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PCB defect detection based on pattern matching and segmentation algorithm

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Abstract: This project presents a new implementation which separates two of the existing groups containing two defects each into four new groups containing one defect each by processing synthetic images of bare through-hole single layer PCBs using MATLAB Image Processing. This also will use Mathematical Morphological Toolbox here. Morphological process involves techniques such as dilation, erosion, opening and closing which helps in partitioning the images and associates certain types of defects with certain patterns. This project separates the defects in larger groups into smaller groups. This increases the efficiency of the inspection system in classifying defects. Since certain PCB pattern are produced in different processes, classification of defects can help in determining the root causes of error and reduce production cost in the long run. Focus is given to separate groups of defects in the hole segment, thick line segment and thin line segment.

Keywords: Image Processing, Printed Circuit Board, Defect Classification.

I. INTRODUCTION

One of the key components in the electronics industries is the production of the printed circuit board (PCB). Since the existing technology is going towards full digital implementation, it is envisioned that the manufacturing of PCB will ever growing. In conjunction with this development, Malaysia has taken an important step. Currently there are 37-listed PCB manufacturing companies nation-wide. As important as producing the PCB is to produce a zero-defect PCB. This is to ensure a high quality PCB that translates to reliable and quality digital end products. Initially, the bare PCBs (PCB without components attached to it) were inspected randomly using manual inspection system, which involves human operators. This technique is quite costly since it is highly error-prone due to human error. A more sophisticated way of doing the inspection is the use of in-house circuit testing (ICT) technique. This technique uses a very expensive machine that checks the conductivity of the PCB using probes. However, the limitation of this technique is it can only detect defects that are based on either shorts or open. many levels and different image processing techniques can be used.

Printed circuit board or in short PCB fabrication process is a multidisciplinary process. The most critical part in the PCB manufacturing is the etching process where the copper board will undergo 'peeling' process whereby the circuit layout will be preserved while the rest of the copper background will be washed out. In order to minimize scrap caused by the wrongly etched PCB panel, inspection has to be done. Among the practices is to inspect for any defect visually employing human operators. Not only that this process is time consuming, it is also highly prone to errors due to humans' factors. The next trend then is to use a computerized inspection system. However, all of the inspections are done after the etching process where any defective PCB found is no longer useful and is simply thrown away. Since etching process costs 70% of the entire PCB fabrication, it is definitely uneconomically to simply discard the defective PCBs. Hence, this project proposes an automatic visual inspection on the PCB before the etching process so that any defect that could be found on a PCB would be able to be reprocessed.

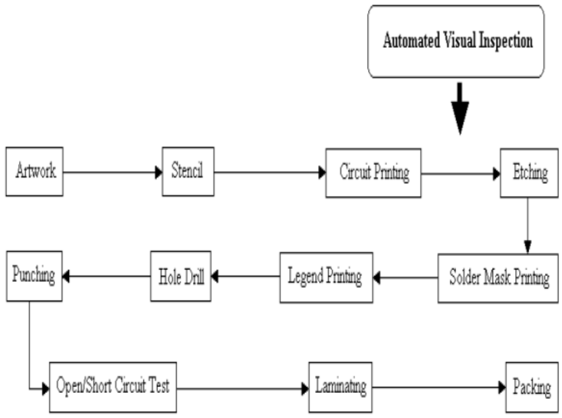

Figure: PCB fabrication process

At various stages of the fabrication process, inspection is done. If the panel is accepted at that stage, it is passed on to the next stage. Otherwise, the panel goes back to rework, to the same stage of operation. But in some of the cases, the panel is rejected. For such cases, the panel inspection is critically important.

Current practice in PCB fabrication requires etching process. This process is an irreversible process. The printing process, which is done before etching process, caused most destructive defects found on the PCB. Any misprint will cause the etched board to be useless. Since laminated board constitute most of the total production cost, it is important that the board is properly inspected before being etched. Otherwise, the wrongly etched board will be thrown away. This, in return, requires a system to detect online or in real-time any defect caused by the printing process.

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This project is motivated mainly by the need for more efficient techniques in inspection of the PCB panel in PCB fabrication process. Normally, a couple of operators are assigned in each station to manually check the PCB panels. This technique is not economical in a long run as it takes many man hours. In addition, humans are prone to making errors especially due to fatigue. Moreover, it is impossible to check the entire PCB panels at every location without any delay. Instead, the printed laminate is sampled a certain interval of quantity for manual inspection.

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Visual inspection is one of highest cost in printed circuit boards (PCB) manufacturing. Although many algorithms are available in defect detection, both contact and non-contact methods, none is able to classify these defects. Contact method tests the connectivity of circuits but unable to detect major flaws in cosmetic defects. Non-contact uses methods such as ultrasonic and x-ray imaging to detect anomalies in the circuit design, both cosmetic and functional. The use of manual labor to visually inspect each PCB is no longer viable since it is prone to human errors, time consuming, requires large overhead costs and results in high wastage. Thus an automation inspection system is highly desirable. 'Many important applications of vision are found in manufacturing processes, such as inspection, measurement, and some assembly operations. One of these applications is the automatic visual inspection of printed circuit boards (PCB). The circuits on PCBs are becoming much finer and more complex, so it would be a challenge for manual inspection. Comparing manual and automatic optical inspection (AOI), Moganti and AOI relieves human inspections of the tedious jobs involved.

- Manual inspection is slow and 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 faultfinding rate of a human being is about 90%. However, on multi-layered boards (say, six-layered), the rate drops to about 50%. Even with fault-free power and ground layers, the rate does not exceed 70%.
- The 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.
- Packaging technologies become increasingly complex, substrates become more costly; hence, scrap is minimized.

In image comparison techniques field, Hamada and Nakahata took inspected patterns to compare with design patterns to achieve a highly reliable inspection in 1990. They proposed two-step image processing inspection. The first step is the coarse alignment between the detected patterns and the design patterns. The second step is the defect detection named "Local Pattern Comparison" method in which small defects up to 1.5 pixel-size can be detected without being influenced by pattern registration errors and sampling errors. Ito and Nikaido proposed a topological comparison method, which compares the inspection graph obtained from the skeletons of the conductor and insulator images of an inspection PCB with those of the standard or reference boards.

II. EXISTING SOLUTIONS & PROBLEMS

Although many algorithms are available in defect detection, both contact and non-contact methods, none is able to classify these defects. Contact method tests the connectivity of circuits but unable to detect major flaws in cosmetic defects. Non-contact uses methods such as ultrasonic and x-ray imaging to detect anomalies in the circuit design, both cosmetic and functional. The use of manual labor to visually inspect each PCB is no longer viable since it is prone to human errors, time consuming, requires large overhead costs and results in high wastage. Thus an automation inspection system is highly desirable. 'MATLAB Based Defect Detection and Classification of Printed Circuit Board' seeks to improve the classification of defects by an algorithm developed by Indera Putera.

Disadvantages:
- Defects are not realized properly
- Classification accuracy is less
- Thick line and thin line segn is not proper
- Production cost in long run is high due to improper inspection
- Only one defect detection possible in each group

III. PROPOSED SOLUTION

The PCB manufacturing process is based on chemical and mechanical actions that may damage the intended design. Frequently, various PCB defects such as break out, pin-hole, open-circuit, under-etch and mouse-bite occurred during production. Any anomalies between Template and Test Image are declared as defects. a PCB image segmentation algorithm to separate PCB images into four main segments which are square segment, hole segment, thin line segment and thick line segment using mathematical morphology and windowing technique. This project minimizes the number of defects for each classified groups. Wrong size hole is successfully separated from G21 and placed in G28 while missing hole remains as an individual defect in G21. Both G32 and G42 contain missing conductor and open circuit defects. Both these defects have the same characteristic which is the absence of copper which acts as connectors or conductors between pads. The only significant difference between missing conductor and open circuit is that in missing conductor the entire conductor that connects to the circuit is lost, while in open circuit, only a small portion of conductor is absent as a result of errors in the printing or etching process.

Color Image & RGB Image

The RGB color model is an additive color model in which red, green, and blue light is added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary

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colors, red, green, and blue. The main purpose of the RGB color model is for the sensing, representation, and display of images in electronic systems, such as televisions and computers, though it has also been used in conventional photography. Before the electronic age, the RGB color model already had a solid theory behind it, based in human perception of colors. RGB is a device-dependent color model: different devices detect or reproduce a given RGB value differently, since the color elements (such as phosphors or dyes) and their response to the individual R, G, and B levels vary from manufacturer to manufacturer, or even in the same device over time. Thus an RGB value does not define the same color across devices without some kind of color management. Typical RGB input devices are color TV and video cameras, image scanners, and digital cameras.

Image Representation.
Quantized images are commonly represented as sets of pixels encoding color/brightness information in matrix form. An alternative model is based on contour lines: A contour representation allows for easy retrieval of the full image in bitmap form. It has been used primarily for data compression of an image. The idea is to encode, for each level, the boundaries of connected regions of pixels at levels greater than or equal to. It is easy to reconstruct an original image from those boundaries. There exist output-sensitive algorithms for computing contour representations.

Image Segmentation
In computer vision, image segmentation is the process of partitioning a digital image into multiple segments . The goal of segmentation is to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze. Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images. More precisely, image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain visual characteristics.

Thresholding
The simplest method of image segmentation is called the thresholding method. This method is based on a clip-level (or a threshold value) to turn a gray-scale image into a binary image. The key of this method is to select the threshold value (or values when multiple-levels are selected). Several popular methods are used in industry including the maximum entropy method, Otsu's method (maximum variance), and k-means clustering.

Compression-based methods
Compression based methods postulate that the optimal segmentation is the one that minimizes, over all possible segmentations, the coding length of the data. The connection between these two concepts is that segmentation tries to find patterns in an image and any regularity in the image can be used to compress it. The method describes each segment by its texture and boundary shape. Each of these components is modeled by a probability distribution function and its coding length is computed.

Image segmentation and primal sketch
There have been numerous research works in this area, out of which a few have now reached a state where they can be applied either with interactive manual intervention (usually with application to medical imaging) or fully automatically. The following is a brief overview of some of the main research ideas that current approaches are based upon.

Morphological segmentation
Referring to Heriansyah et al, images are segmented into primitive patterns using morphological techniques such as dilation, erosion, opening, and closing. The windowing technique is used to enclose the segmented pattern in a compact window with an assigned coordinate which helps in partitioning the inspection tasks among multiple processors for faster on-line processing, and associates certain types of defects with certain basic pattern, thus making inspection easier.

Table :PCB Defects

1	Breakout
2	Pin hole
3	Open circuit
4	Wrong size hole
5	Missing hole
6	Spur,Short
7	Under etch
8	Conductor too close

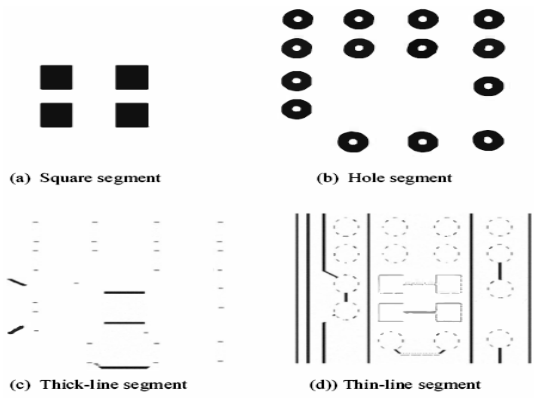

Fig. 1 Morphological Segmentation for Template Image

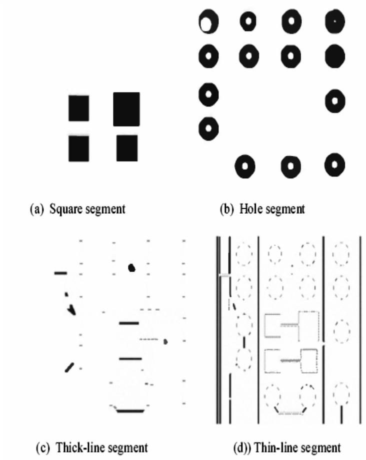

Fig. 2 Morphological Segmentation for Test Image

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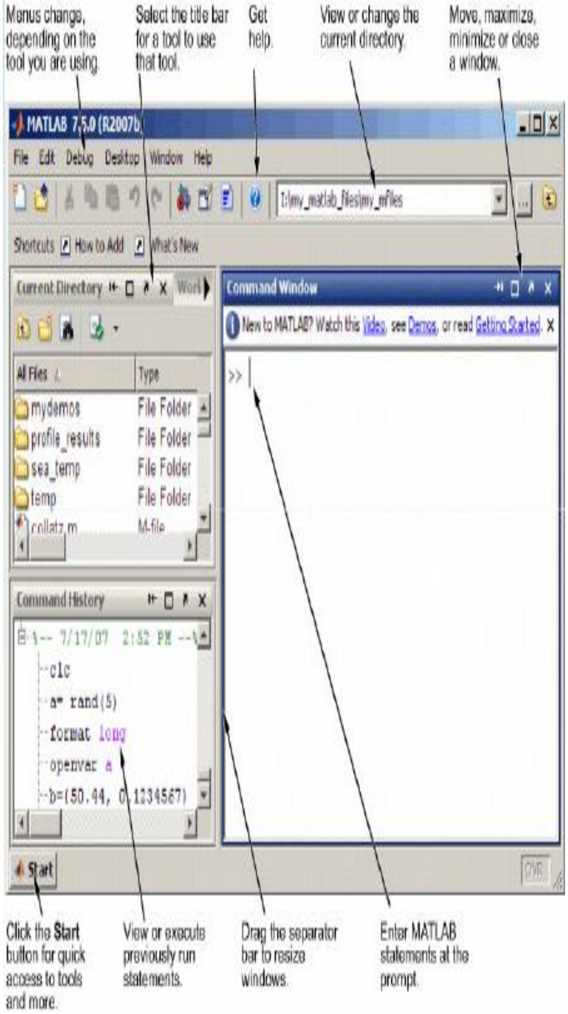
Advantages:

- All defects are realized properly
- Classification accuracy is higher
- Thick line and thin line segmentation is properly achieved
- Production cost in long run is reduced
- Two defect detection possible in each group

IV. ANALYTICAL EVALUATION

Desktop Tools and Development Environment:

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, a code analyzer and other reports, and browsers for viewing help, the workspace, files, and the search path.



Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

V. METHODOLOGY

Printed circuit defects are mainly missing or extra elements on the board. PCB defects can be categorized into two groups; functional defects and cosmetic defects. Functional defects can be fatal to the circuit operations while cosmetic defects affect the appearance of the circuit board but may affect the performance of the circuit in long term. The PCB manufacturing process is based on chemical and mechanical actions that may damage the intended design. Frequently, various PCB defects such as break out, pin-hole, open-circuit, under-etch and mouse-bite occurred during production. Types of defects on single layer bare PCBs are shown in Table I.

Computer generated printed circuit board images absent from any defects, known as Template Images are designed as control images to compare with the circuit that contains defects, knows as Test Images as shown in Figure 1. Any anomalies between Template and Test Image are declared as defects. Indera Putera classified these defects into seven groups. Based on reviews of previous works, Heriansyah develop a PCB image segmentation algorithm to separate PCB images into four main segments which are square segment, hole segment, thin line segment and thick line segment using mathematical morphology and windowing technique.

Morphological process involves techniques such as dilation, erosion, opening and closing which helps in partitioning the images and associates certain types of defects with certain patterns. Refer to Figure 2 for an example of PCB image segmentation.

Then Khalid produced an image processing algorithm using Matlab by subtracting the images and performing logical operations such as X-OR, IMFILL and N OT. X-OR is used for image subtraction. Positive image is the result of subtracting the test image from the template image and the negative image is the result of subtracting the template image from the test image as in Figure 3 and 4. The IMFILL operation fills out the pad holes and pin holes while NOT operation inverts the binary value of template and test images as in Figure 5 and 6. Grey-scale images with values ranging from 0 to 255 are converted to two level bin nary images with a value of either 0 or 1 each image is segmented into four patterns, 20 new images are produce. Out of this, seven images are beneficial for classification of defects as in Table II. For this particular exercise each group consist of minimum 1 defect and maximum 4 defect and consequently improve the image processing done by Khalid by increasing the number of group from 5 to 7.

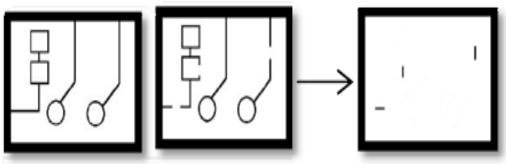


Figure 3: Positive Image from X-OR Operation

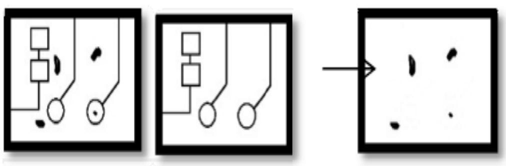


Figure 4: Negative Image from X-OR Operation

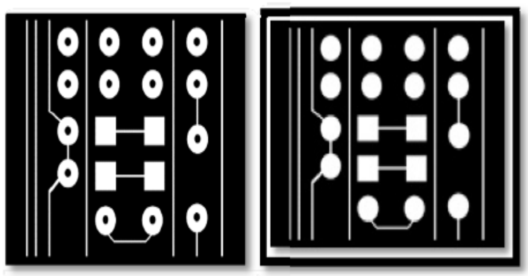


Figure 5: IMFILL Operation

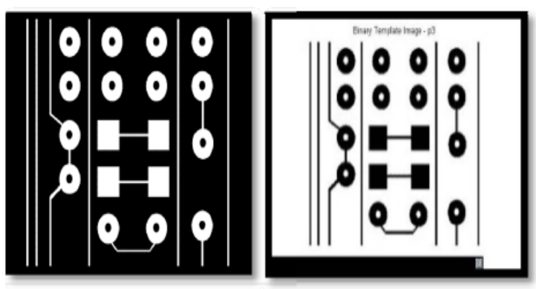


Figure 6: NOT Operation

In order to increase the number of groups and reduce the number of defects in each group, image property measurement method is used to measure image regions. In this study, group G21 from the hole segment is separated into individual groups each containing one defect namely over etch and mouse-bite. The same technique is applied to G42 from the thin line segment where the two new groups created contains only one defect namely missing conductor and open circuit. The procedure is extended to group G32 from the thick line segment which contains the same type of defect as in G42. The output images are increased from 20 to 23.

This project minimizes the number of defects for each classified groups. Wrong size hole is successfully separated from G21 and placed in G28 while missing hole remains as an individual defect in G21. Both G32 and G42 contain missing conductor and open circuit defects. Both these defects have the same characteristic which is the absence of copper which acts as connectors or conductors between pads. The only significant difference between missing conductor and open circuit is that in missing conductor the entire conductor that connects to the circuit is lost, while in open circuit, only a small portion of conductor is absent as a result of errors in the printing or etching process. In this section region props method used is by measure properties of image regions. Programs code has been developed to isolate defects in this G42 group. Open circuit is maintained in group G42 while missing conductor is placed in new group named as G48.

VI. CONCLUSION

It can be concluded that this project have been implemented successfully since number of groups is increased from 7 into 11 However, there are groups which still contains more than one defect such G22, G25 and G33 because the image came from the same negative image. Subtraction of images is not possible since defects in the same group have similar characteristics. Future improvement for the algorithm should overcome this limitation. Integration with an image capturing system such as camera is also essential for actual performance verification of defect detection and classification of PCBs. The scheme has been tested with success on various test images on a MATLAB simulation platform along with use of Mathematical Morphological Toolbox.

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