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A Survey : Automated Visual PCB Inspection Algorithm

Prof. Malge P. S.[1] Nadaf R. S.[2]

Department of Electronics,
Walchand Institute of Technology, Solapur.413006

Abstract:An automated visual printed circuit board (PCB) inspection is an approach used to counter difficulties occurred in human's manual inspection that can eliminate subjective aspects and then provides fast, quantitative, and dimensional assessments. A printed circuit board (PCB) is a basic component of many electronic devices. The quality of PCBs will have a significant effect on the performance of many electronic products. Presently, there has been a lot of work concentrating on the detection and classification of defects on PCB. There are so many approaches for automated visual inspection of printed circuits have been reported over the last two decades. In this survey the various algorithms and techniques are examined. A summary of commercial PCB inspection system is also presented.

I. INTRODUCTION

Visual inspection is generally the largest cost of PCB manufacturing. It is responsible for detecting both cosmetic and functional defects and attempts are often made to ensure 100% quality assurance for all finished products. There are two main processes in PCB inspection: defect detection and defect classification. Currently there are many algorithms developed for PCB defect detection, using contact or noncontact methods [3]. Contact method tests the connectivity of the circuit but is unable to detect major flaws in cosmetic defects such as mouse-bite or spurious copper and is very setup-sensitive [12]. Any misalignment can cause the test to fail completely. Non contact methods can be from a wide range of selection from x-ray imaging, ultrasonic imaging, thermal imaging and optical inspection using image processing [5 - 6]. Although these techniques are successful in detecting defects, none is able to classify the defects.

Some approach utilizes a non contact reference based, image processing approach for defect detection and classification. In these approaches template of a defect free PCB image and a defected test PCB image are segmented and compared with each other using image subtraction and other procedures. Discrepancies between the images are considered defects and are classified based on similarities and area of occurrences.

Bare printed circuit board (PCB) is a PCB without any placement of electronic components (Hong et al., 1998) which is used along with other components to produce electrics goods. In order to reduce cost spending in manufacturing caused by the defected bare PCB, the bare PCB must be inspected. Moganti et al. (1996) proposed three categories of PCB inspection algorithms: referential approaches, non-referential approaches, and hybrid approaches.

- Referential approaches consist of image comparison and model-based technique.
- Non-referential approaches or design-rule verification methods are based on the verification of the general design rules that is essentially the verification of the widths of conductors and insulators.
- Hybrid approaches involve a combination both of the referential and the non-referential approaches.

These PCB inspection approaches mainly concentrated on defects detection (Moganti et al., 1996). However, defects detection did not provide satisfactory information for repairing and quality control work, since the type of detected defects cannot be clearly identified. Based on this incapability of defects detection, defect classification operation is needed in PCB inspection. Therefore, an accurate defect classification procedure is essential especially for an on-line inspection system during PCB production process.

Human operators simply inspect visually against prescribed standards. The decisions made by them often involve subjective judgment, in addition to being labor intensive and therefore costly, whereas automatic inspection systems remove the subjective aspects and provide fast, quantitative dimensional assessments. Due to the following criteria, the sophistication in automated visual inspection has become a part of the modern manufacturing environment.

- They relieve human inspectors of the tedious jobs involved.

- Manual inspection is slow, costly, leads to excessive scrap rates, and does not assure high quality.
- Multi-layer boards are not suitable for human eyes to inspect.
- With the aid of a magnifying lens, the average fault- finding rate of a human being is about90%. However, on multi-layered boards (say 6 layered), the rate drops to about 50%. Evenwith fault free power and ground layers, the rate does not exceed 70% [9].
- Industry has set quality levels so high that sampling inspection is not applicable.
- Production rates are so high that manual inspection is not feasible.
- Tolerances are so tight that manual visual inspection is inadequate.

A variety of approaches for automated optical inspection of printed circuit boards (PCBs) have been reported over the last two decades.

The most recent review on automatic visual inspection [18, 19] has a section dedicated to the inspection of PCBs. This survey is an attempt to put together the advances made solely in the field of bare PCB visual inspection. In this survey, algorithms and techniques for the automated inspection of PCBs are examined. This survey concentrates mainly on image analysis and fault detection strategies.

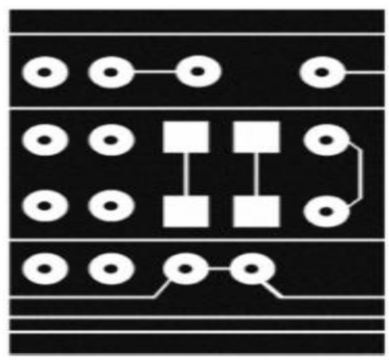
TABLE 1
DEFECT ON SINGLE LAYER BARE PCB

No	Defect Name
1	Breakout
2	Pin hole
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
14	Over etch

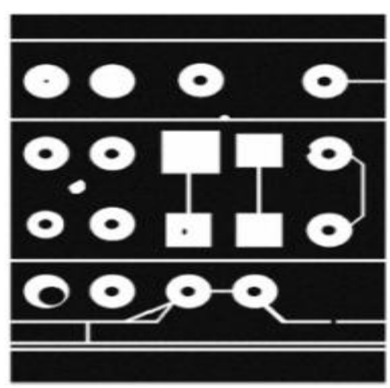
This paper is organized as follows. Section 2 contains the defects related to the bare PCB. Section 3 and 4 describes the types of inspection and algorithms for detection and classification of PCB defects. Section 5 contains summary of commercial PCB inspection system while the discussion and conclusion is described in section 6.

II. DEFECTS

PCB defects can be categorized into two groups; functional defects and cosmetic defects [22]. Functional defects can seriously affect the performance of the PCB or cause it to fail. Cosmetic defects affect the appearance of the PCB, but can also jeopardize its performance in the long run due to abnormal heat dissipation and distribution of current. There are 14 known types of defects for single layer, bare PCBs as shown in Table I. Figure 1 shows a gray scale image of a single layer, bare PCB and Figure 2 shows the same image but with defects as listed in Table 1.



Fig, I Template Greyscale PCB Image



Fig, 2 Test Grayscale PCB Image

Based on reviews of previous works, Heriansyah et al [23] developed a PCB image segmentation algorithm by clustering primitive patterns of a PCB image into four main segments using mathematical morphology and windowing technique. Later Heriansyah [25] classifies 12 out of the 14 known PCB defects by combining the image segmentation with artificial neural network (ANN). Recently, Khalid [26] produced an image processing algorithm using MATLAB by subtracting the images and performing X-OR operation. The 14 defects are then grouped into 5 categories. First, the complex PCB images are divided into four different segments of well-defined generic patterns [24], and later fed into the image processing algorithm [26] where defects are detected and classified. The new visual inspection systems techniques using real time machine vision replace the human visual manual inspection on PCB flux defects, which brings harmful effects on the board which may come in the form of corrosion and can cause harm to the assembly.[27]

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].

III. TYPES OF INSPECTION

PCB flaw detection procedures can be broadly divided into two classes [2, 13]: contact methods and non-contact methods. Contact test methods can find flaws such as shorts and opens, the others require some other methods of detection.

This section briefly lists some of the different inspection systems based on different imaging technologies. Some of the non-contact automatic inspection methods that are currently available are [13, 11, 16, 14, 20]:

1. **Automatic Visual/Optical inspection:** Automatic optical inspection (AOI) systems detect the same type of surface-related defects as manual inspection; including bare board inspection, solder bridging, lack of solder, missing components, poor part orientation, lifted leads, tomb stoning, and solder balls. Automatic optical inspection has the following characteristics that contact testing does not have [9, 8, 15]:
    - It recognizes potential defects such as out-of-specs, line widths, line spacing, voids, pin holes, etc.
    - AOI can inspect artwork and provides strict product control from the onset of production.
    - AOI is a non-contact inspection, thus avoiding mechanical damage.

1. **X-ray imaging**: X-ray imaging systems[16, 15] are used for rapid and precise measurement of multi-layered PCBs.
2. **Scanned-Beam Laminography:** Laminography [15] provides cross-sectional X-ray imaging which separates the top and bottom sides, or any other layer of the PCB, into cleanly separated images.
3. **Ultrasonic Imaging**: Ultrasonic imaging technology best detects solder-joint defects such as internal voids, cracks, and disbands.[21]
4. **Thermal Imaging**: Thermal imaging systems [16] indicate hot spots on operating PCBs indicating shorts and overstressed components.

IV. ALGORITHMS

Eduardo [18] has grouped the conventional visual inspection tasks into three broad categories based on the types of defects they detect: (a) dimensional verification, (b) surface detection methods, and (c) inspection of completeness. The conventional PCB bare-board inspection algorithms could as well be put into these categories. Sanz and Jain [7] classified the printed wiring board inspection techniques into the following four different categories: run-length-based methods, boundary analysis techniques, pattern detection methods, and morphological techniques. A classification based on the nature of the information of the algorithms use for fault identification is presented here. In general, PCB inspection algorithm falls into fall into one of three categories: reference comparison (or referential approaches), non-referential approaches, and hybrid approaches. [9]

The reference approaches use complete knowledge of the circuit under test. There are two types of reference comparison methods: the simpler approaches involve some kind of direct image comparison, between pixels in the test image and in an idealized reference image. Somewhat more sophisticated approaches involve recognition of circuit features in the test image followed by a comparison against a set of reference features. The referential methods execute a real point-to-point (or feature-to-feature) comparison whereby the reference data from the surface image of a good" sample is stored in an image database. These methods detect errors like missing tracks, missing termination, opens, shorts, etc. The drawback of this method is that, since differences between the PCB under inspection and a \golden board" or CAD data are called defects, board distortions, as a consequence of processing, may be identified as anomalies inspection problem. This is one of the earliest techniques employed in inspection [1]. The board to be inspected is scanned and its image is compared against the image of an ideal part. The subtracted image, showing defects, can subsequently be displayed and analyzed.

Advantages of referential approach:

- This method is that it is trivial to implement in specialized hardware and therefore high pixel rates can be obtained.
- It allows for verification of the overall defects in the geometry of the board.

Practical problem encountered in Reference approaches:

- This technique suffers from many practical problems, including registration, color variation, reflectivity variation, and lighting sensitivity.
- A fairly high tolerance of the PCB board makes the method too restrictive for practical use.
- One other problem is that statistical analysis must be performed to determine if the differences are due to nonconformities or due to alignment.

The non-referential approaches either work on the assumption that features are simple geometric shapes and the defects are unexpected irregular features or on directly verifying the design rules. The non-referential approaches use the knowledge of properties common to a circuit family but not knowledge of the specific circuit under test. Non-Referential methods do not need any reference pattern to work with; they work on the idea that a pattern is defective if it does not conform with the design specification standards. These methods are also called design-rule verification methods or generic property verification methods.[1].

Advantages of non-referential approach:

- Minimum and maximum trace widths for all the different traces used.
- Minimum and maximum circular pad diameters.
- Minimum and maximum hole diameters.
- Minimum conductor clearance.
- Minimum annular rings, trace termination rules, etc.

Morphological Processing is one of the widely used techniques in PCB inspection. The inspection involves the expansion-contraction process, which does not require any predefined model of perfect patterns. Ye and Danielson [10] presented an algorithm for verifying minimum conductor and insulator trace widths. The method iteratively applies shrinking (similar to contraction operation) and connectivity preserving shrinking (similar to thinning) operations on the image.

After some number of iterations, the difference (logical AND) between the results gives the defects present in the patterns. The main advantage of these methods is that the alignment problem is eliminated.

The hybrid approaches involve combination of one of these methods. The hybrid flaw-detection techniques increase the efficiency of the system by making use of both referential and design-rule techniques exploiting the strengths and overcoming the weaknesses of each of the methods. These methods have the added advantage that they cover a large variety of defects compared to either referential or non-reference methods alone. For example, most of the design-rule verification methods are limited to verifying minimum conductor trace and land widths, spacing violations, defective annular ring widths, angular errors, spurious copper. Printed circuit board errors which do not violate the design rules are detected by reference comparison methods. These methods can detect missing features or extraneous features like isolated blobs, etc. The design-rule process detects all defects within small and medium sized features; the comparison methods are equally sensitive right up to the largest features. Hybrid systems make use of both the design-rule methods and comparison methods as they complement each other and therefore achieve 100% error sensitivity, irrespective of feature sizes on the printed circuit boards.

V. COMMERCIAL SYSTEMS

Many factors must be considered in designing a commercial inspection system: hardware, software, system throughput, versatility, and reliability. Versatility refers to the number of different inspections the system can perform. The following is a list of capabilities and features a typical commercial PCB inspection system is expected to have:[23]

System capability:

- Minimum flaw that can be repeatedly detected at the stated escape rate:- 2.0 mil.
- Scan rate: - 4.0 ft^2 / min.
- Panel through-put:- inspect both sides of 18×24 inch panel (85% active) including setup, loading, scanning, and unloading at a rate of 40 panels/hour.
- Typical pixel size:- 1.0 mil.
- False alarm rate (fail good product):- less than 2.0 per ft^2.
- Escape rate (pass bad product):- less than 1.0 per 100 ft^2(depends on defect criteria)
- Gaging capability (where specified):- measure feature size to 1.0 mil.

Typical dimensions of panels to be inspected:

- Panel dimension: - 20"×26".
- Scan area: - 18"×24".
- Nominal conductor width:- 4 mil.
- Nominal conductor spacing:- 4 mil.
- Pad size:- round or rectangular pads of dimension between 3 and 10 mil.
- Conductor via hole diameter size:- 5 mil or larger.

Types of panel to be inspected:

- Conductor layout:- all possible line orientations and power/ground layers.
- Photo printed boards: - all commercial photoresist types.
- Inner layer metallization: - drilled and undrilled PCBs in copper technology.
- Artwork: - most forms including silver-halide and diazo on both Mylar and glass substrate.
- Finished boards: - without solder and prior to solder mask.
- Substrates:- FR4, polymide and other common substrate material.

Types of defects to be inspected:

- Voids: - Any void in a conductor that exposes bare substrate material and exceeds 5% of the design width.

- Shorts: - Any short with a width in access of 2 mil at any point.
- Opens: - Any conductor open exceeding 2 mils in width.
- Spacing: - Any metallization that reduces the space between conductor by more than 5 % of design spacing.
- Extraneous metal: - Any isolated spot whose area exceeds 2 mil^2.
- Artwork: - Any defect violating the above rules for voids, spacing, or extraneous metal; as well as any pinhole in excess of 3 mil.

VI. CONCLUSION

Various advances take place in PCB manufacturing industry over the last decade. Machine vision may answer the manufacturing industry's need to improve product quality and increase productivity. This study presented a survey of algorithms for visual inspection of printed circuit boards. The major limitation of all the existing inspection systems is that all the algorithms need a special hardware platform in order to achieve the desired real-time speeds, which make the systems extremely expensive. Any improvements in speeding up the computation process algorithmically could reduce the cost of these systems drastically. Also, forefront in the challenges confronting the automated visual inspection research is the development of generic inspection equipment, hardware and software, capable of handling a wide variety of inspection tasks. Many efforts are underway to improve flexibility in the field of visual inspection systems. With more efforts in this direction systems in the future will be easier to operate than those now available.

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