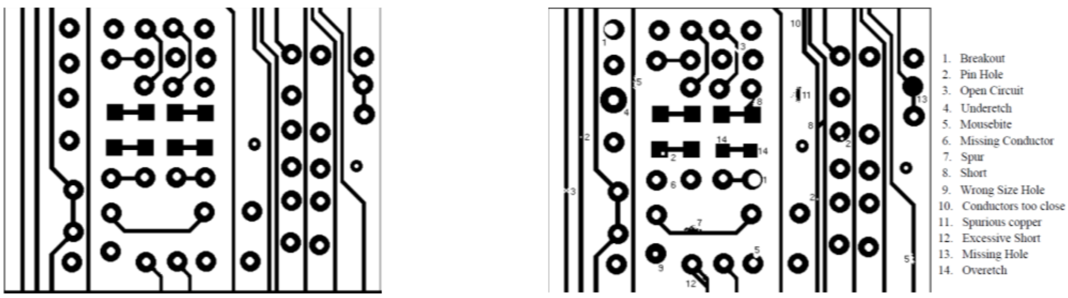
2.2.2. Non-referential method

This type of method uses the generic rules for PCBs, also known as design rule verification method. This technique uses design characteristics like minimum and maximum trace widths for all the different traces, minimum and maximum circular pad diameters, minimum and maximum hole diameters, minimum conductor clearance, minimum annular rings and trace dimensions for testing. This approach uses no reference pattern for defect detection.

Main requirements of PCBs inspection system are [6]:

1. High speed
2. High data rate
3. High detection accuracy
4. Low false-alarm rate

In this paper, we use the referential methods for detection of defective PCBs.



(a)

(b)

Fig.1 (a) defect free PCB image pattern [6] Fig. 1(b) PCB image with number of defects [6]

2.3 Techniques for Inspection of Defective PCBs based on image processing

Different methods based on image processing for finding defective PCBs are as follows:

2.3.1 Image subtraction

To get the difference between two images, image subtraction has been performed [7]. In this method, the two images are used in which one is taken as a reference image and other as test image (the image which has to be tested or inspected).

The following rules are applied for image subtraction operation [7]:

Rule 1: If 1-0 = 1 then it gives positive pixel image

Rule 2: If 0-1 = -1 then it gives negative pixel image

Both the images have been subtracted from each other to get the two resultant positive and negative images. And at the end both positive and negative images are added to get all possible defects on the PCBs [8].

Positive Image=Reference image - Test image (1)

Negative image= Test image - Reference image (2)

The addition of the positive image and the negative image gives all potential defects present in the test image. Many researchers have used this technique for finding the defects on PCBs [9, 10, and 11]. Fig. 3 shows the result of the implementation of this method on PCB images.

2.3.2. Correlation coefficient

This is another commonly used method for defect detection in PCBs based on referential technique. In this process, the correlation between the two PCBs images is found. Its value varies between -1 and 1. If it is equal to 0, it means no relationship and if it is equal to 1, it means both images are same or defect free. And if it is equal to -1, they are anti-correlated [12].

The correlation coefficient can be calculated as [13]:

$$r= \frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (3)$$

r is the Pearson's correlation coefficient ;

x_i is the reference image; y_i is test image ;

$\bar{x}$ and $\bar{y}$are the mean value of the pixels of the reference image and test image

2.3.3. Histogram

The distribution of numerical data can be represented on a graph by using a histogram. But in the case of digital image processing, the histogram shows the tonal distribution in a digital image. The horizontal axis of the graph represents the tonal variations, whereas the vertical axis represents the number of pixels of that particular tone. The left side of the histogram represents black and dark areas, and grey is represented in middle and light and pure white areas are on right side.

Many researchers have used histogram for finding information content in an image and used in the different application like face recognition, image registration and in medical applications like enhancing the local contrast of digital mammographic images [14, 15,16]. In this paper, we have used this technique for comparison of contained information in two images.

If information in both the images is same, the image would be defect free otherwise it would be a defective image. Hence in this way, the method is used to detect the defective PCBs.

2.3.4. Edge detection

Edges are known as the points where the brightness of image changes sharply and are organized into a set of curved line segments.Canny, LoG (Laplacian of Gaussian), Robert, Prewitt are widely used edge detection algorithm [17].

The main purposes of finding edges are as follows:

1. To locate the line drawing of a scene from an image of that scene.
2. To extract the relevant features like corners, lines and curves.
3. To find the discontinuities in depth and surface orientation.

So by applying edge detection techniques, the boundaries of objects, the boundaries of surface markings as well as curves that correspond to discontinuities in surface orientations can be detected.

Advantages of using edge detection are as follows:

1. It will reduce the amount of data to be processed.
2. It filters out the information that may be less relevant.
3. It preserves the important structural properties of an image.

In this paper, edges of two images have been found and compared with each other. If both are same, it would be defect-free image otherwise, it would be defected.

2.3.5. Similarity structural index measure (SSIM)
This method has been used for predicting the perceived quality of digital images, image matching, retrieval and analysis [18].

The SSIM can be calculated as:

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c1)\,(2\sigma_{xy} + c2)}{(\ \mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2\ )} \quad (4)$$

x is the reference image and y is the test image;
μ_x is average of x;
μ_y is the average of y;
σ_x^2 and σ_y^2 are the variance of x and y;
c_1 and c_2 aretwo variables to stabilize the division with weak denominator.
In this paper, SSIM is used to find the defective PCBs images. If the value of SSIM is 1, the PCB images would be defect free otherwise, it would be defective.

2.3.6. Mean Square error based (MSE)
In image processing, mean square error measures the averages of squares of the errors which is the difference between the two images. The difference occurs because of randomness of pixel values.
The mean square can be calculated as:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[x(i,j - y(i,j)]^2 \quad (5)$$

where x and y is reference and test image

In this paper, the mean square error is used to find the defective PCB images. If the two images are same, the value of MSE would be zero and it would be defect free otherwise it would be defective.

2.3.7. Peak signal to noise ratio (PSNR)
PSNR is a quality metric which provides a quality measurement based on squared error between the reference and test image. It is used in various application like template matching, compressed images and image quality [21], [22],[23].
It can be calculated as:

$$PSNR = 10.\log_{10}\left(\frac{MAX_I^2}{MSE}\right) \quad (6)$$

where MAX_I is the maximum possible value of pixel in an image. In gray scale images, its value is 255.

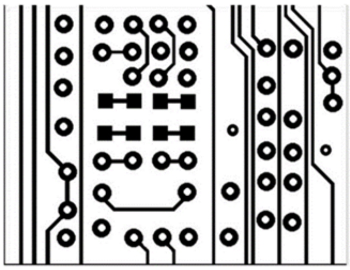
2.3.8. Entropy
In general, entropy is the expected value of the information contained in each message. Any change in information change. Itis a statistical measure of randomness that can be used to characterize the texture of the input image [24].It is employed in various applications like multiscale analysis, feature selection and image registration [25],[26],[27]. It can be calculated as:

Entropy= -sum(p.*log2(p)) (7)

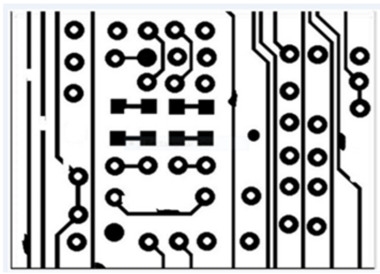
where p contains the histogram counts.

3. Results and Discussions

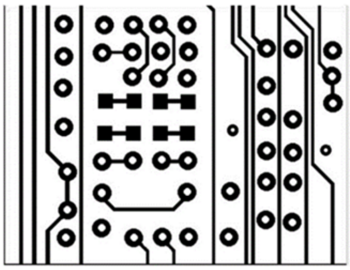
The methods presented in this paper were tested on three images. The defective images were manually generated from defect-free PCB image, used as a standard image in many papers. The following results have been generated using MATLAB. Fig. 2(b)-Fig. 2(d) shows the test images for inspection.



(a)



(b)



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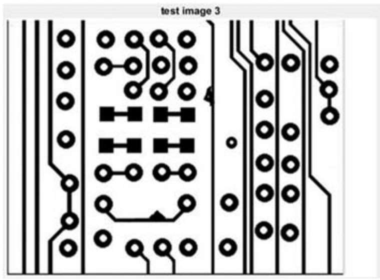
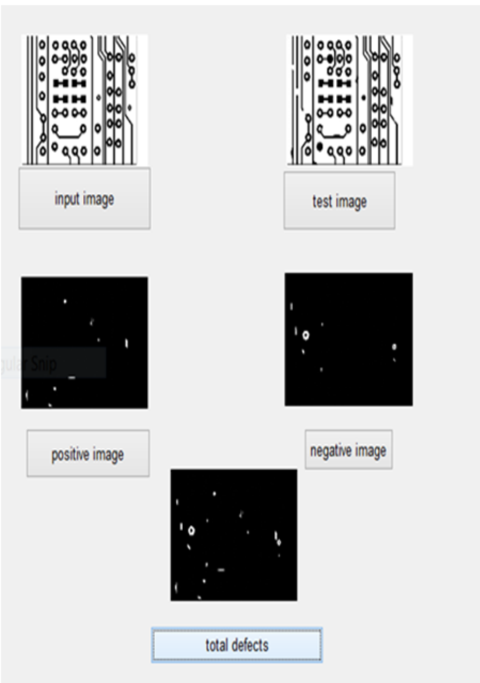


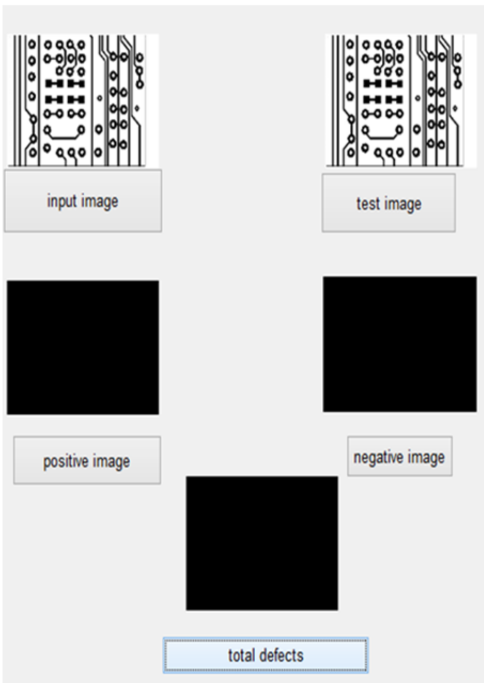
(d)

Fig. 2 (a) Reference PCB image (b) Test image 1 (c) Test image 2 (d) Test image 3

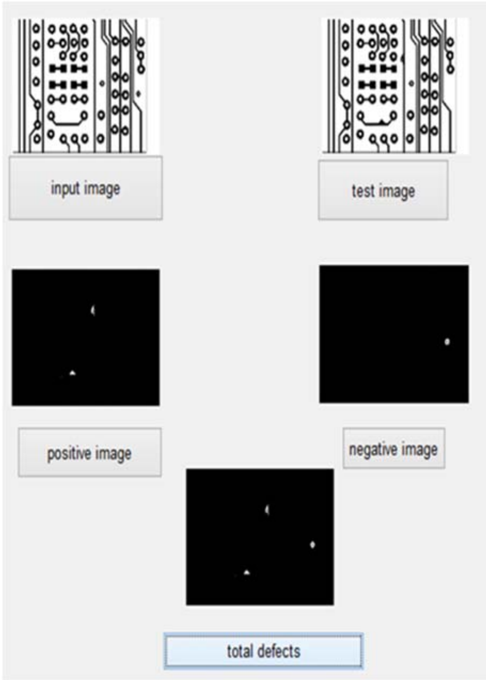
Results of image subtraction method are shown in Fig.3 (a) to Fig. 3(c).



(a)



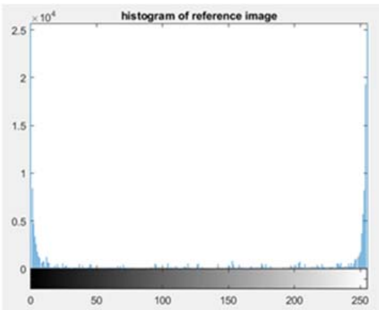
(b)



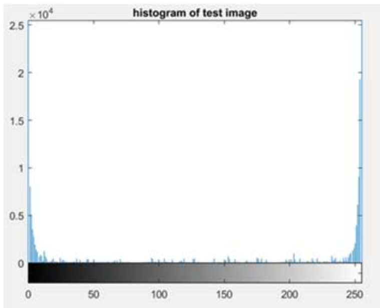
(c)

Fig.3 Results of image subtraction (a) Test image 1 (b) Test image 2 (c) Test image 3

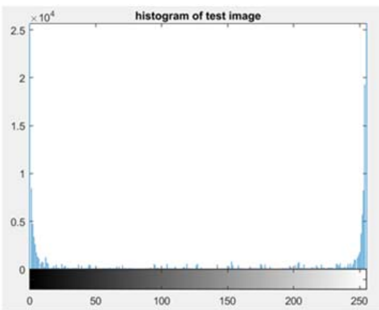
Figures from Fig. 4(a) to Fig. 4(d) show results of histogram-based technique.



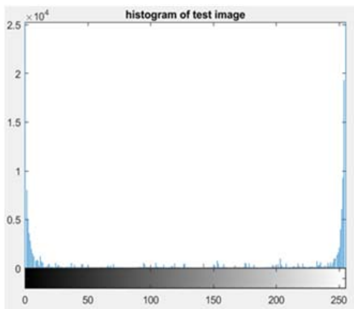
(a)



(b)



(c)



(d)

Fig. 4 Results of Histogram a) Reference image b) Test image 1 c) Test image 2 d) Test image 3

Results of edge detection are shown in Fig. 5(a) to Fig. 5(d).

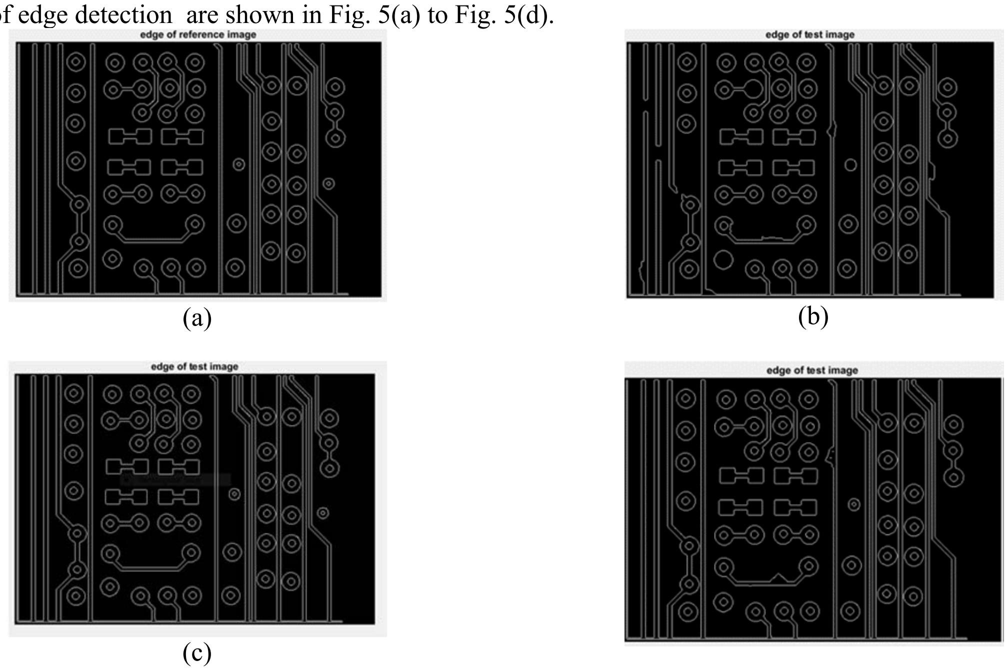


Fig.5 Results of Edge detection (a) reference image (b) test image 1 (c) test image 2 (d) test image 3

Table 1. Result of Inspection

Method used	Test image 1	Test image 2	Test image 3
Correlation Coefficient	0.9755	1	0.9927
SSIM	0.9782	1	0.9937
MSE	510.8465	0	151.8215
PSNR	21.0479	Inf.	26.3175
Entropy *	3.5228	3.5045	3.5633

* Entropy for reference image is 3.5045

Table 1 shows the result of inspection of test images using different techniques like correlation coefficient, SSIM, MSE, PSNR and entropy. The result of test image 2 shows that it is same as of reference image, because correlation coefficient is 1, which shows both the images are correlated with each other without any difference. SSIM of test image 2 is 1, which shows the similarity between two images. As there is no change of pixel values of reference image and test image 2, hence MSE is also 0.Entropy of reference and test image 2 is also same.

4. Conclusion

It is concluded that PCB defect detection is one of the important steps for manufacturing process. In this paper, different methods have been used to detect PCB defects. From the results, in Table 1, it has been concluded that test image 2 is defect free which is same as the reference image and test image 1 and test image 3 have defects. In this way the defected PCBs images have been detected using these software-based methods.

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