AUTOMATIC IDENTIFICATION, ANALYSIS AND INVESTIGATION OF PRINTED CIRCUIT BOARDS FOR DEFECTS AND ERRORS DISCLOSURE AND CLASSIFICATION BASED ON NATURE

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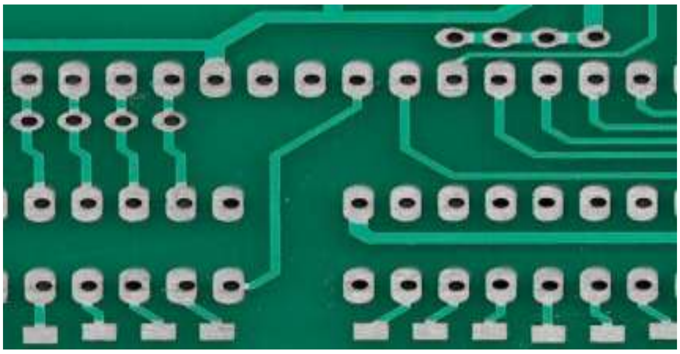
Abstract – *In the era of electronics, computers and high - end machine and various high-performance devices the printed circuit boards and integral part of any equipment. This printed circuit boards plays a very important role in smooth functioning of any devices. So, for successful operation of any equipment this printed circuit boards should be properly tested, inspected and investigated. Also, Inspection and Investigation of printed circuit board (PCB) has been a crucial process in the electronic manufacturing industry to guarantee product quality & reliability, cut manufacturing cost and to increase production. The PCB inspection involves detection of defects and errors in the PCB and classification of those defects and errors in order to identify the roots of defects. In this paper, all 14 types of defects are detected and are classified in all possible classes using referential inspection and investigation approach. The proposed algorithm is mainly divided into five stages: Image registration, Pre- processing, Image segmentation, Defect detection and Defect classification. The proposed algorithm is able to perform inspection even when the various operations are done on the test image. The various operation on captured test image is rotated, scaled and translated with respect to template image which makes the algorithm rotation, scale and translation in-variant. The novelty of the proposed algorithm lies in its robustness, reliability and efficiency to analyze a defect in its different possible appearance and severity. In addition to this, algorithm takes only 2.528 s to inspect and investigate a PCB image. The efficiency and reliability of the proposed algorithm is verified by conducting experiments on the different PCB images and it shows that the proposed algorithm is suitable for automatic identification visual inspection of PCBs.*

Key Words: Printed Circuit Boards, Automatic Visual Inspection, Detection and Inspection, Machine Vision and Classification.

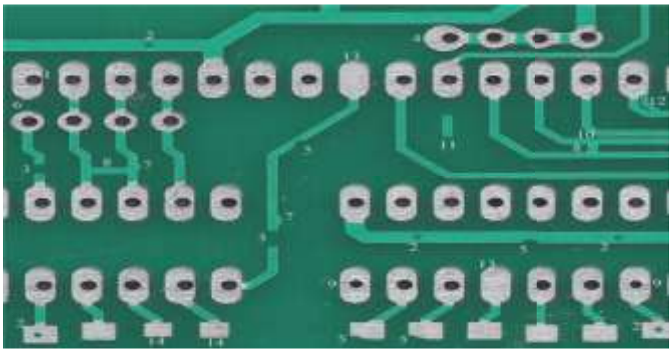
I. INTRODUCTION

Production and manufacturing of Printed Circuit Boards is an essential component in the electronics and semiconductor industries. The performance and efficiency of a PCB is significantly dependent on its quality and reliability. A defective PCB may result in undesirable circuit behavior and may end up in a defective, unwanted and unreliable product. Due to this Printed Circuit Board inspection and investigation is a crucial process in electronics industries. The aim of this inspection process is to assure 100% quality and reliability of all parts, which costs the most in manufacturing [1], [2]. Conventionally, human operators are involved in the visual inspection of PCB to detect and classify the defects and various types of errors occurring and unwanted noises. This conventional manual inspection and investigation process is time-consuming, tedious and error-prone. Also, the results of inspection and investigation may vary person to person due to human inconsistency and operating nature. The quality control problem can be solved by using developments in advanced computer vision field. In order to make PCB inspection and investigation process fast, reliable and efficient, automatic visual inspection (AVI) systems is more useful in various types of electronics industries.

Automatic Visual Inspection (AVI) based approaches are mainly divided into three different categories: The first is referential, second is non-referential and last one is hybrid methods [3]. Considering the first case of referential method, the given test image of the PCB is compared with its predefined template image in order to locate and finding out various defects. In another case of non-referential method which is based on the design rule-based method which verifies whether the design of PCB is in predefined limits or not. But the disadvantage of the non-referential method is that it is not able to identify defects in their distorted appearance. The hybrid method is most advanced one. The hybrid method is generally the combination of both referential and non-referential methods. But, the disadvantage of the hybrid method is its higher and advanced computational complexity. The sample template and sample defective images of PCB are shown in Fig. 1(a) and (b), respectively. There are 14 types of various underlying known defects in PCB as shown in Fig. 1(b).



(a) Template image of PCB



(b) Test image of PCB with defects:

Fig. 1: PCB images for referential method

(1) Breakout, (2) Pinhole, (3) Open circuit, (4) Under etch, (5) Mouse bite, (6) Missing conductor, (7) Spur, (8) Short, (9) Wrong size hole, (10) Conductor too close, (11) Spurious Copper, (12) Excessive short, (13) Missing hole and (14) Over etch

In the literature survey, numerous authors tried to disclose and classify the major possible occurring defects in generated PCB image using different methods. Wu et al. [4] used the referential method in order to disclose and classify the defects into various types of seven defined groups. The classification is performed according to three indices of a defect based on type and number of objects. Putera et al. [5] utilize the area property of defect for classifying it into seven defined groups, with maximum allowable four defects in a group. Further, Nakagawa et al. [6] propose a differential method and it classifies the defects into three defined classes. The research articulated in [6] differentiates the PCV image with the help of multiple support vector machine (SVM) which is trained with 24 various features of defect candidate. In [7], authors propose a referential method by using the edge grey gradient of the PCB image in order to classify defects into 5 defined classes. Furthermore, Kumar et al. [8] propose a non-referential method for further classification of defects into 4 defined classes. While, this method is having disadvantage that it can classify only one defect per image. The classification of defects in their class is as crucial as detection of defects. This classification is a naturalized process in order to identify the roots and basics of defects. As per the literature survey no author has tried to classify all various types of 14 PCB defects into all 14 possible classes.

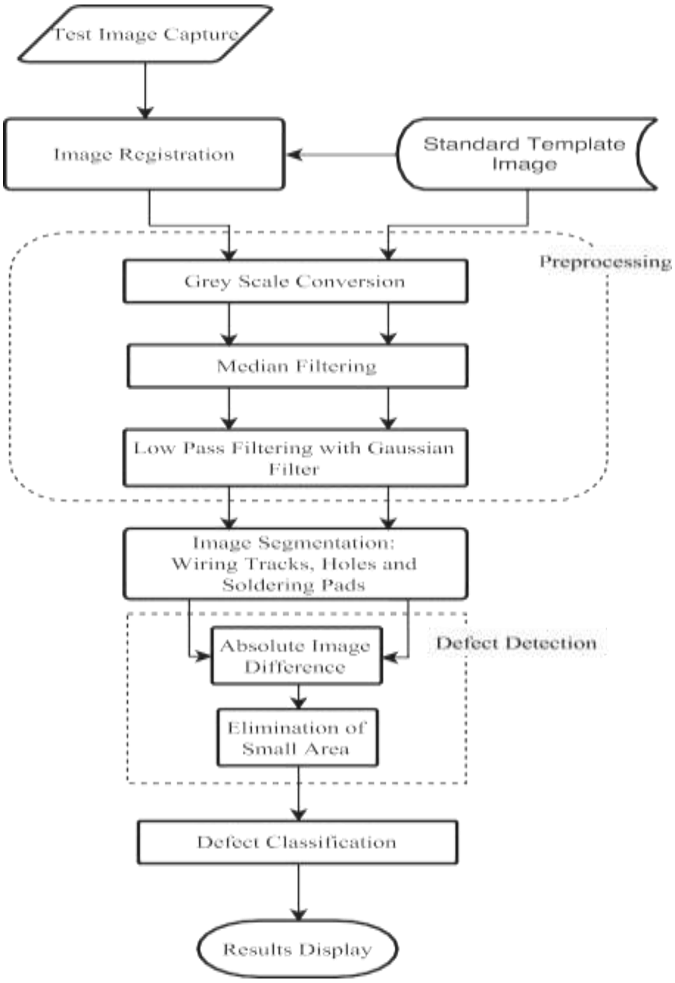


Fig. 2: Block schematic of the proposed algorithm

In this paper, I propose a referential method to disclose and classify the occurring defects of PCB into all possible 14 classes. The proposed algorithm is mainly divided into five operational stages: Image registration, Pre-processing, Image segmentation, Defect detection and Defect classification. Firstly, in Section II, image registration technique is articulated in order to remove unnecessary variation in captured test image like rotation, angular position, scale and translation with respect to template image of the same PCB. Next to that in Section III, pre-processing steps are elaborated in order to reduce noise factor, increase the efficiency and enhance the image quality. In Section IV, the image segmentation is produced. The defect detection and classification are the topics of discussion in Sections V and VI, respectively. At last, observed results and generated timing report of the algorithm is shown in Section VII. Finally, conclusion is given in Section VIII. The complete block schematic of the proposed algorithm is shown in Fig. 2.

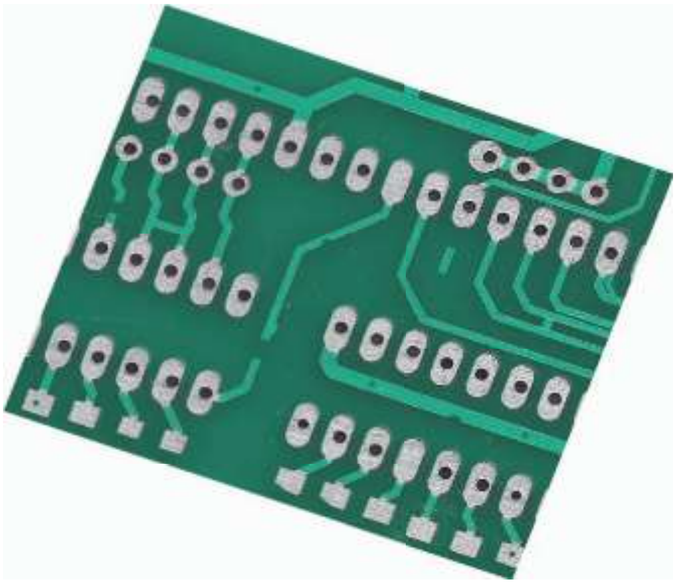


Fig. 3: Un-registered test PCB image

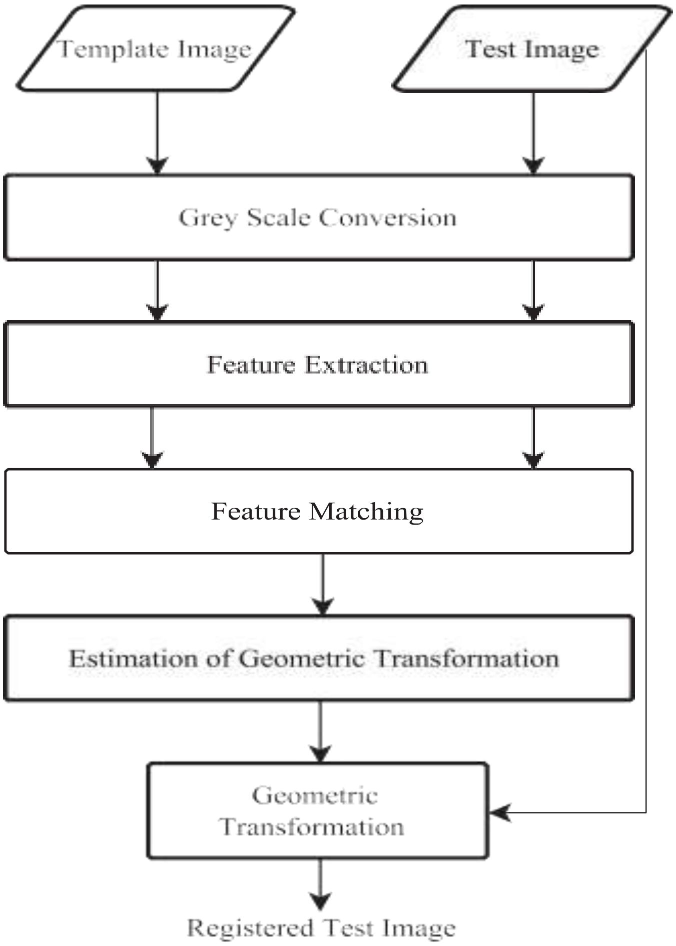


Fig. 4: Block diagram of image registration process

II. IMAGE REGISTRATION

Sample Test PCB is scanned by HP LaserJet scanner in order to generate the test PCB image. This image may have variations to an extent in terms of rotation, angular position and translation with respect to the template image as shown in Fig. 3. Such variations can be abolished by using image registration techniques [9]. The proposed block diagram of image registration process is shown in Fig. 4. The generated test image and template images are converted into grey scale by with the help of Eq. (1)

$$Greylevel = 0.299 \cdot R + 0.587 \cdot tt + 0.114 \cdot B, \qquad (1)$$

TABLE I

REGISTRATION TIME USING DIFFERENT FEATURE EXTRACTION METHODS

Feature Extraction Method	Execution Time (s)
SURF [11]	2.04
Harris [12]	2.635
BRISK [13]	1.497
FAST [10]	1.143
MSER [14]	4.411
MinEigen [15]	5.2

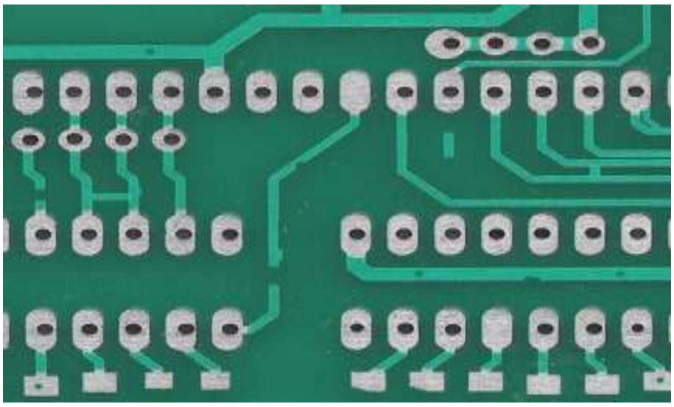


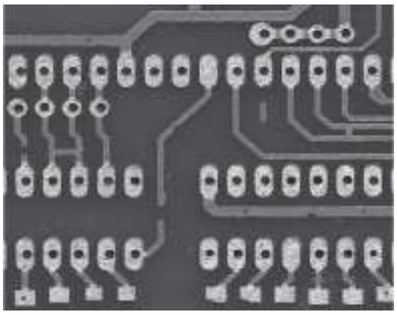
Fig. 5: Output of image registration process

where R, tt and B are the red, green and blue channels in color image. Next to this is the process of extraction of the features from the both present template and test images. Since this process is most time-consuming and long lasting in nature in image registration algorithm it is desirable to use high speed computational algorithm for this. Table I shows required time to execute registration process using different feature extraction techniques and methods. Features from accelerated segment test (FAST) algorithm [10] is used since it takes lowest time comparing to other present extraction methods as shown in Table I. The extracted features are matched and verified using sum of squared difference (SSD) metric. Geometric transformation matrix is then estimated from matched features using *m*-estimator sample consensus (MSAC) algorithm [16]. The estimated transformation is then enforced to test image in order to generate the registered image. The output of image registration is depicted in Fig. 5.

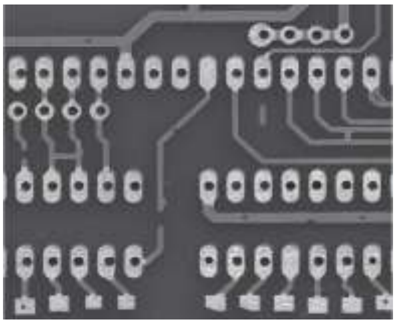
III. PRE-PROCESSING

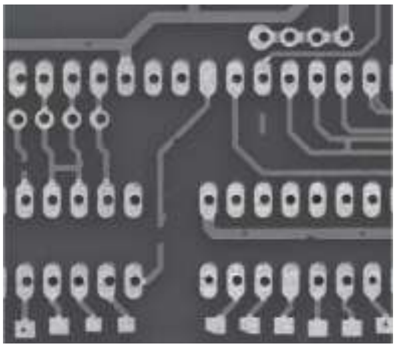
The acquired PCB images may have presence of noises such as salt and pepper noise. Also, these images may have high variations in intensity levels due to different lighting position and brightening exposure, which eventually leads to improper binarization of image. The objective of pre-processing is to remove noise and enhance the image details and improve the efficiency. Fig. 6(a) depicts the grey scale image of PCB using Eq. (1). Median filter of mask size 7*7 is then enforced on to the grey scale image for the purpose of removing salt and pepper noise. The output image is shown in Fig. 6(b). Next to the process of removal of noise, high-intensity variation is suppressed to an extent by applying Gaussian low pass filtering method having standard deviation = 1. In Fig. 6(c) we have shown a gaussian low pass filtered image.

(a) Test image in grey scale



(b) Output of median filtering





(c) Output of low pass filtering

Fig. 6: Preprocessing steps

IV. IMAGE SEGMENTATION

Succeeding to pre-processing step, there is occurrence of image segmentation. The objective of image segmentation is

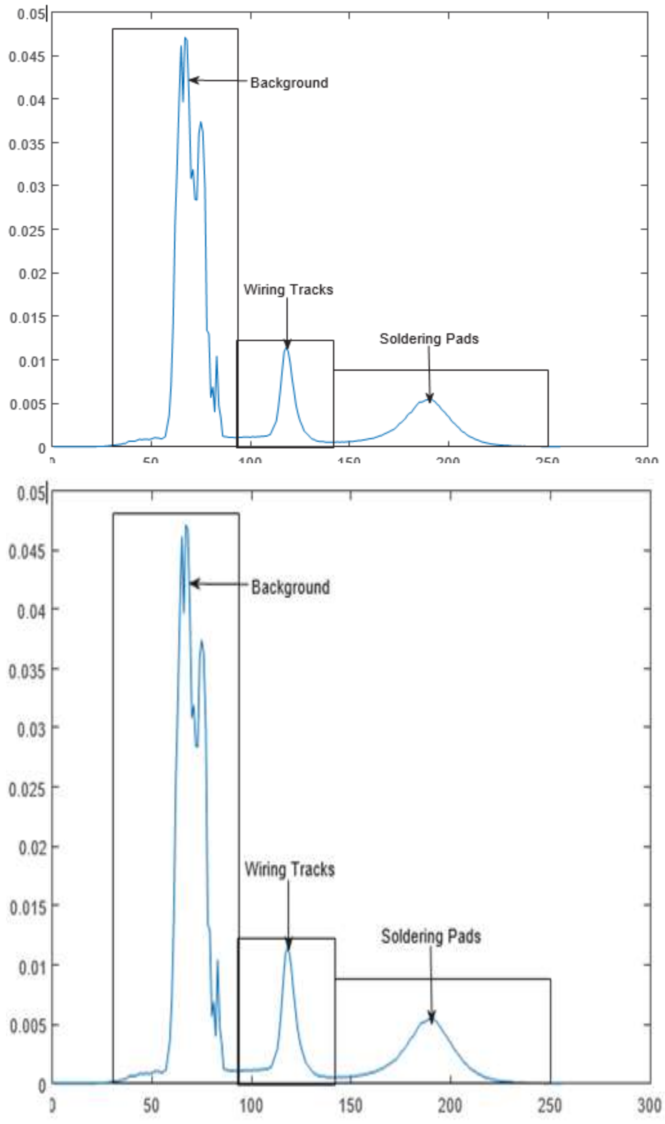
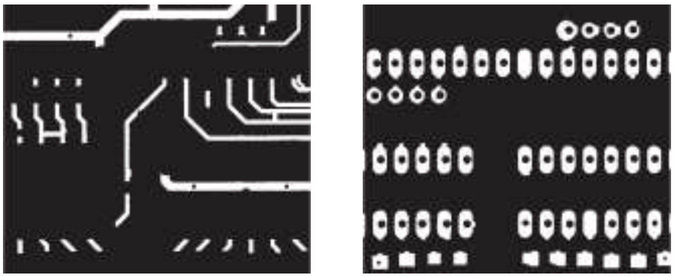
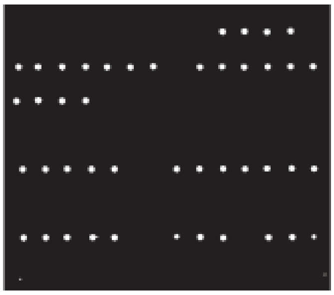


Fig. 7: Normalized histogram of PCB image



(a) Wiring tracks (b) Soldering pads



(c) Holes

Fig. 8: Segmented images

$$\text{Soldering pads} = \begin{cases} 1, & \textit{if} \text{ greylevel} > 140; \\ 0, & \text{else} \end{cases} \quad (3)$$

The zero regions inside the soldering pads show holes. These zero regions are now full of with region filling operations. Soldering pads regions are then subtracted from this filled image in order to produce the regions of holes. The segmented images are shown in Fig. 8.

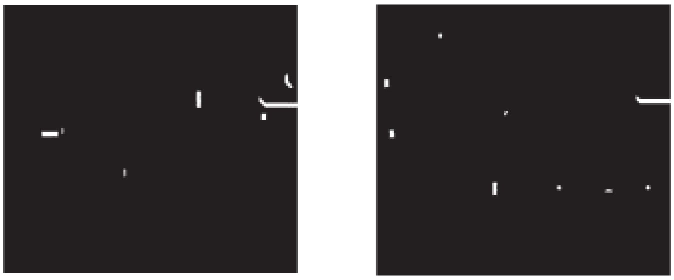
V. DEFECT DETECTION

The segmented images (including wiring tracks, soldering pads and holes) of test and template images have difference in each other due to defects occurring in testing PCB image. So, the defects can be simply disclosed by process of image subtraction. These defects generally are of two types: (1) positive defects (PD) and (2) negative defects (ND). As shown in Eq (4) positive defects can be disclosed by subtracting segmented template images from the corresponding segmented testing images; and vice versa for negative defects Eq (5)

$$PD_i = testing_i - template_i \quad (4)$$

$$ND_i = template_i - testing_i \quad (5)$$

where, *i gives idea of* wiring, tracks, soldering, pads and holes. Uneven binarization of edges also produces small differences between test and template images. This kind of small differences can be removed by method of area filtering. Disclosed defects after area filtering are depicted in Fig. 9.



(a) PD- Wiring tracks (b) ND- Wiring tracks

(c) PD- Soldering pads (d) ND- Soldering pads

(e) PD- Holes (f) ND- Holes

Fig. 9: Defect Detection

TABLE II
DEFECTS RELATED TO WIRING TRACKS

Positive Defects (PWD)	Spur, Short, Spurious copper, Excessive short, Conductor too close
Negative Defects (NWD)	Pinhole, Mouse bite, Open circuit, Missing conductor, Conductor too close

VI. DEFECT CLASSIFICATION

A. Defects Related to Wiring Tracks

Positive and negative defects related to wiring tracks are shown in Table II. Centroid and maximum radius of defects are obtained from PDW and NDW images by adopting 8-connected components. To verify the neighborhood of a defect, a square region (where length = maximum radius of defect, center = centroid of defect) is cropped from the divided wiring track image of template image (WT). The flowchart of defect classification is depicted in Figs. 10 and 11 for obtained positive as well as negative defects, respectively. Here, WT and SP represent wiring track segmented image and soldering pads segmented image, respectively for template image. WT1 serve segmented wiring track image of testing image (Fig. 8) (a).

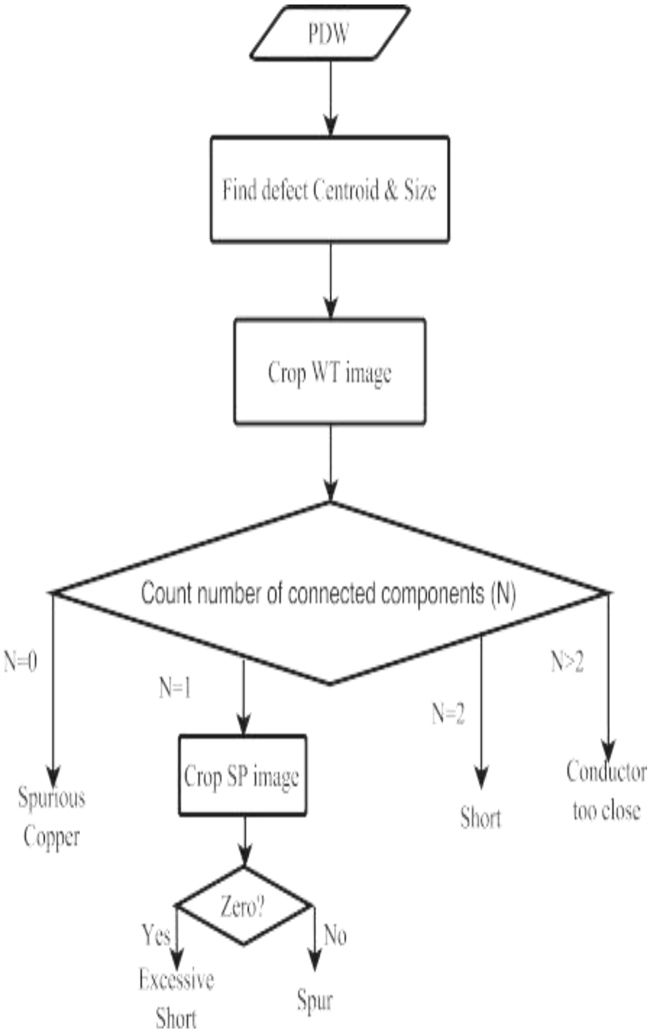


Fig.10: Classification of wiring track defects (positive)

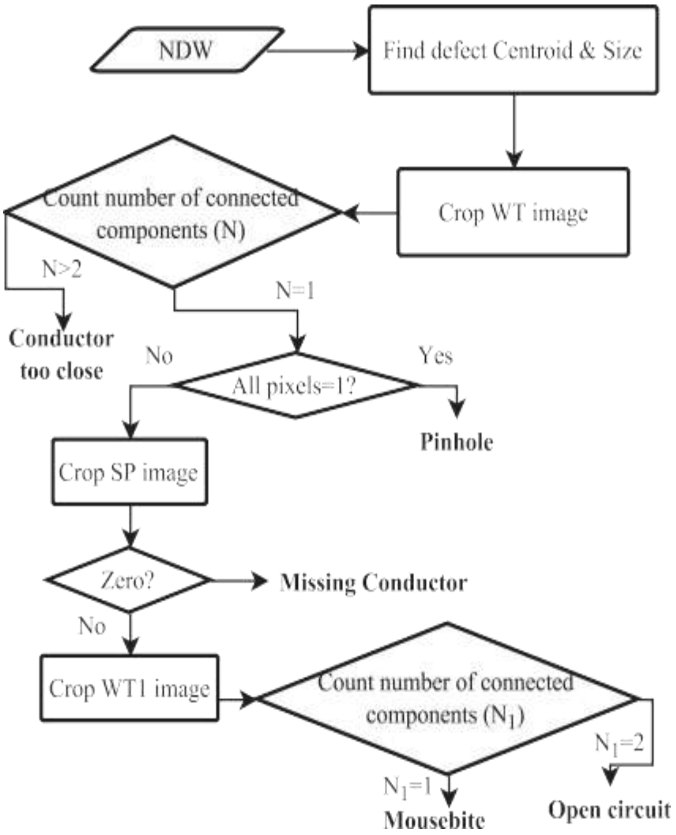


Fig. 11. Classification of wiring track defects (negative)

B. Defects Related to Soldering Pads

Positive as well as negative defects analogous to soldering pads are depicted in Table III. Under and Over etch defects have larger area (~2000) compared to the area of spur and mouse bite defects (~400). Adopting this difference in area soldering pad defects are classified as shown in Fig. 12.

C. Defects Related to Holes

Positive and negative defects related to holes are depicted in Table IV. Bold fonts in Table IV performs shape of the defect.

TABLE III

DEFECTS RELATED TO SOLDERING PADS

Positive Defects (PDS)	Under etch, Spur
Negative Defects (NDS)	Over etch, Mouse Bite

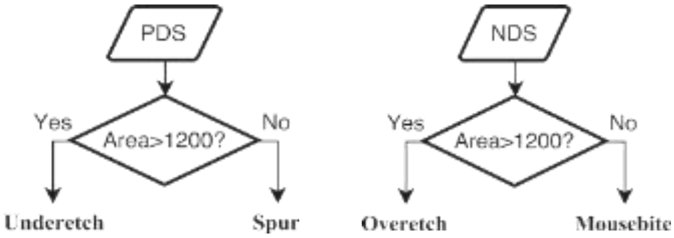
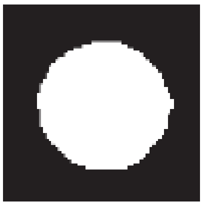


Fig. 12: Classification of soldering pad defects

TABLE IV

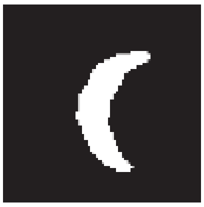
DEFECTS RELATED TO HOLES

Positive Defects PDH	Pinholes (Circle), Wrong size (Big) hole (Ring) and Breakout (Half-moon)
Negative Defects NDH	Missing holes (Circle), Wrong size (Small) hole (Ring) and Breakout (Half-moon)



(a) Circle shaped defect

(b) Ring shaped defect



(c) Half-moon shaped defect

Fig. 13: Hole defects shapes

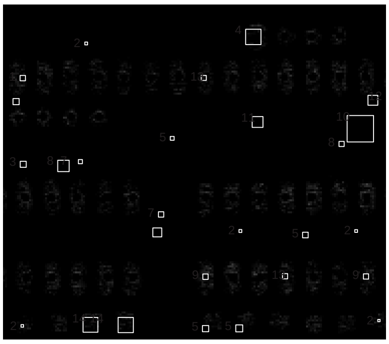


Fig. 14: Result generated by the proposed algorithm

There are mainly three shapes recognized in hole defects: (1) circle (2) ring and (3) half-moon as shown in Fig. 13. To make the classification process invariant to rotation, angular position and scale, Hu's 2nd invariant moment [17] is used to differentiate these shapes. Hu's 2nd moment for circle, ring and half-moon shapes are 3×10^{-5}, 40×10^{-5} and 6390×10^{-5}, resp.

TABLE V

TIMIMG REPORT OF THE PROPOSED ALGORITHM

Step	Time (s)
Registration	1.143
Preprocessing	0.223
Defect Detection	0.001
Defect Classification	1.161
Total	2.528

VII. RESULTS

The final result gathered after classification step is depicted in Fig. 14. It is observed that all the defects are successfully disclosed and classified into correct classes. In addition to this, the proposed algorithm takes just 2.528 s to execute the investigation of a PCB image. The complete timing data for each step of algorithm is explained in Table V. In the proposed approach, except soldering pad defects, the prospective algorithm uses scale invariant parameters (e.g. number of connected component and shape-based moment of defect) instead of using scale-based parameters like area of defect. Scale invariant features make classification process robust to defect severity.

VIII. CONCLUSION

In this paper, I have proposed a novel method to disclose and classify all available 14 types of defects of PCB using referential investigation method. Uniqueness of the algorithm is that it classifies all type of defects which is robust to defect appearance and severity. The testing (defective) image is coordinated with the template (standard) image using image registration techniques. Noise in the image is reduced with help of process of median filtering and hence increasing reliability and efficiency. Further- more, Gaussian low-pass filtering is used in order to evade uneven binarization due to sharp transitions present at edges. The PCB image is divided in three parts: wiring tracks, soldering pads and holes in order to evaluate defects in different parts of PCB image. The defect is disclosed using two-step process: image subtraction followed by area filtering to eliminate small areas after subtraction. After disclosing defects, each defect is classified using various region properties like number of connected components, shape-based descriptors and area.
The prospective algorithm is able to identify all 14 types of PCB defects, which is not covered in the state-of-the- art algorithms. Also, prospective method takes only 2.528 s to investigate a PCB image which makes it more suitable for AVI. The algorithm is useful in electronics manufacturing industries to investigate PCB quickly and accurately, that may lead to reduced manufacture time and improvement in overall efficiency, robustness and reliability of product.

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