AN ALGORITHM TO GROUP DEFECTS ON PRINTED CIRCUIT BOARD FOR AUTOMATED VISUAL INSPECTION

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Abstract: Due to disadvantages in manual inspection, an automated visual inspection system is needed to eliminate subjective aspects and provides fast and quantitative assessment of printed circuit board (PCB). Up to the present, there has been a lot of work and research concentrated on PCB defect detection. PCB defects detection is necessary for verification of the characteristics of PCB to make sure it is in conformity with the design specifications. However, besides the need to detect the defects, it is also essential to classify these defects so that the source of these defects can be identified. Unfortunately, this area has been neglected and not been given enough attention. Hence, this study proposes an algorithm to group the defects found on bare PCB. Using a synthetically generated PCB image, the algorithm is able to group 14 commonly known PCB defects into five groups. The proposed algorithm includes several image processing operations such as image subtraction, image adding, logical XOR and NOT, and flood fill operator.

Keywords: printed circuit board, defects detection, automated visual inspection.

1 INTRODUCTION

During the manufacturing of printed circuit boards, widths of insulators and conductors can change because of manufacturing defects such as dust, overetching, underetching, and spurious metals. The objective of printed circuit board (PCB) inspection is to verify that the characteristics of board manufacturing are in conformity with the design specifications [Mesbahi and Chaibi, 1993].

For many years, human operators are employed to inspect PCB and monitor the results of more than 50 process steps of PCB fabrications. As PCBs normally contain complex and detailed patterns, manual visual inspection is very tiring and very subjective to errors. Furthermore, manual inspection is slow, costly, and can leads to excessive scrap rates. Besides, it also does not assure high quality of inspection.

The technology of computer vision has been highly developed and used in several industry applications. One of these applications is the automatic visual inspection of PCB. The automatic visual inspection is important because it removes the subjective aspects and provides fast and quantitative assessments. It also relieve human operator from tedious, boring, and repetitive tasks of inspection. On the other hand, automatic systems do not get tired and are consistent [Moganti et al, 1996].

In general, PCB inspection can be divided into three categories: reference comparison approach, design rule checking (non-referential) approach, and hybrid approach.

The reference comparison approach is based on a comparison between the image of the PCB to be tested and that of an ideal PCB which is conform to pre-defined design specifications. There are two major techniques: image comparison methods and model-based inspection.

Image comparison, which is the simplest approach, consists of comparing both images pixel-by-pixel using simple logic operators such as XOR. The main difficulty found in these techniques is determining a precise alignment of the reference image and the test image, which makes its utilization difficult. More sophisticated proposals under the same idea, involve feature and template matching [Moganti et al, 1996], but suffer from the same problem and normally require a large number of templates.

Model-based methods are techniques, which match the pattern under inspection with a set of predefined models. They are also called *Graph-Matching Methods* [Moganti et al, 1996] and are based on the structural, topological, and geometrical properties of the image. The major difficulty of those methods is related to the matching complexity. Although Sun and Tsai [Sun and Tsai, 1993] proposed a technique called *Pattern Attributed Hypergraph* to make the method more practical, it still remains a complex and time-consuming method.

The design rule checking approach is based on the verification of the general design rules that is essential in the verification of the widths of conductors and insulators. As a kind of automatic inspection algorithm for bare PCB, the design rule checking has been proposed and well known to the automatic visual inspection system manufacturers [Hong et al, 1998].

The design rule checking (DRC) method checks if all patterns and spaces of PCB surface meet or violate common knowledge, which is called the design rule. Because a simple algorithm is applied directly to an image, the implementation of this algorithm is comparatively easy. This means that it does not require severe alignment and adjustment of a mechanical part to get a non-distorted image. However, this method is a very time consuming process and a great computing power is needed to meet user's requirement of inspection time.

Nowadays, considering the state of affairs of an inspection system, the combined inspection methods are used. This hybrid approach merges the advantages of the reference comparison method and the DRC method to overcome the weaknesses of each method. For example, most of the design-rule verification methods are limited to verifying minimum conductor trace, angular errors, and spurious copper.

Then, PCB defects which do not violate the design rules are detected by reference comparison methods. These methods can detect missing features or extraneous features. The design rule process detects all defects within small and medium features while the comparison methods are sensitive to the largest features. Hybrid approach makes use both of these methods as they complement each other and therefore achieve a full sensitivity of PCB inspection.

From the literature review, it is found that only Wu [Wu et al, 1996] and Heriansyah [Heriansyah, 2004] carried out the defects classification of PCB. The other algorithms concentrated only on PCB defects detection. In defect detection, the type of defects is not important. However, in defects classification, the types of each defect need to be obtained.

Firstly, Wu [Wu et al, 1996] developed PCB defects classification based on pixel processing operation. The method is divided into two stages: defect detection and defects classification. Defect detection stage is accomplished using subtraction procedure while the second stage is completed using three indices: the type of object detected, the difference in object numbers, and the difference in background numbers between the inspected image and the template.

Secondly, Heriansyah [Heriansyah, 2004] developed an algorithm using the advantages of artificial neural network to correctly classify defective PCB patterns. Binary morphological image processing concept and Learning Vector Quantization (LVQ) are employed in this algorithm. The morphological operations such as erosion, dilation, opening, and closing are used to segment PCB image into basic primitive patterns. The LVQ neural network, which consists of input, competitive layer as the first layer (hidden layer), and linear layer as the second layer (or output layer), has been selected as the classifier for the proposed technique to classify the defects that could occur on the PCB. This type of neural network has been chosen because of its ability to converge based on the training set available.

2 DEFECTS

There are some defects commonly found on PCB. Conductor breaking and short-circuit are characterized as fatal defects. Pinhole, breakout, overetch, and underetch are characterized as potential defects. Fatal defects are those in which the PCB does not attend the objective they are designed for, and potential defects are those compromising the PCB during their utilization [Tatibana et al, 1997].

During etching process, the anomalies occurring on bare PCB could be largely classified in two categories: the one is excess of copper and the other one is missing copper. The incomplete etching process leaves unwanted conductive materials and forms defects like short, extra hole, protrusion, island, and small space. The excessive etching makes open, pin hole, nick (mouse bite), and thin pattern. In addition to the defects mentioned above, some other defects may exist on bare PCB, for example, missing holes (due to tool break), scratch (due to handling mistake), and cracks.

Figure 1 and Figure 2 show the examples of defect free PCB image and defective image, respectively. Though each defect shown in the Figure 2 is a representative example of certain defects, the shape and the size of the defects may vary from one occurrence to another.

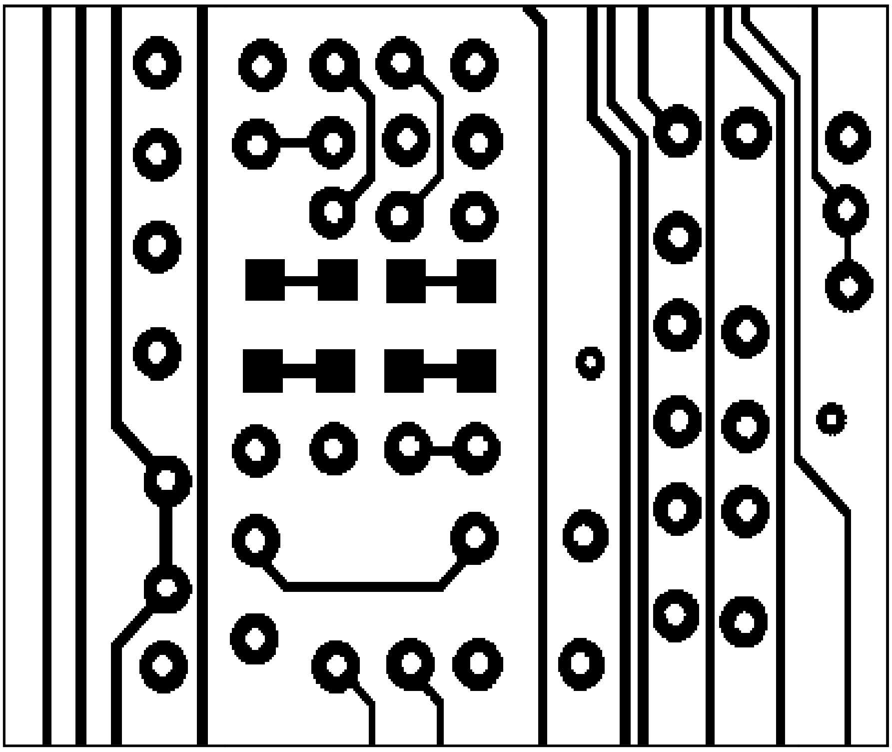

Figure 1: Template image of a bare PCB

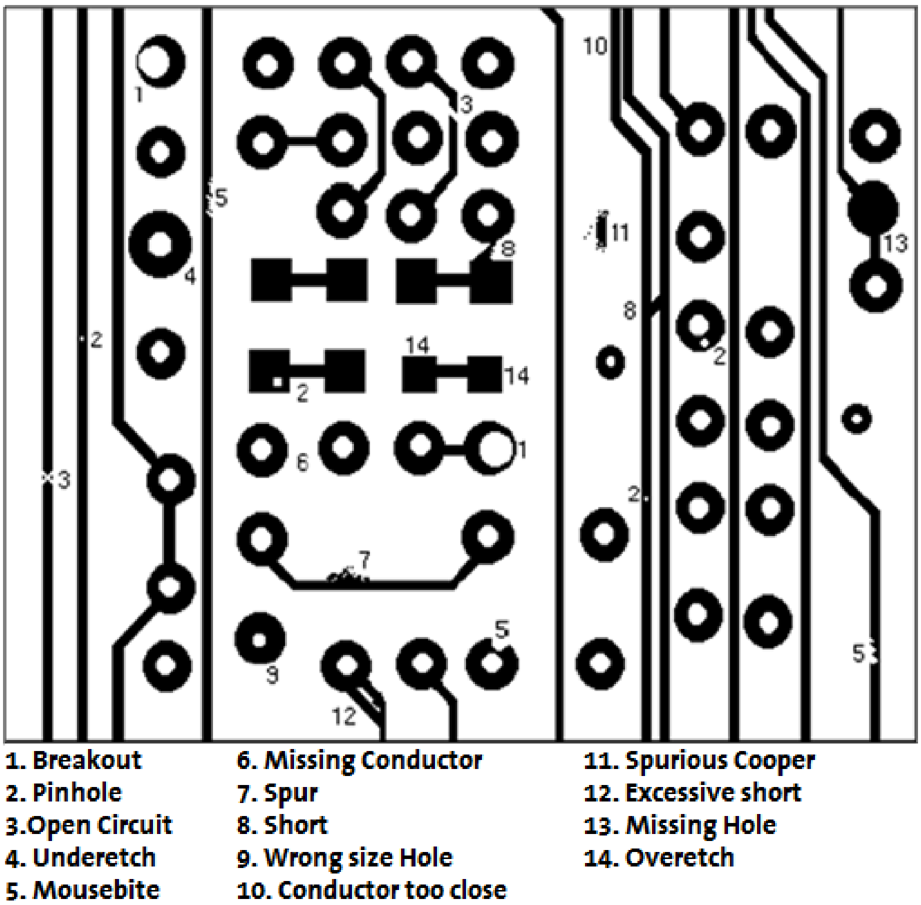

Figure 2: Defective image of a bare PCB

In recent years, the pattern width and space become smaller and smaller to increase the integration rate of electrical components per unit area of PCB. This means the size of defect is also minute and actually may be less than 30 micron. These defects are not easily detected by the human eyes and would take too much inspection time. For this reason, an automatic visual inspection system is needed.

3 METHODOLOGIES

3.1 Image difference operation

Image difference, which is the simplest technique, consists of comparing both images pixel-by-pixel by XOR logic operator. The operation is also called as image comparison operation. The truth table of XOR is given in Table 1.

Image difference operation is developed in order to get the differences between two images. Most likely, in this study, the images are the template image and the defective image. The method compares these two images and the results obtained are the defects as shown in Figure 3.

3.2 NOT operator

NOT operator is normally used to change an image from black to white and vice versa. This operator inverts the bit values of any variable and sets the corresponding bit according to Table 2. As a result, the image is changed from black to white and vice versa as shown in Figure 4 and Figure 5.

3.3 *Flood-fill* operator

The *flood-fill* operator changes the colour of a region, given an initial pixel in that region on binary and grayscale images. For binary images, *flood-fill* operator changes connected background pixels to foreground pixels until it reaches object boundaries. This operation could be useful in removing irrelevant artefacts from images. In this study, this operator is used to fill the holes in a binary image. For example, Figure 6 and Figure 7 show the effect of *flood-fill* operator on a binary image.

A hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image. By default, *flood-fill* uses 4-connected neighbours for 2-D inputs and 6-connected background neighbours for 3-D inputs. For example, the simplest algorithm for the *flood-fill* operator is as the following [Jaime Silvela and Javier Portillo, 2001]:

```
FLOOD-FILL-1 (initial-pixel,
Initial-colour, final-colour)
   colour (initial-pixel) final-colour
```

Table 1: Truth table of XOR logic operator

Bit 1	Bit 2	Output
0	0	0
0	1	1
1	0	1
1	1	0

Table 2: NOT truth table

Input	Output
1	0
0	1

```
for each n ∈ Neighbours (initial-
pixel)
    if colour(n) = initial-colour
    FLOOD-FILL-1 (n, Initial-colour,
    final-colour).
```

The input for this algorithm is an image before *flood-fill* operation and the output is the image after *flood-fill* operation. This image will be used in image difference or subtraction operations for defect detection. The parameters used are the initial pixel, initial colour, and final colour. If a hole with white fill and black pixels as boundaries are used as the input, the initial pixel is located in the hole with white as the initial colour. Then, the final colour is black, same as the colour of the hole's boundaries. After the algorithm is executed, the white fill of the hole is changed to black pixel. The output is no longer a hole, because the hole is filled with the black pixel.

3.4 Image Subtraction

Image subtraction method used the concept of simple subtraction and rule as shown in Table 3. In this work, both images of template image and defective image are compared pixel by pixel. The subtract operation produces either negative or positive pixel value. Therefore, the outcome of this operation is divided into negative image and positive image.

3.5 Image addition

Image addition is a method for combining objects in two images into one image. In this paper, this operator combines the defects from one group with the defects from another group in one image. This is possible using OR logic operator. For 2 inputs 2-bit data, the truth table of OR is given in Table 4.

3.6 The proposed algorithm

Five algorithms shown in Figure 8 to Figure 12 are developed to detect and classify the defects into five groups. Those groups with the respective defects are as follows:

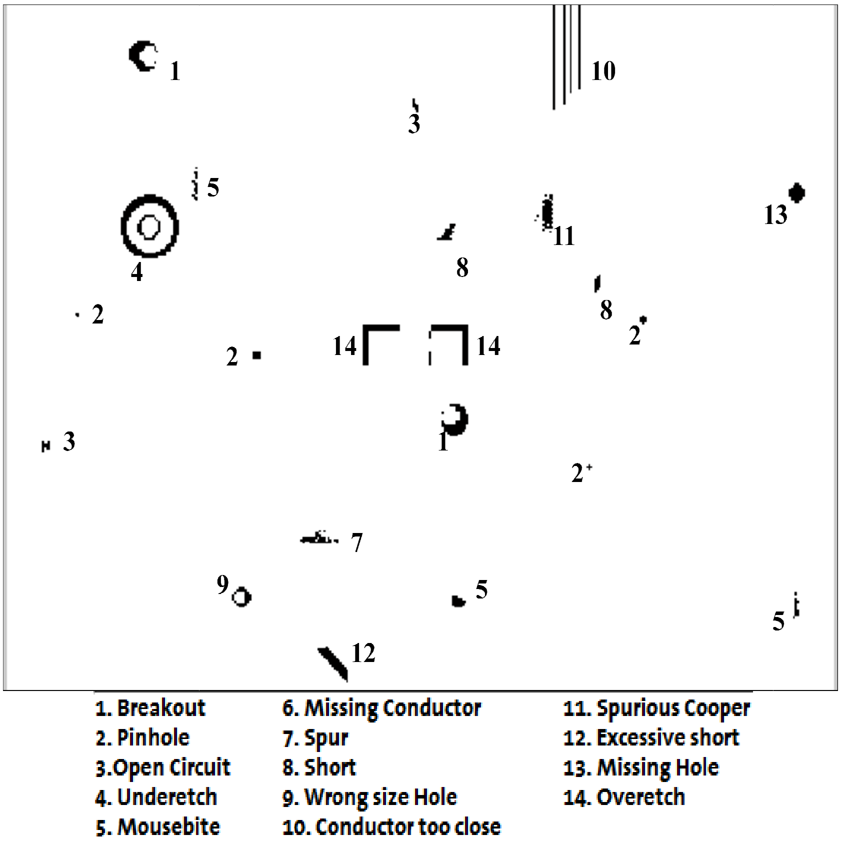

Figure 3: An example of image manipulation using XOR logic operator where Figure 1 and Figure 2 are used as the input.

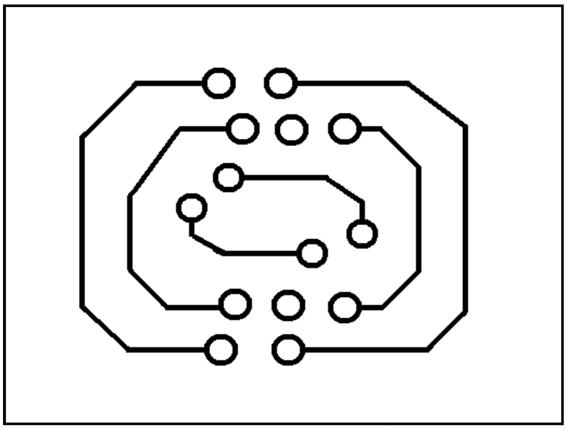

Figure 4: An image before NOT operator is applied

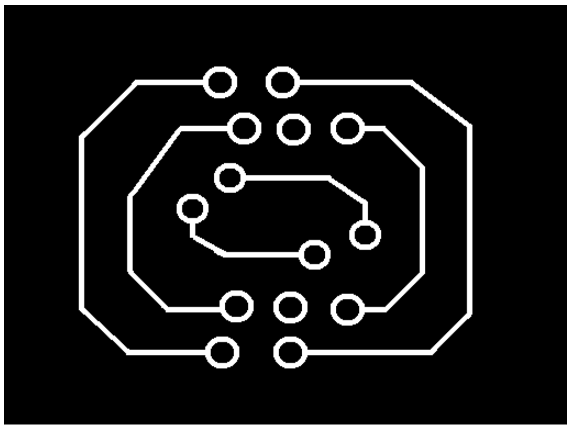

Figure 5: An image after NOT operator is applied

Group 1: missing hole and wrong size hole.
Group 2: spur, short, spurious copper, excessive short, underetch negative, and conductor too close negative.
Group 3: open circuit, mouse bite, overetch, and conductor too close positive.
Group 4: underetch positive.
Group 5: pinhole and breakout.

The proposed algorithm has been implemented using Image Processing Toolbox, available in MATLAB 7.0. The developed program was executed on 1.8-GHz Pentium 4 PC.

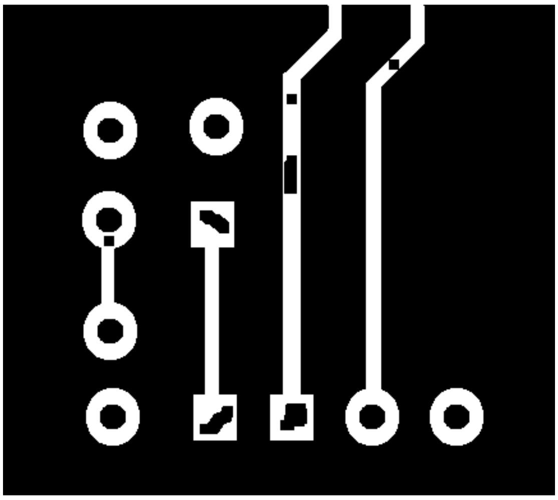

Figure 6: An image before *flood-fill* operator is applied

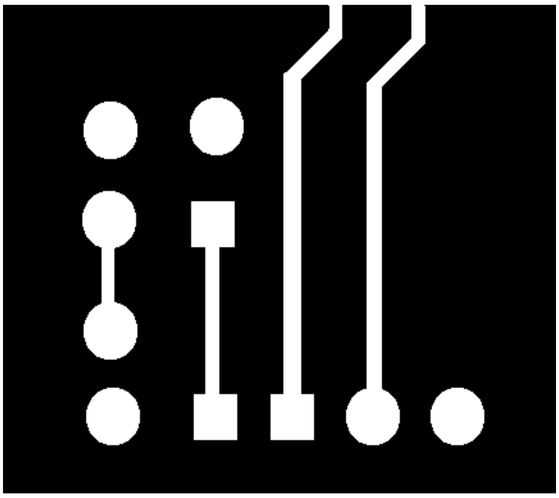

Figure 7: An image after *flood-fill* operator is applied

Table 3: Two rules for image subtraction

Rule	Result
If 1 - 0 = 1	Positive pixel image
If 0 - 1 = -1	Negative pixel image

Table 4: The truth table of OR logic operator

Bit 1	Bit 2	Output
0	0	0
0	1	1
1	0	1
1	1	1

5 RESULTS AND DISCUSSION

Based on the algorithms shown in Figure 8 to Figure 12, these algorithms need two images, namely template image and defective image. In this paper, these algorithms use Figure 1 as template image and Figure 2 as defective image.

At first, both images are subjected to image subtraction operation to produce negative image and positive image. Then, NOT operator and *flood-fill* operator are applied to template image and the defective image separately to produce *A1* and *A2* images, respectively. From there, the algorithms continue to produce the results. The results shown will be based on these images.

5.1 Group 1

The algorithm shown in Figure 8 produces two types of defects. These defects are missing hole and wrong size hole, as shown in Figure 13. These defects are obtained after image subtraction operation is applied between *A1* image and negative image.

5.2 Group 2

The negative image initially consist of eight types of defects including the defects in Group 1, which are missing hole and wrong size hole. As shown in Figure 9, in order to eliminate those defects in Group 1 from negative image, image difference operation is applied between the negative image and Group 1 image to produce Group 2 image. Group 2 consists of six types of defects: spur, short, spurious copper, excessive short, underetch negative, and conductor too close negative, as shown in Figure 14.

5.3 Group 3

Initially, positive image consists of seven types of defects including the defects in *A3* image. As shown in Figure 10, in order to eliminate those defects in *A3* from the positive image, image difference operation is applied between positive image and *A3* to produce Group 3. As a result, Group 3 consists of four types of defects: open circuit, mouse bite, overetch, and conductor too close positive, as shown in Figure 15.

5.4 Group 4

By combining Group 2 and *A3* image, the defects from both images are combined in an image, namely *A4* image. *A4* image consist of nine defects from *A3* and from Group 2. *A4* image is then subjected to *flood-fill* operator and *A5* image is produced. As shown in Figure 11, by comparing *A4* and *A5* images using image difference operator, *A6* image is obtained. Then, *A7* image is obtained after *flood-fill* operator is applied to *A6* image. Similarly, Group 4 image, which shows only underetch positive defect is produced as shown in Figure 16.

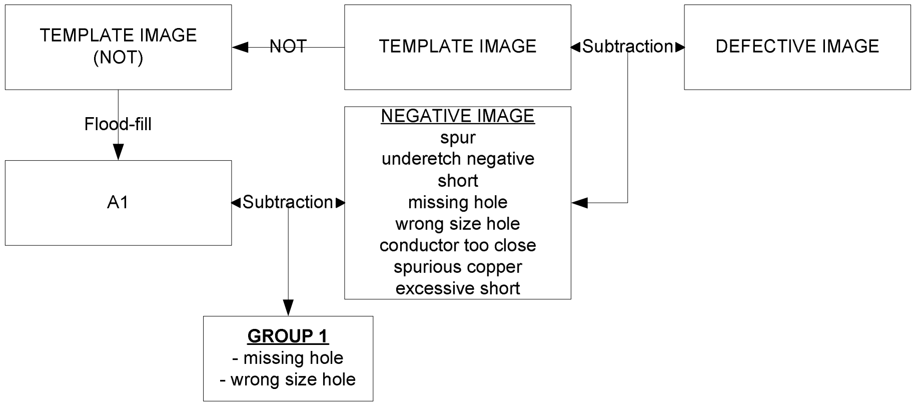

Figure 8: The algorithm to obtain defects in Group 1

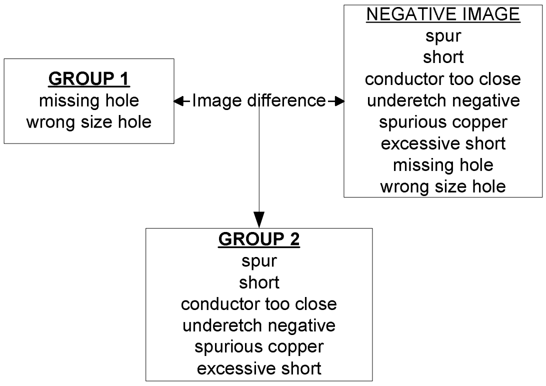

Figure 9: The algorithm to obtain defects in Group 2

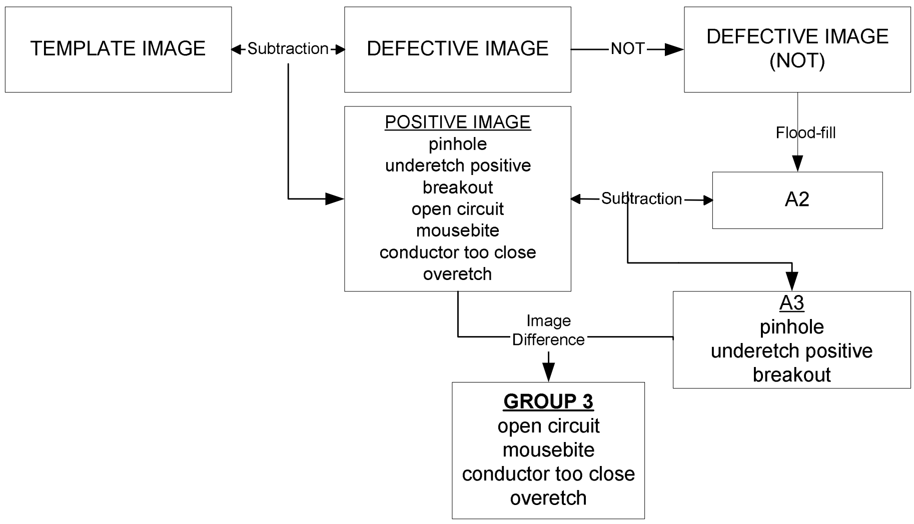

Figure 10: The algorithm to obtain defects in Group 3

5.5 Group 5

Initially, A3 image is obtained by applying image subtraction operator between the positive image and A2 image. The A3 image consists of three defects: pinhole, underetch positive, and breakout. As defects from Group 4 have been obtained previously, those defects should be taken out from A3 image. Therefore, image difference operator is again employed between Group 4 image and A3 image to produce Group 5 image. Group 5 image consist of two defects (pinhole and breakout) as shown in Figure 17.

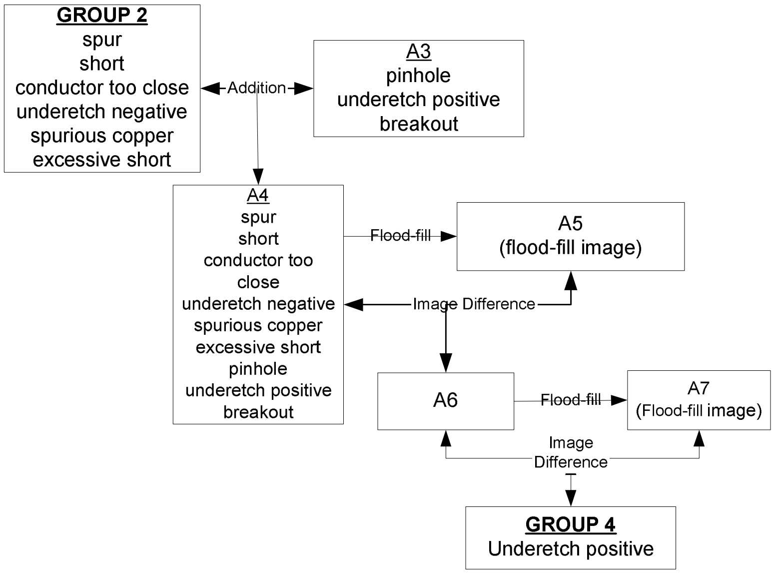

Figure 11: The algorithm to obtain defects in Group 4

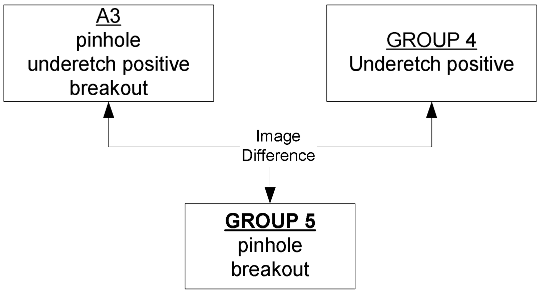

Figure 12: The algorithm to obtain defects in Group 5

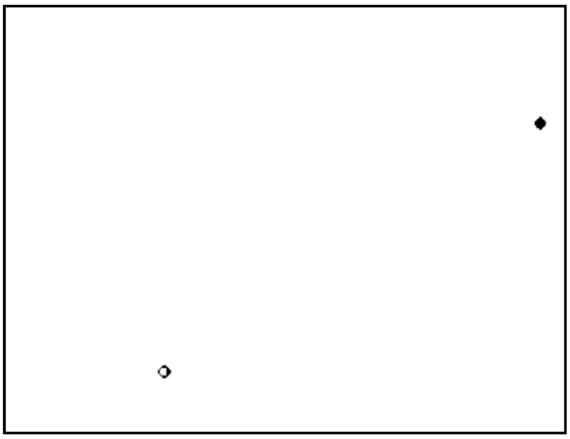

Figure 13: Image of Group 1

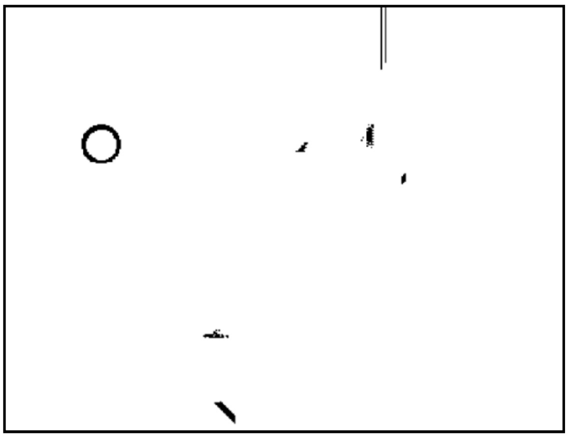

Figure 14: Image of Group 2

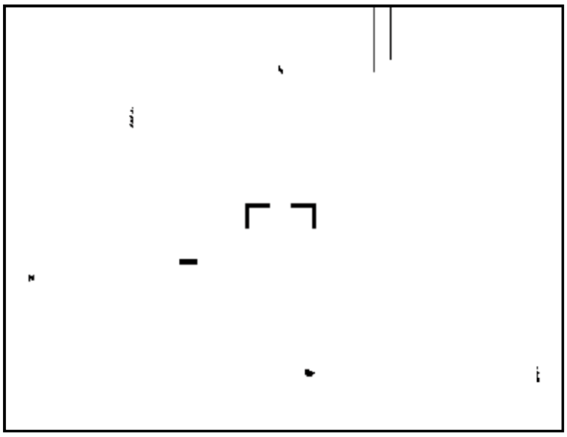

Figure 15: Image of Group 3

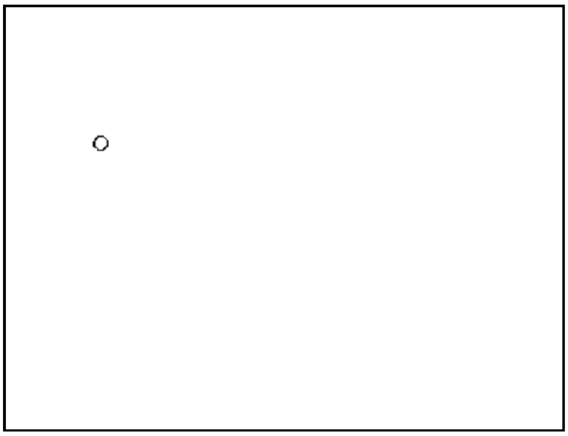

Figure 16: Image of Group 4

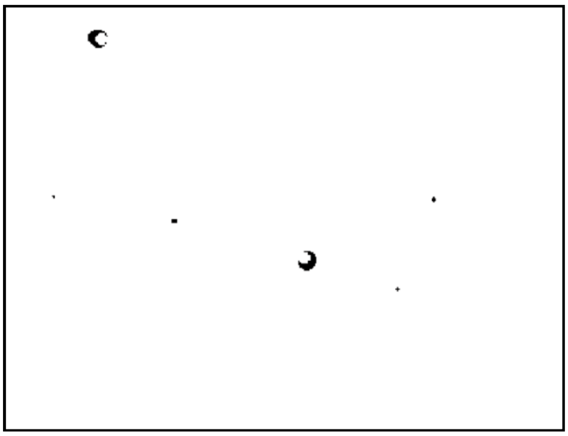

Figure 17: Image of Group 5

6 CONCLUSION

As a conclusion, the proposed algorithm can be implemented on bare PCB to identify and to group PCB defects. However, the major limitation of this algorithm is that the proposed algorithm is developed to work with binary images only, whereas the output from the cameras is in grayscale format [Heriansyah, 2004]. Although the conversion can be made from grayscale to binary format imperfection still can be occurred. Thus, this algorithm should be improved to handle the grayscale image format. Also, during the computation of defect detection and implementation, this operation brings along the unwanted noise due to misalignment and uneven binarization. Thus, in order to improve the algorithm, unwanted noise should be considered. Since the proposed algorithm, at the moment, is only able to separate 14 types of defects into five groups, therefore, it is highly suggested that the algorithm should be improved to achieve better result, which is to classify all the 14 types of defects separately.

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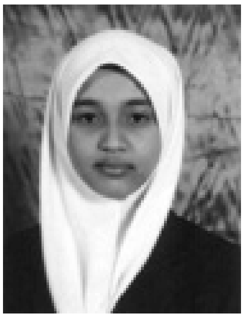

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