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Bare PCB Verification System Using Optical Inspection & Image Processing

Prof. Ruchir V Nandanwar
Department of Electronic Design Technology
Shri Ramdeobaba College of Engineering and Management,
Nagpur-440013, Maharashtra, India

Akanksha S. Singh
Department of ElectronicDesign Technology
Shri Ramdeobaba College of Engineering and Management,
Nagpur-440013, Maharashtra, India

Abstract*—PCBs have emerged tremendously and has led to evolution of new era in consumer electronic products industry. There are challenging design aspects and design considerations associated such as inclusion of flexibility, ease-of-use, reduction in the cost of components, reduction in power consumption, and enhancement of reliability and increase in performance, it is important to produce a zero-defect PCB (Printed Circuit Board). With increasing complexity of PCB boards, and with the marketplace now requiring high volume, high quality products very quickly, manual inspection is not a viable option. Thus very reliable and fast techniques are required to ensure that product quality remains high. We are hereby proposing PCB verification system using optical inspection & image processing to ensure a high quality PCB that translates to reliable and quality of electronic products.** *PCB verification system is an automated visual inspection of (PCB) where a camera autonomously scans the board under test and image processing algorithm is used to classify defects as catastrophic defects (e.g.* ***variation in track width, missing conductor) *also called fatal defects and quality defects (e.g.* ***wrong Size hole)*** *also called potential defects. It can be used during manufacturing process because it is a non-contact test method and can be implemented at several stage of manufacturing process including bare board inspection, after component placement as well as other stages.*

***Keywords*—PCB, Defect Classification, Defect Detection, Image Processing.**

I. INTRODUCTION

In order to decrease costs involved in manufacturing of electronic product, the inspection of bare PCBs defects is essential and foremost step involved in the manufacturing process. Nevertheless, various visual inspection systems aid in carrying out the process. The process begins with inspection task, measurement, and different assembly operations. One of the crucial systems is the automatic visual inspection used for printed circuit boards (PCB) defect detection.[4] Moganti et al. proposed the improved PCB inspection system in which an image registration operation is performed to resolve the alignment problem. A noise elimination procedure is designed so that the resultant defects found in this algorithm is more sensitive as compared to previous algorithm. Limitation of this algorithm is that it can onlywork with binary images. Although the conversion can be made from gray scale to binary format imperfection still can be occurred.[12]

Shih-Chieh Lin et al [Shih-Chieh Lin and Chia-Hsin proposed the method that can be bifurcated into two stages, i.e. first stage in which screening process takes place and the second stage were neural network tool is utilized to categorize defect more precisely[8]. 558 training samples were used to train the system. It was shown that foreground pattern matched index is the optimized screen index in the first stage and in the second stage; depicting that more than three indexes can be used to detect PCB defects effectively.[6] This was later expanded to 1949 samples which were used to train the system. The false alarm rate is 12.3%.

Khalid et al. N. K. Khalid proposed algorithm that implements on bare PCB to detect and to classify PCB defects. However, the major disadvantage of this algorithm is that it is developed to work with binary images only, whereas the output generated from the cameras is in gray scale format.[5][1] Although the image with greyscale format is convertible to binary format easily but due to transformation involved, imperfection still occurs. Thus, algorithms need to be analysed and modified to process the image which is in greyscale. Also, during the identification of defect detection and its implementation, this operation brings along the undesired noise due to misalignment of image and uneven finalisation due to optical device.[7] Thus, in order to improve the algorithm, undesired noise should be eliminated effectively.

Issues Related To Existing Solutions:

- Minor defects are not detected effectively.
- Classification accuracy is not significant.
- Thick line and thin line segmentation is not properly conducted.
- Production cost in long run increases due to improper inspection.

In this paper we have proposed certain algorithms for PCB inspection. The method is divided into two stages namely defect detection and defect classification.

II. PROPOSED METHOD

A. PCB Defect Detection

In PCB manufacturing, there are various processes that must be followed sequentially with utmost attention: artwork layout, image acquisition using photo tools, exposure to UV radiation and development of inner mask (layer), etching of inner layers using photoresists, laminating and drilling, plating through holes, exposure to UV radiations and development of outer layers (masks), plating process using tin-lead and etch, and machine and solder mask .[7] The printing processes of artwork layout, photo tools, and exposure and development of inner layers, are carried out prior to etching process that comprises the source of two groups of bare PCB defects.

PCB defect is broadly classified as-

- Fatal Defect – those defects in which the PCB does not satisfy the objective for which it is fabricated.
- Potential Defect–those defects which degrades the performance of PCB but does not affect its functionality.

There are broadly three proposed categories of algorithm for PCB defect detection using image processing:

- Referential inspection which is performed by making a comparison between the reference PCB image and tested PCB images. [6]
- Non-referential approach that is based on the verification of the design considerations of PCB that essentially verify the widths of track, size of holes, transmission line spacing etc.[9]
- Hybrid approach which involve a combination both of referential approaches and non-referential approaches. This method includes the advantage of both the techniques namely referential approaches and non-referential approaches, but it is very complex algorithm.[5]

B. PCB Defect Classification

A PCB defect classification algorithm proposed in this work is based on a referential approach which detects defects by identifying negligible error with maximum efficiency. PCB inspection algorithms mainly focus on defect detection. However, defect detection does not meet objectives and does not provide sufficient information regarding repair and quality control task in fabrication step because the type of defects identified cannot neither be located nor it is precisely categorized.[3][2] Based on this deficiency of defect detection technique, a defect classification algorithm is of utmost importance in PCB inspection.

Therefore, an effective defect classification procedure is designed especially for an on-line inspection system during the PCB fabrication process. PCB defects classification method is based on pixel processing. An algorithm is applied which uses the advantages of artificial neural networks to correctly classify defective PCB patterns.

In this paper algorithm focuses on defect detection as well as a defect classification simultaneously in order to provide satisfactory information for repair and quality control work.

The development of this research is divided into five stages:

- Test Image Registration
- Pre-processing
- Image segmentation using basic primitive patterning
- Defect Detection
- Defect Classification

III. IMPLEMENTATON TECHNIQUE

A. Input Image Acquisition

To perform image processing operation two images, namely reference image and test image are required. To acquire test images real PCB images are captured using industrial area scan camera. Image captured is stored into computer where it is digitized and processed further. Reference image is Gerber layer images, Gerber or Excellon drill files, IPC-D-356 netlist and component that are generated after post processing of artwork being designed using CAD tool (OrCAD). The bitmap export of these Gerber files are generated using Gerb tool and then it is used as reference image for processing test image in MATLAB. Note that gerber file cannot be processed directly in matlab and thus bitmap conversion is needed. Other alternative is to do xml file conversion using matlab coding.

There is a mounting platform on which camera is mounted which scans the PCB board autonomously and acquires the PCB images real-timely and preprocesses them using MATLAB.

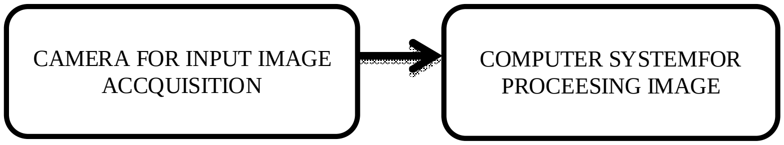

Fig.1 Block Diagram of PCB Verification System.

B. Image Processing

The image acquired is stored in the central computer. Central computer is the core of the system. It receives image data, conducts pre-defined processing on received image, identifies the defect and yields the detection report.The proposed algorithms consist of two stages i.e. defect detection and defect classification

These two stages are employed to detect and classify the defects, including missing hole, open-circuit, mouse bite, short-circuit, pinhole, and under etch defects. To perform the proposed algorithms, two images are needed, a reference image and a test image. In this project, these algorithms are used.

Later, the identified defects are categorized, an optimum threshold value is set to separate defect with unwanted values, and filtering is applied. The classification algorithms are applied at the end to produce desired results.

Major steps involved in image processing are:

- Image Registration
- Image Pre-Processing
- Image Segmentation using Basic Primitive Pattern& Feature Matching
- Subtraction of Image-generating positive & negative image
- Defect Classification

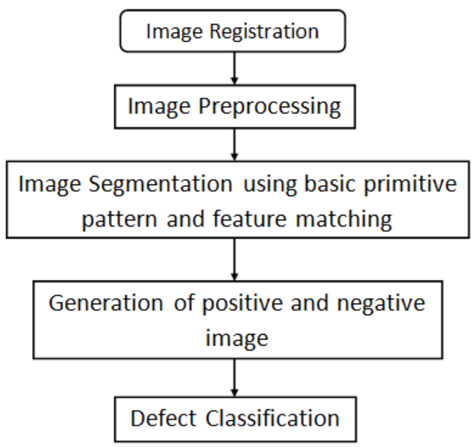

Fig.2 Block Diagram of Proposed Method.

IV. METHODOLOGY

A. Image Registration Process

The image registration process is an important stage in inspecting real PCB images. Image registration is defined as the process of aligning test image on reference image with the aid of geometric transformations. In this paper, besides geometric transformation control point selection tool is also used to set moving and fixed points between reference image and a test image.

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The main geometric transformations used for the image registration process are rotation and scaling.

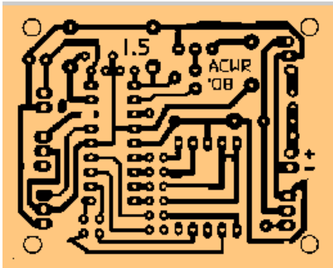

Fig.3 Test PCB Image

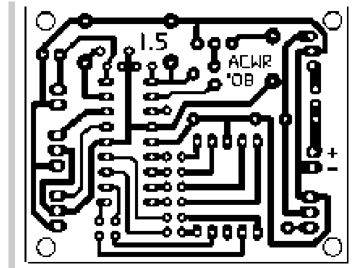

Fig.4 Reference Artwork Image.

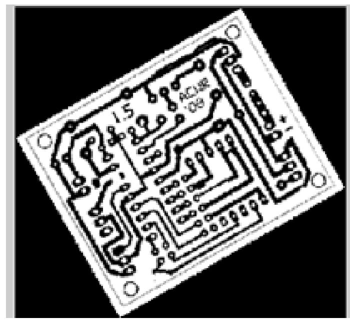
Fig.5 Distorted Test PCB Image.

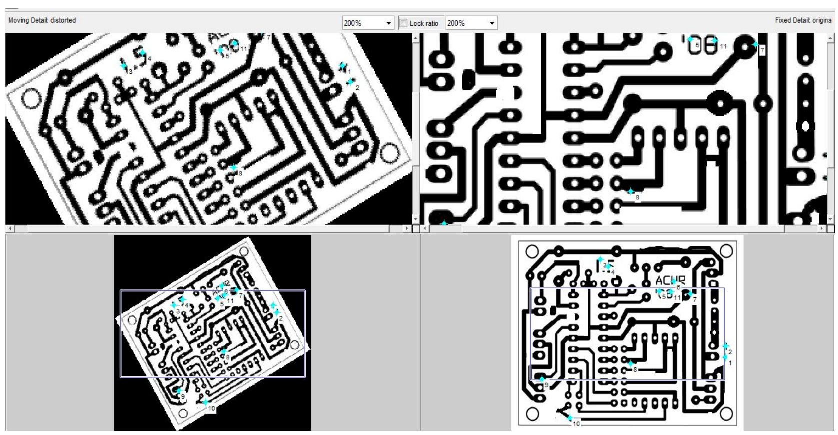
Fig.6 Control Point Selection Tool Image For Selecting Fixed & Moving Points.

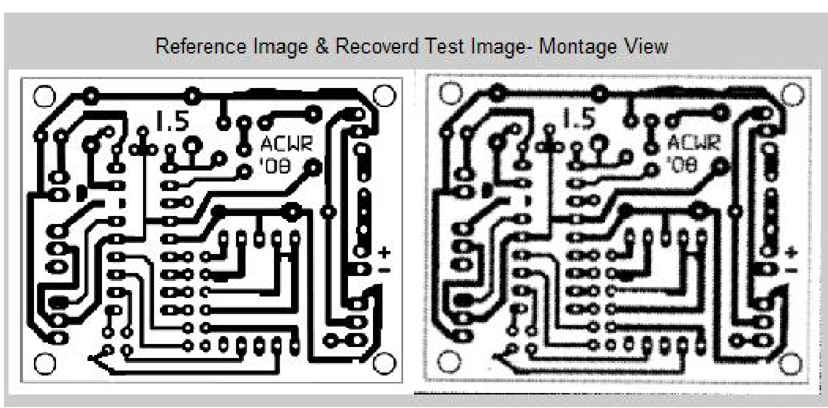

Fig.7 Proper Alignment Of Test & Reference Image.

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B. Image Pre-Processing

Preprocessing of image is an essential technique to enhance precision of total processing procedure. Image which is captured by camera is in RGB format. To eliminate the impact of inconsistent colors, we firstly convert all color face images into gray scale which is essential for further processing part. After this Image enhancement is necessary to enhance the edges and to normalize the intensity of the image. For enhancement we use histogram equalization. Because of enhancement, image shows dense wire and edges area becomes clear. Also Wiener filtering is done. Wiener de-convolution can be used effectively when the noise present in image is deterministic and frequency characteristics of images are known. It helps in minimizing harmonics to at least some degree.

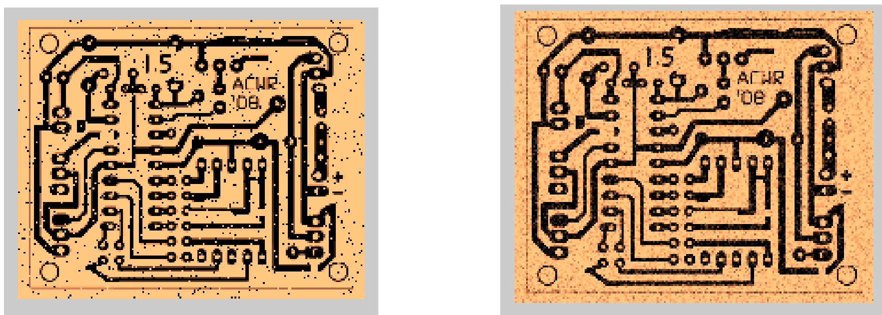

Fig.8Unwanted Noise Due To Misalignment In Test Image

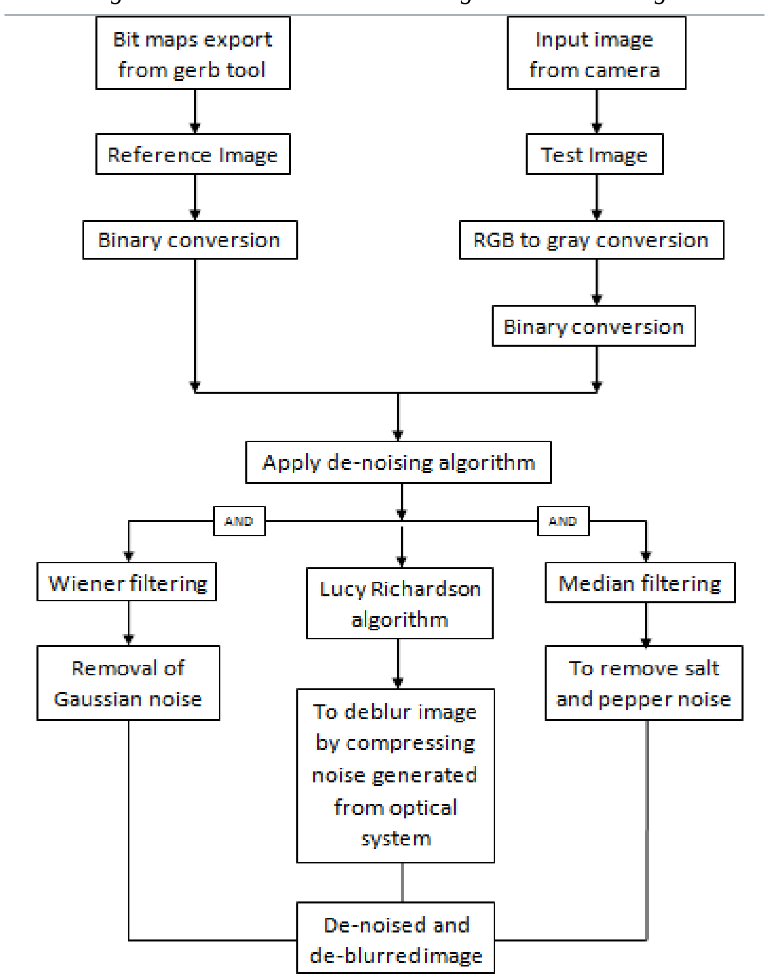

Fig.9 Flowchart for Test Image Pre-Processing

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Issue 04, Volume 3 (April 2016) www.irjcs.com

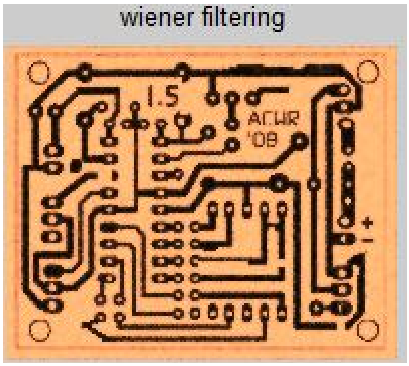

Fig.10 Gaussian Noise Elimination From Test Image Using Weiner Filtering

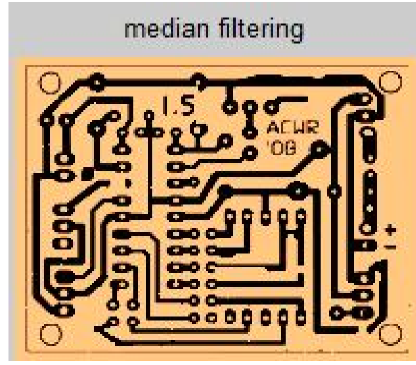

Fig.11 Salt & Pepper Noise Elimination From Test Image Using Median Filtering [3x3]

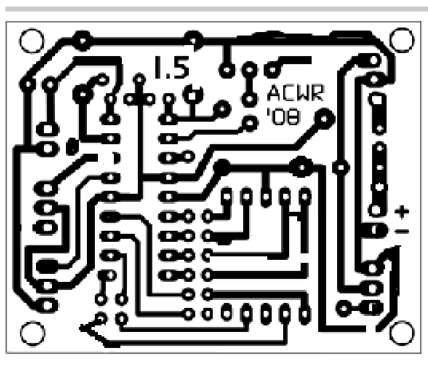

Fig.12 RGB to Gray Conversion Of Test Image

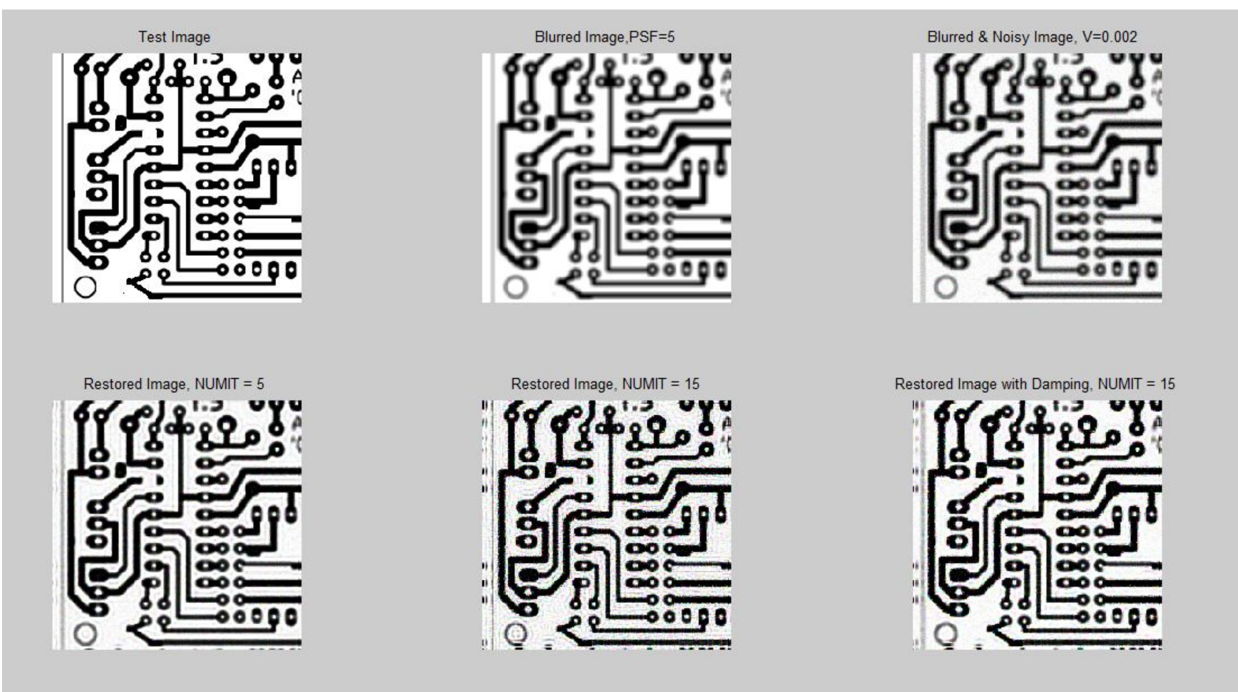

Fig.13 Correcting Uneven Binarization of Test Image Using Lucy Richardson Algorithm

International Research Journal of Computer Science (IRJCS)
Issue 04, Volume 3 (April 2016)
ISSN: 2393-9842
www.irjcs.com

C. Image Segmentation Using Basic Primitive Pattern

There are mainly four types of pattern been found on bare PCB. They are as follows-

- Square Segment (The Image Of Square Pads)
- Hole-Segment (The Image Of Hole Pads)
- Thick-Line Segment (The Image Of Thick Conductors)
- Thin-Line Segment (The Images Of Thin Conductors)

The conductor having width less than 20 mills are classified as thin conductors and the transmission lines having width more than or equal to 20 mills are classified as thick line conductors. Thick line conductors are mainly ground lines or power lines (VCC).

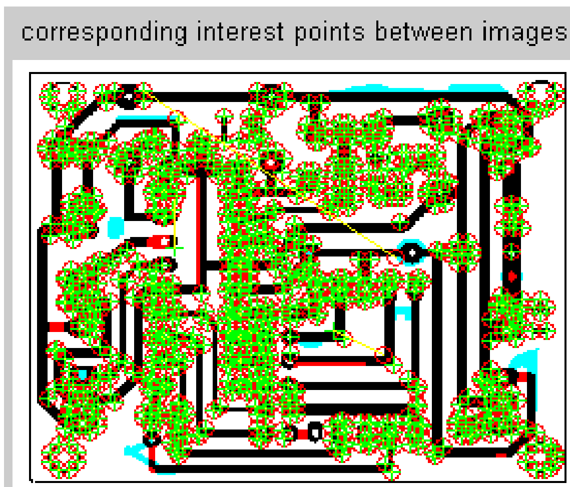

Fig.14Interest Point Selection between Test & Reference Images

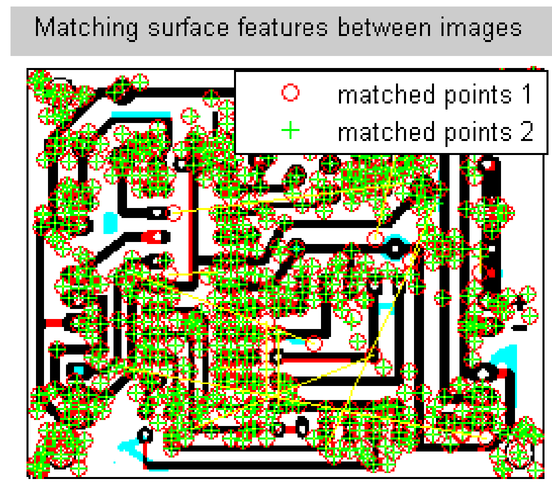

Fig.15Matching Surface Features Between Test & Reference Image

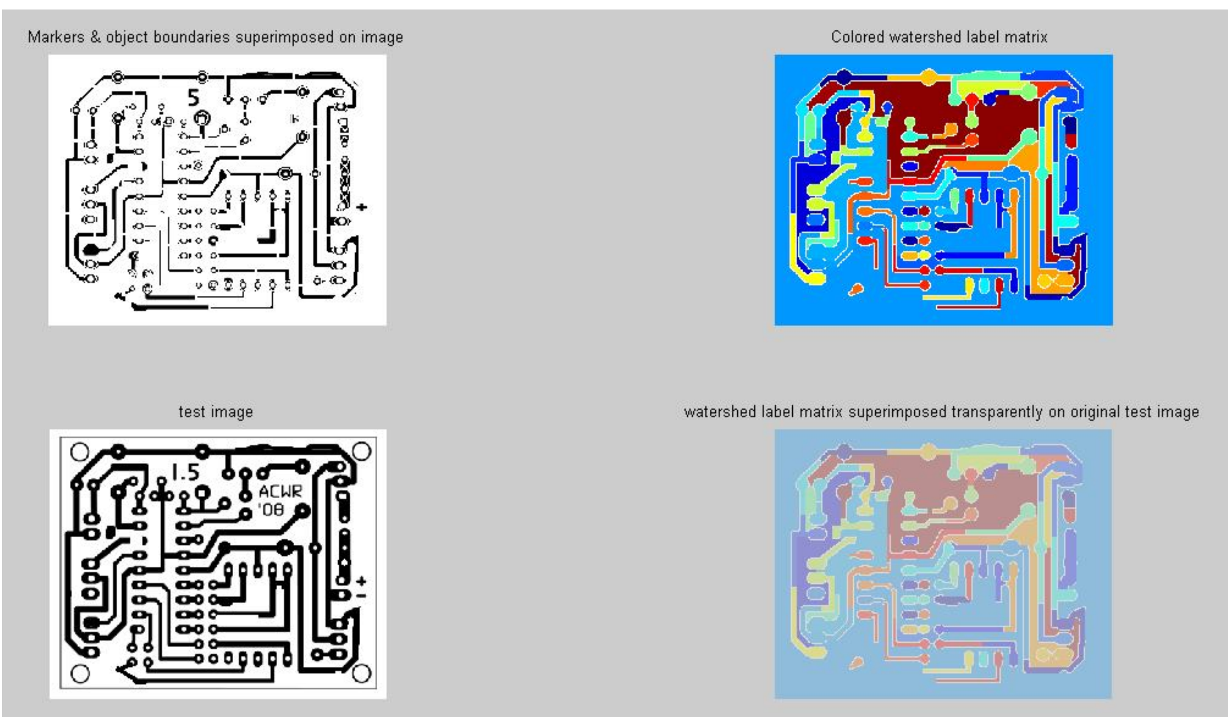

Fig.15 Segmentation of Test Image Using Marker Controlled Watershed Algorithm

International Research Journal of Computer Science (IRJCS)
Issue 04, Volume 3 (April 2016)
ISSN: 2393-9842
www.irjcs.com

V. ARITHMETIC OPERATIONS USED

A. Subtraction of Image

The image subtraction operation is a powerful tool used in the reference based inspection. This method is quick in finding defects effectively by subtracting pixel values from corresponding positions of image with each other. Thus, this technique is used for defect identification. By performing this method two resultant images are produced-a negative image and a positive image.

The reference image was subtracted from the test image (defective-reference) to generate the positive image. To generate the negative image, the test image was subtracted from the reference image (reference-defective).

After registration of two images, pre-processing and de-noising algorithms are applied and later the images are subjected to image subtraction operation to produce corresponding negative and positive image. However, this method gets affected from inspection errors when noise is introduced by the environment therefore the information transformation process is used for noise elimination. The negative and positive images generated are in gray level image. Hence, these two images are threshold in order to convert them to binary images, and at the same time to reduce noises occurred in both images.

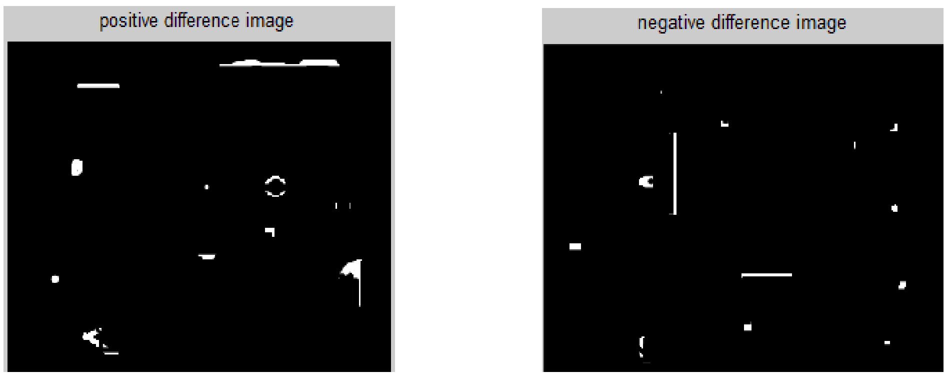

Fig.16 Generation of Positive & Negative Difference Image

B. Image Difference Operation

The image difference operation is performed to obtain a difference image of two images, specifically the reference image and the test image. The operation is carried out by comparing both images corresponding each pixel values using the XOR logical operator. This operation is similar to the image subtraction operation. The main difference between these two operations is that positive and negative pixel images are combined together in an output image of image difference operation and it is a logical operator i.e. the pixel value remains non-negative.

Fig.17 Generation of Absolute Difference Image

C. Image Separation Operation

Image separation operation is used to compare the identical and difference in features between two images and then it separate the objects into two groups of output images. The first group of image output comprises of objects that have different pixels value and the second group of image output comprises of objects that have identical pixels value.

International Research Journal of Computer Science (IRJCS)
Issue 04, Volume 3 (April 2016)
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D. Not Operator

NOT operator is normally used to complement the foreground and background pixel value of an image from 0 to 1 f and vice versa. This operator complements the individual bit value of any variable and sets the corresponding bit accordingly. As a result, the object in an image is transformed from black to white and vice versa.

E. Image Addition Operation

The image addition operation is a method for obtaining linear combination of objects present in two images into one image by using the OR logical operator. In other words, this operation is used to create double exposures. If two images are combined, the corresponding pixel values overlap to generate linear combination of image which has feature of both the images.

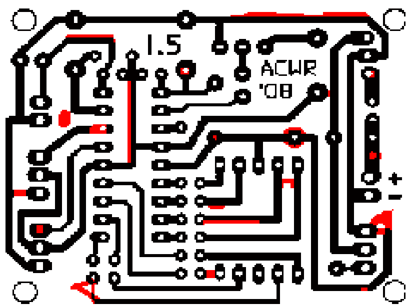

Fig.18 Combined Test & Reference Image

F. Flood-Fill (Filling Hole) Operator

A hole exists as a background region in having a connective border of foreground pixels that has contrast value. In this paper, a flood fill operation is applied which is a combination of various arithmetic and morphological techniques namely dilation, inversion of pixel value. An intersection operation has been employed for filling hole in an image.

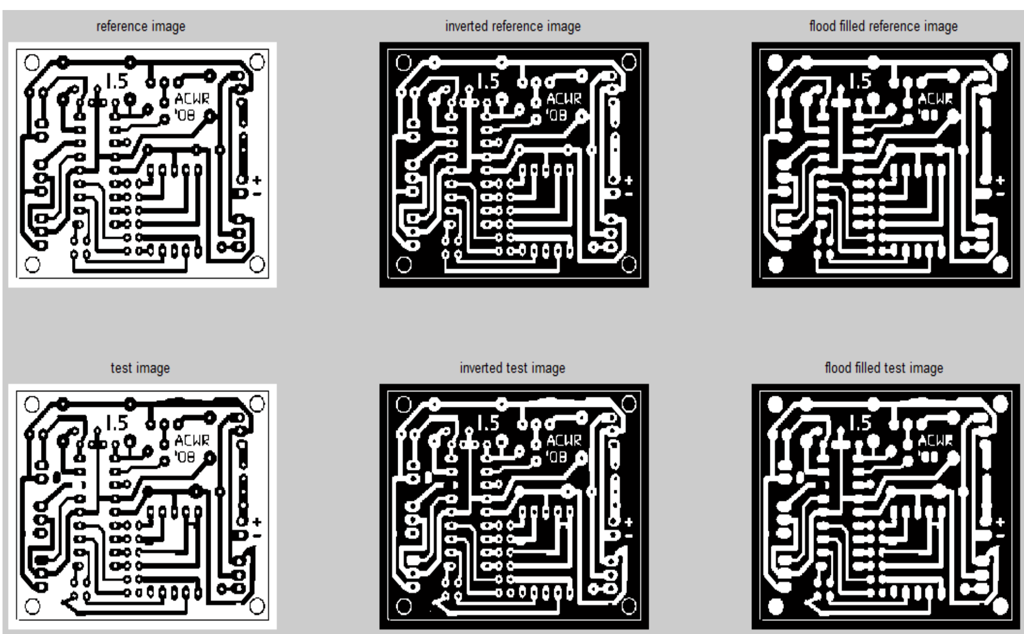

Fig.19 Flood Fill Operation Result for Test & Reference Images

VI. THE PROPOSED DEFECT CLASSIFICATION ALGORITHM

Five algorithms are developed to detect and classify the defects into five groups.

A. GROUP I -Missing Hole& Wrong Size Defect Classification Algorithm

First, the image difference operation is applied between the positive image and the reference image that has gone through the flood fill operation. This operation detects a particular defect, namely, the missing holedefect.

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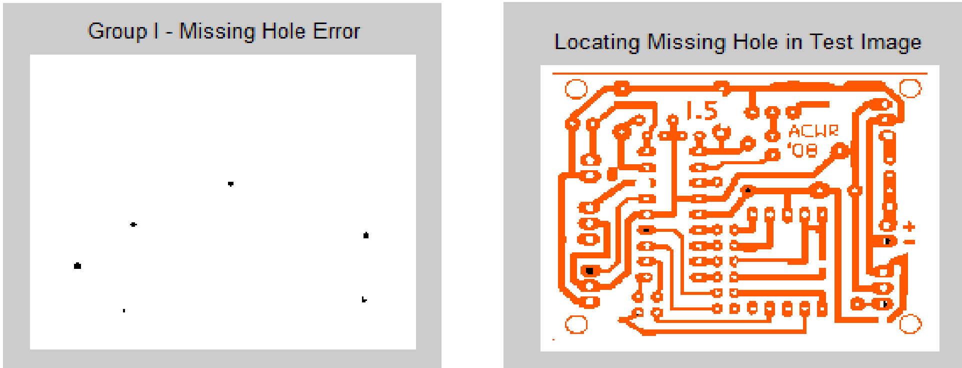

Fig.20 Identifying and Locating Group-I Defect in Test PCB

B. *GROUP II - Spur, Short, Spurious Copper, Excessive Short, Under-Etch Negative, and Conductor too Close Negative Defect Classification Algorithm*

To classify the short-circuit defect, firstly, the image difference operation is executed between positive image and missing hole defect obtained previously. This operation produces a group of defect images that consists of an under etch positive and short-circuit defect image. Then, all foreground objects pixel are set to 1 for each object. The food fill operation is then executed and image subtraction operation between negative difference image and image generated after flood fill is carried out.

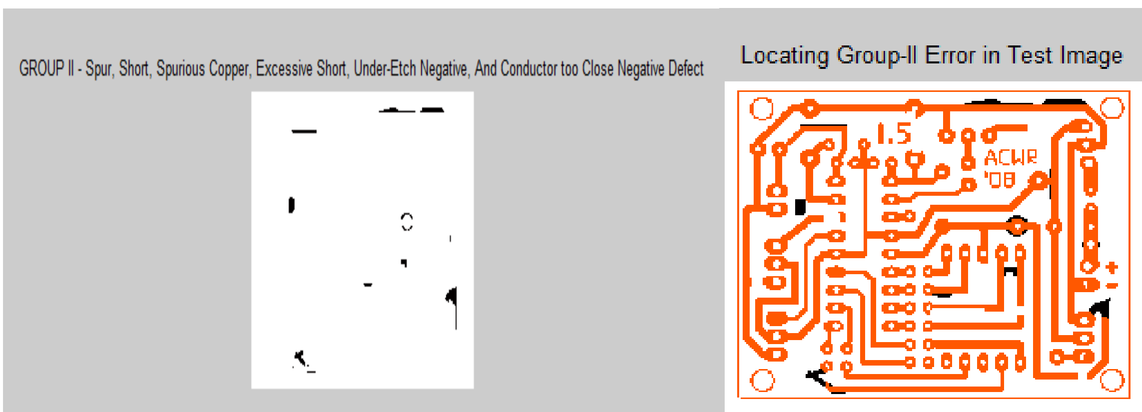

Fig.21 Identifying and Locating Group-II Defect in Test PCB

C. *GROUP III- Open Circuit, Mouse Bite, Over Etch & Conductors too Close Positive Defect Classification Algorithm*

Initially, a negative image is produced by executing image subtraction operation on a reference image and test image. Then, the test image undergoes not and later flood fill operation. Next, the image difference operation is applied between flood filled & negative image. This operation produces an image containing pinhole and under etches negative defects. Then, foreground objects pixels in are set to 1. Next, the flood fill operator is used to fill all holes in the image. Then, the image separation operation rule is applied.

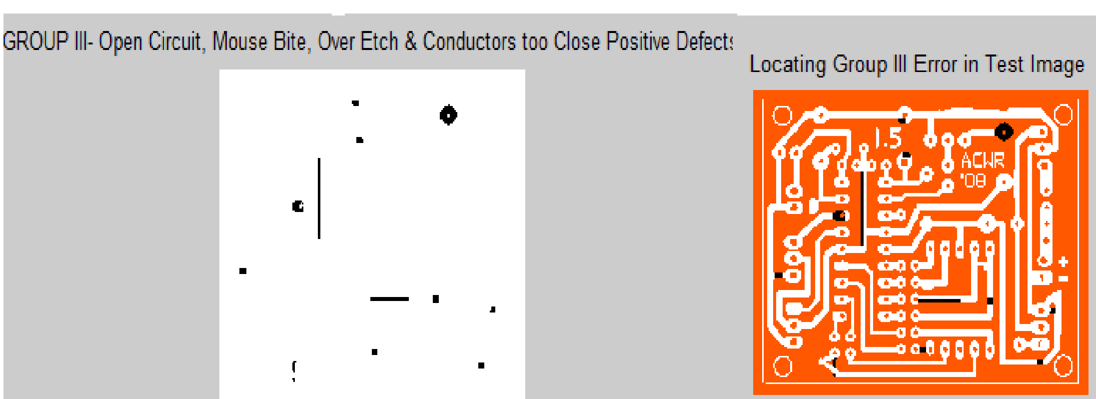

Fig.22 Identifying and Locating Group-III Defect in Test PCB

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D. *GROUP IV- Under Etch Defect Positive Defect Classification Algorithm*

Under etch defect can be obtained by using image addition operation to under etch positive image and under etch negative image obtained previously.

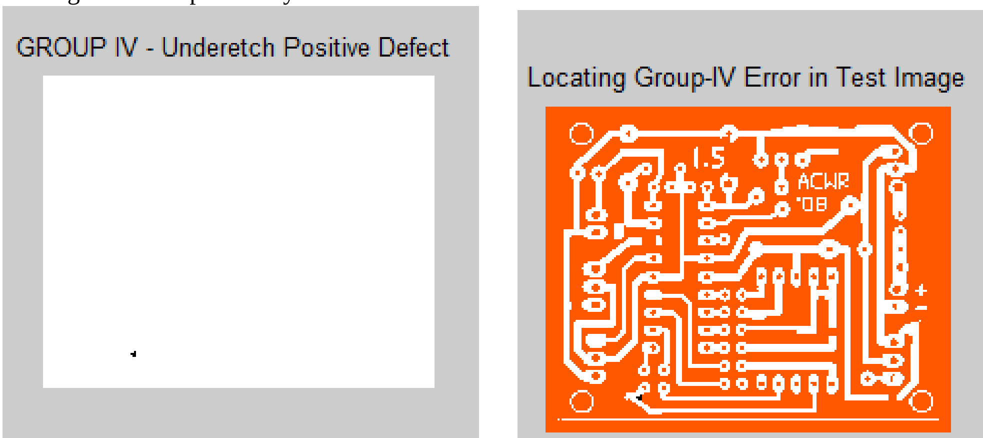

Fig.23 Identifying and Locating Group-IV Defect in Test PCB

E. GROUP V- Pinhole, Breakout Defect Classification Algorithm

To acquire an image of open-circuit and mouse bite defects, the image difference operation is first performed between the negative image and the image of pinhole and under etches negative defects. This operation produces an image of open-circuit and mouse bite defects. Foreground object pixels in are set to 1. The image addition operation is then executed between flood filled and generated image.

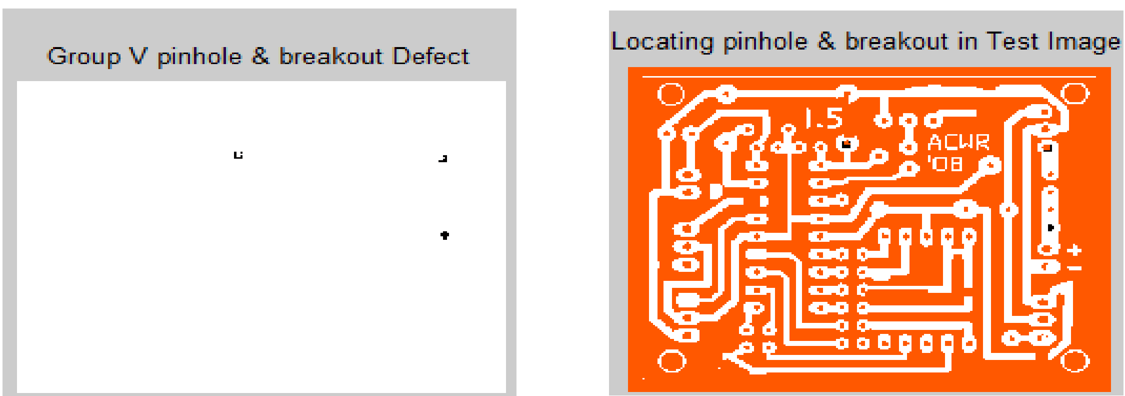

Fig.24 Identifying and Locating Group-V Defect in Test PCB

VII. ADVANTAGES

Without a proper image registration operation, the PCB inspection system is likely to totally fail. Hence, in this project we are incorporating a reliable image registration operation using control point selection tool box.

The proposed defect classification algorithms use the image subtraction operation to locate the defects. However, the subtracted image may still feature interference by unwanted noise due to slight misalignment and uneven binarization. To effectively eliminate the noise, Gaussian filtering, wiener filtering and Lucy Richardson algorithm is applied. This operation aids in generating noise-free positive and negative images for detecting defects precisely.

To prevent difficulties in detecting and classifying actual defects, the medium of the image subtraction operation is carried out in grey-scale. If the reference and test images are first converted to binary images, the noise may likely appear as actual defects which will provide false defects and adversely affect the performance of the proposed defect classification algorithms. In this research work it is taken into consideration.

VIII. CONCLUSION

This paper explores an optical inspection system for detecting bare PCB defects of single sided printed circuit board. Algorithm for the classification of defects on bare PCB is devised. The defect classification algorithms are capable of detecting various types of defects such as missing hole, wrong size, open-circuit, short-circuit,pinhole, under etch and mouse bite defects. Samples of real PCB images have been tested using the proposed algorithms. Moreover it also classify whether the defect is potential effect or fatal defect.

Mounting platform using two stepper motors can be devised and camera can be mounted at the top so as to rotate it along two axis namely x and y axis. This will reduce parallax error. Also multiple small size PCBs can be scanned simultaneously.

The proposed method proved to be an alternative way to efficiently detect and classify defects. It is expected that the proposed method is well suited for small and medium scale PCB manufacturers where the sophisticated alignment facilities are hard to purchase.

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