A Noise Elimination Procedure for Wavelet-Based Printed Circuit Board Inspection System

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Abstract

Image difference operation is frequently used in automated printed circuit board (PCB) inspection system as well as in many other image processing applications. The previously proposed wavelet-based PCB inspection approach also incorporated the point-to-point image difference operation as part of its algorithm. Unfortunately, during the implementation, this operation brings along the unwanted noise due to misalignment and uneven binarization. Thus, this paper proposes a method to eliminate, if possible, or to reduce as much as possible such noise during the computation of defect detection. The results of applying the proposed method showed a significant improvement during the real-time inspection of printed circuit boards.

1 Introduction

There exist numerous numbers of algorithms, techniques, and approaches reported in the area of automated visual PCB inspection to date. As stated by Moganti et al. [1], these can be divided into three main categories: referential approaches, rule-based approaches, and hybrid approaches.

Referential approaches, consists of image comparison and model-based techniques. Image comparison technique simply compares the tested PCB image against the reference PCB image using simple XOR logic operator [2]. Model-based technique, on the other hand, matches the tested PCB image by using a predefined model [3]. Rule-based approaches test the design rule of the PCB traces to determine whether each PCB trace fall within the required dimensions or not. Mathematical morphological operation is frequently used where dilation and erosion are basic operation [4]. Lastly, hybrid approaches combines the referential approaches and design-rule approaches to make use the advantages and overcome the shortcomings of each approach.

In the previous research work on the automated visual PCB inspection, we investigated a new PCB inspection technique, which is based on the wavelet transform [5-6]. The proposed wavelet-based PCB inspection algorithm falls in the referential approaches under the model-based techniques. As a result, from the simulation point of view, the inspection time of the proposed method showed a significant improvement compared to another methods, within the same category [7-8].

In the wavelet-based PCB inspection, an image difference operation is employed as part of the algorithm. During the real-time implementation, this operation normally contributes unwanted noise due to misalignment and uneven binarization and thus, the accuracy of the defect detection could be degraded. Hence, it is critically important to design a noise elimination procedure in order to eliminate, if possible, or rather to reduce as much as possible the noise cause by image difference operation.

In this paper, the noise elimination procedure employed during the implementation of the wavelet-based PCB inspection algorithm is proposed. It is discovered that if the image difference operation is performed as an image subtraction operation, the noise interference in the output image is actually the combination of noise in the positive and negative images. Note that after the image subtraction, three types of data are produced: *positive*, *negative*, and *zero* values of data. Only the two-dimensional data, images, of *positive* and *negative* value contain the undesired noise, if any, and the *zero* one did not affect the output of the algorithm. Due to this argument, one possible way to reduce the noise is by separating the image difference output into the positive and negative image by using image subtraction and then, the noise reduction is applied to the positive and negative images to remove unwanted noise occurs in the images. Next, the noise free positive and negative images are combined together to produce the output of the inspection. Before the image difference operation is utilized, it is also important to bring the tested and reference image as close as possible during alignment. In this inspection system, the manually mechanical and software approaches are employed for the alignment purpose.

Before the defect elimination is discussed in more details, the wavelet-based PCB inspection will be presented to provide a brief picture of various operations involved in the inspection system. The more details of this algorithm can be found in [9].

2 Wavelets

Wavelet is a zero mean function [10] and satisfies the so-called *admissibility condition* [11]:

$$C_\psi = \int_{-\infty}^{\infty} \frac{|\hat{\psi}(\omega)|^2}{\omega} d\omega < \infty \qquad (1)$$

where ψ is a fixed function, called 'mother wavelet' and $\hat{\psi}$ is the Fourier transform of ψ. The constant c_ψ designates the admissibility constant. According to Mallat [12], the continuous wavelet transform (CWT) of a function f is given by:

$$f_\psi(a,b) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) dt \qquad (2)$$

The parameter a is called the dilation factor and has a constraint such that $a > 0$ and b, a real number, is the translation parameter. A wavelet transform decomposes a signal $f(t)$ into many coefficients, which are the function of scale (dilation) and position (translation). The computation of the wavelet transform of a two-dimensional signal, an image, is applied as a successive convolution by a filter entry of row/column followed by a column/row as depicted by Figure 1. Thus, for two-dimensional wavelet transform, after the first level wavelet transform operation, the input image can be divided into 4 parts: approximation, horizontal detail, vertical detail and diagonal detail where the size of each part is reduced by the factor of two compared to the input image as depicted by Figure 2.

Approximation is a compressed and coarser part than the original input image. Meanwhile, the horizontal detail, vertical detail and diagonal detail contain the horizontal, vertical and diagonal components of the input image. When the second level wavelet transform is applied, the approximation part of the first level will be further decomposed into four components as depicted by Figure 3.

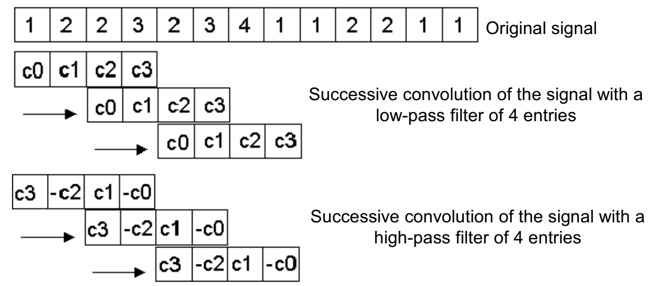

Figure 1: Successive Convolution of Wavelet Transform

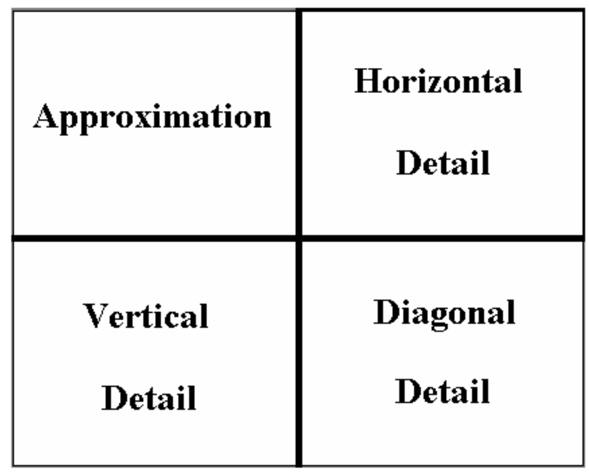

Figure 2: First Level Wavelet Transform

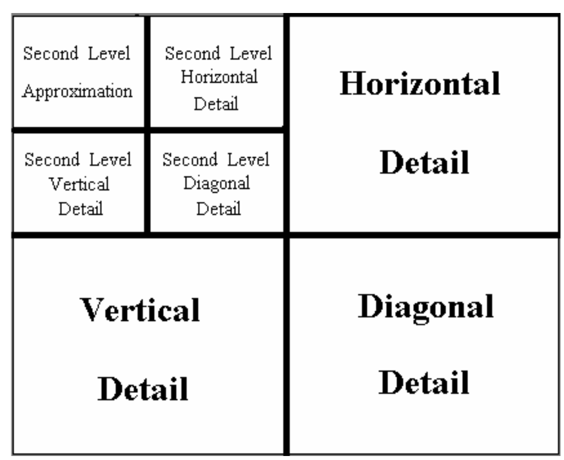

Figure 3: Second Level Wavelet Transform

For the higher level, the iteration is done in the same way until the desired level is reached.

Haar wavelet has two filter entries [13] as shown in Table 1. By using the Haar wavelet for wavelet-based image difference algorithm, no boundary solution is required. Also

Table 1: Analysis Filter for HAAR Wavelet

	Coefficient 1	Coefficient 2
Approximation Filter (Low Pass)	½	½
Detail Filter (High Pass)	½	½

the computation of wavelet transform can be applied as a moving average operation within the original image.

3 Image subtraction operation

As mentioned previously, during the real-time implementation, the image difference operation that is employed in the wavelet-based PCB inspection algorithm is replaced by image subtraction operation. Consider three images named as *Img1*, *Img2*, and *Img3* of size M x N where M is the length and N is the height of the image respectively. The parameter x, denotes the column of the image, from 1 to M, and parameter y, denotes the row of the image, from 1 to N where both x and y are integers. Every pixel in the *Img1*, *Img2*, and *Img3* are denoted by *Img1[x,y]*, *Img2[x,y]*, and *Img3[x,y]* respectively. *Img1* and *Img2* are the input to the image subtraction operation, whereas the *Img3* is created as a place to store the output values. Initially, x and y are set to 1. Therefore;

```
for every x (1,M)
{
        for every y (1,N)
        {
        Img3[x,y] = Img1[x,y] – Img2[x,y];
        }
}
```

4 Implementation and noise elimination procedure

Two images are needed for the inspection, the reference image and the tested image as shown in Figure 4. These images, in gray scale, are captured from the reference and inspected PCB laminate by a high-resolution monochrome CCD camera. Second level Haar wavelet transform is applied to the reference image and then the image and also the wavelet outputs are stored in memory. This step is done offline once only during set up process as indicated by dash line in Figure 5.

For the tested image, as same as the reference image, second level Haar wavelet transform is calculated. The approximation part obtained from the second level wavelet transform is named as coarse image. The advantage of wavelet transform is that it preserves most of the information of the original image in the coarse image. In the inspection system, the alignment of PCB is realized by manually mechanical and software techniques by using

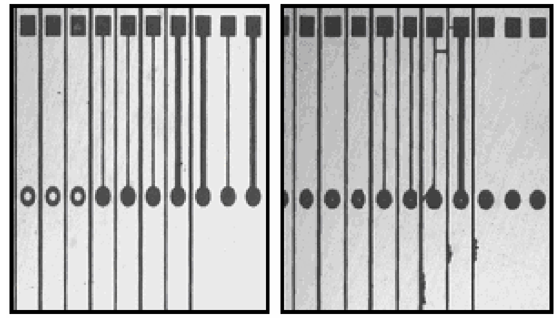

Figure 4: (a) Reference PCB Image (b) Tested PCB Image

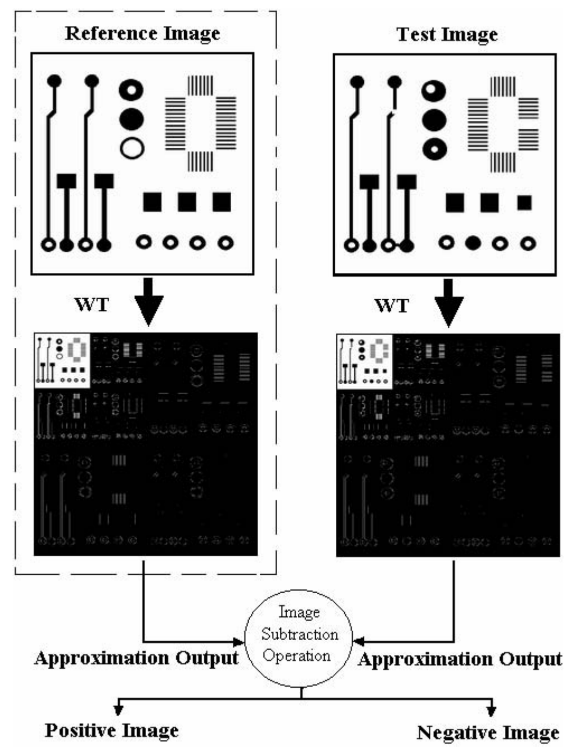

Figure 5: Defect Detection Procedures

mvt_search_train and mvt_smrt_search command available in MVTools, an image processing library programmed via Visual C++. The PCB alignment also can be done automatically by utilizing a mechanical device as well. But the subtracted image could still be interfered by unwanted noise due to slightly misalignment and uneven binarization. Hence, it is difficult to reduce or diminish the noise in the output image. In order to make the noise elimination effectively, the subtracted image is break up to a positive and negative image as shown in Figure 6 and Figure 7. Thus, it is possible to detect all the defects by applying image subtraction operation between the coarse reference image and coarse tested image.

Figure 6 and Figure 7 are then used for noise elimination procedure. The positive and negative images are binarized before the noise elimination procedure. The noise elimination is executed by examining each object pixels by a 3x3 window for the positive and negative images. At every location, the number of foreground pixel, ρ, is calculated and tested whether it is greater than or equal to the specified threshold, τ. If it is greater than or equal to the threshold value, then the object pixels represent the defective pixels in the subtracted image and should be preserve. Otherwise, the object pixels are belonging to noise and must be cleared. For the implementation, the best threshold value, τ, is set to 6. Figure 8 and Figure 9 show the positive and negative image in binary after the noise elimination process respectively.

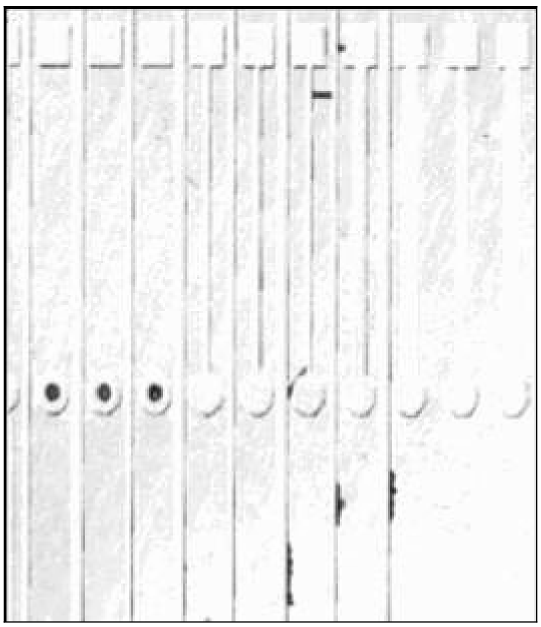

Figure 6: Positive Image

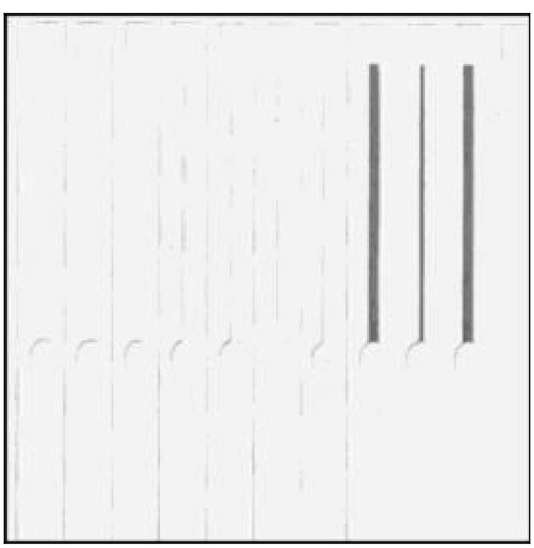

Figure 7: Negative Image

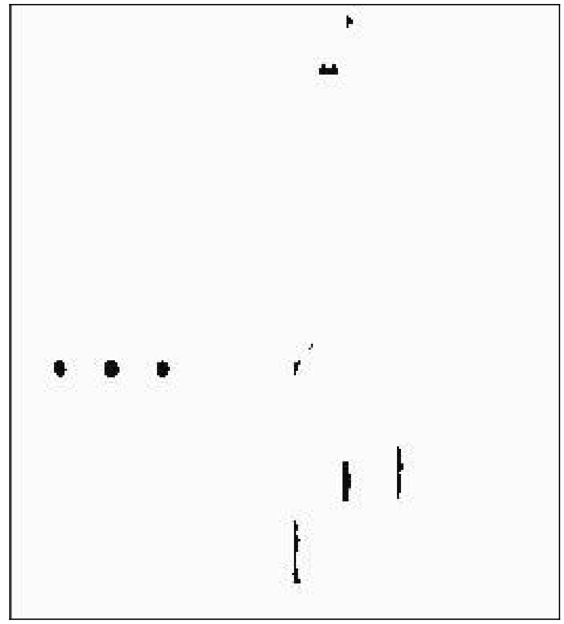

Figure 8: Noise Free Positive Image

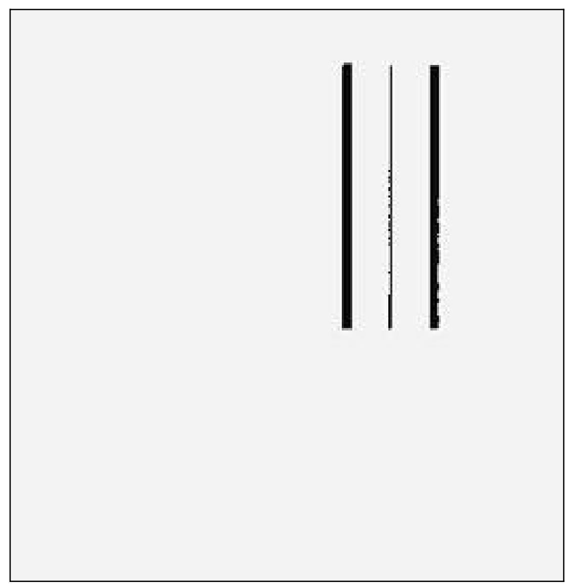

Figure 9: Noise Free Negative Image

The next step is to combine the noise free positive and negative images by simply applying the XOR logic operator. The output is the final result of the inspection process. Finally, the final output image is enlarged by a factor of 4 to convert it back as the same size of input image. The output of the inspection system is illustrated in Figure 10. The overall flow of the noise elimination procedure is illustrated in Figure 11.

The proposed noise elimination procedure is incorporated in the wavelet-based automated visual PCB inspection system and implemented on a Pentium III 800 MHz microcomputer facilitated with a PCVISION Plus frame grabber. The

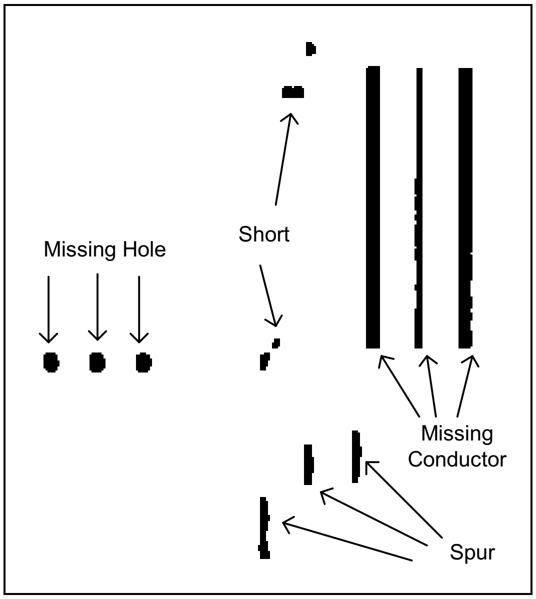

Figure 10: Defect Detected

images are captured by a high resolution 1k x 1k pixels UNIQ monochrome CCD camera. MVTools machine vision library based on Visual C++ is used for programming. The inspection system also consists of a lighting devices and several camera lens for a good quality captured images. The results come out from the processing part is displayed via a monitor to the users.

5 Conclusions

The previously proposed wavelet-based PCB inspection approach consists of point-to-point image difference operation and suffers from the unwanted noise due to misalignment and uneven binarization during the implementation. Hence, a noise elimination procedure is designed and developed in such a way that the positive and negative images are acquired from image subtraction operation and the noise elimination is applied to the positive and negative images, individually. The resultant images are combined to produce the output of the inspection system. It is expected that the proposed method is well suited for small and medium scale PCB manufacturers where the sophisticated alignment facilities is hard to purchase. The prototype of the inspection system is available at Faculty of Electrical Engineering, Universiti Teknologi Malaysia. The correctness and effectiveness of the proposed noise elimination design has been demonstrated in Science and Technology Exhibition, PWTC, Kuala Lumpur, Malaysia.

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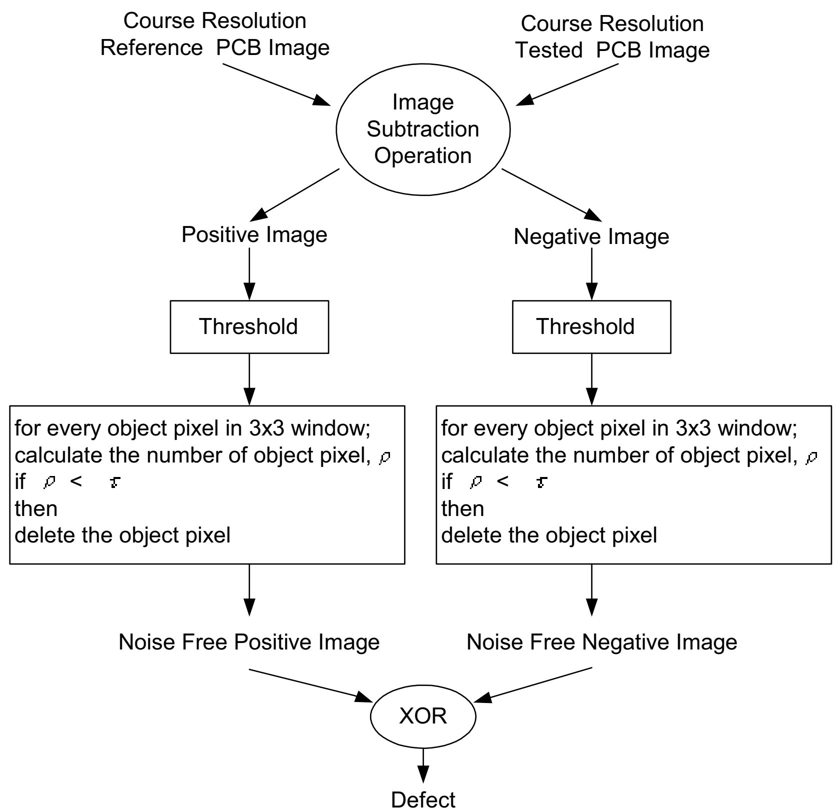

Figure 11: Noise Elimination Procedures