PCB Defect Detection USING OPENCV with Image Subtraction Method

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Abstract—**In the PCB manufacturing industry, one of the most important aspect of the production is quality checking. PCB boards goes through lots of production process from panel cutting to laminating and one single defect in a board will make the entire board become obsolete. With the rise of electronic appliances demand every day, the demand for higher quality components is rising. With the high price tag of commercial AOI, lots of manufacturers are not able to do an automated inspection. This is where Computer Vision can provide an alternative for commercial AOI to assist small scale manufacturers to do an automated inspection. Image Subtraction and Blob detection enable users to easily find numerous visual defects in PCBs especially with a complex method. By dissecting pictures and pointing out the differences on the output image, PCBs can be inspected quickly to find out the defective parts. And thus, this thesis will focus on the basis that a basic image subtraction will be enough to assist Manufacturers in Quality Inspections.**

Keywords— ***AOI; OpenCV; Computer Vision, PCB; Image Subtraction***

I. INTRODUCTION

In this Information Era, the usage of electronic tools and appliances is rising every single day, and therefore it also translates to higher usage of Printed Circuit Boards (PCB) as it is the base platform of nearly every single consumer electronic appliance. With the technological advancements that we see today, PCBs are used not only by the industries, but also small projects by university students and hobbyists which made a market for small scale PCB production industry since production process is getting easier compared to the past.

In order to satisfy the consumers' demand of good quality boards, quality inspection and control have to be carried to ensure there are no defects that will affect the end-product of PCB, in which why nowadays it is necessary to do Machine Vision Inspection Process to make sure the quality of PCB is good to distribute. [1]

To conduct a Machine Vision Inspection Process, generally PCB producers have to utilize an Automated Optical Inspection (AOI) system [2] which can be quite expensive for small scale PCB producers who generally do not use advanced machinery in order to manufacture their PCBs.

This paper will focus in the computer vision technology through OpenCV enables systems to capture, recognize, and analyze images to find out information for the users, in which Computer Vision will be used to detect the defects from bare printed PCBs utilizing image subtraction method contained in OpenCV based on a reference image.

The inspection system will be based on Image Subtraction technique in order to detect residual properties on the result of subtraction which will be declared as defects on the result. All of the methods used within the system are based on OpenCV library including Image Processing, Image Subtraction, and Blob detection method.

The aim of the system is to provide a small system capable to do a quality inspection to find out any defects on the bare printed boards on the PCB production which will automatically find defective parts, provide the status of the PCB, and point out where the defective parts are on the PCB boards to the system user.

There are several limitations that can be found within the project, with time and technology constraints considered. The most glaring limitation is that the reference image and the inspected image must have the same dimension and image alignment in order for the system to achieve the desired accuracy since Image Subtraction method is utilized.

II. RESEARCH METHODOLOGY

The basic concept of the PCB inspection system is that it enables the system users to inspect their PCB by inputting their reference image of the PCB, which will be a non-defective PCB or aligned with the initial PCB design and then compare it to the inspected PCB image which will result in a new Image where the defective parts of the PCB will be pointed and shown in a display window, in addition, information containing the inspected PCB's information such as number of defects found, status of the PCB, and time taken to process will be shown to measure the performance of the system.

The inspection system utilizes OpenCV library's methods and functions especially Image processing techniques including Gaussian Blurring, Thresholding, Image Morphology, Image Subtraction, and Blob detection.

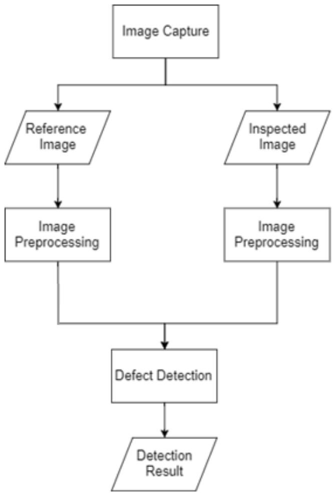

Fig. 1. System Flowchart

The first process is Image Capture, where the referential Image and inspected PCB's image are inserted into the system. Within this project, the method of acquiring the PCB image are done through the program manually from the code. Images are put into the folder of the program and then picked up by the system automatically.

The next process is the Image Pre-processing stage in which each Image will be prepared using several Image Processing process to turn the raw images into binary form which will be used to discover defective parts of the PCB.

The last process contained within the system is the Defect Detection process, which will have an output of the result of PCB Inspection image. Both of the processed reference and Inspected PCB image will go into the same step which is Image subtraction to find out the differences between the two images, this process will create a new image which is the absolute difference between the reference image and the inspected PCB image. After that, the image will go through blob detection process where the system is looking for any blobs of object remains in the difference image. If there are blobs remaining, the system will mark them and then draw the Keypoints to be reported to user where the defective parts of the PCBs are.

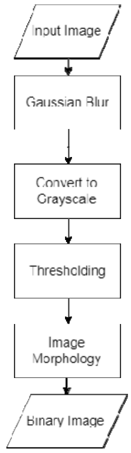

Fig. 2. Image Preprocessing

The second process that the images have to go through is the Pre-processing design. In this stage, the Images will have several Image processing methods applied in order to extract relevant information that is required. Below are the functions of OpenCV used within this process.

Gaussian Blurring is first applied to the images in order to smoothen the image and reduce any noise that can affect the accuracy of the system. To conduct the process, a function from OpenCV library, GaussianBlur() is called

Convert to Grayscale stage, the blurred image will be converted into a grayscale image. At the start of the process, the image was inserted as an RGB model image, which will not be optimal for the system to convert into a binary image. In this process, the cvtColor() function is used**.**

Thresholding process start after the image is converted into grayscale, the system will continue to convert it into binary form. Which is using a function called threshold() contained within the OpenCV library. For this process, the threshold value used is 127 with the maximum value of 255 and Inverted Binary Threshold type. This process is done for the system to be able to create blobs for the later stage of inspection.

In **Morphology** step, structuring element operation is done through morphology function which is contained within the OpenCV library. The morphology method used is Closing which removes small holes and dots that has a potential to affect the accuracy of the system. Closing Morphology method consisted of conducting a Dilation followed by Erosion which repeats until the system requirement is met. The called function is morphologyEx().

Defect Detection start after the Image Preprocessing step is done, both of the processed reference and Inspected PCB image will go into the same step which is Image subtraction to find out the differences between the two images, this process will create a new image which is the absolute difference between the reference image and the inspected PCB image.

Then, the image will go through blob detection process where the system is looking for any blobs of object remains in the difference image. If there are blobs remaining, the system will mark them and then draw the Keypoints to be reported to user where the defective parts of the PCBs are.

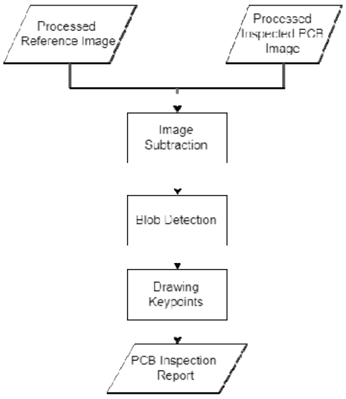

Fig. 3. Defect Detection Process

Below are the functions of OpenCV used within the defect detection process.

Image Subtraction

After both reference and inspected PCB images are finished with the pre-processing, the format of both images is in Binary, which only consist of 0 and 1. Using the absdiff() function included in the OpenCV library, an XOR operation is carried on which will create a new temporary image containing the difference between the reference image and inspected PCB image. To continue into the next step, which is blob detection, a threshold function is applied again to invert the color.

Blob Detection

To find out the residual remains from the image subtraction method which is also known as Blobs. There are several parameters that are used for the PCB inspection method, which are Area, Circularity, Convexity, and Inertia. Area translates to the density of the residual blobs, Circularity measure how close to a circular form a blob is, Convexity refers to the convex shape of the blob, and Inertia which refers to the form of the blob whether it is circular or close to a line. The system uses a minimum Area of 50, minimum Circularity of 0.01, minimum Convexity of 0.5, and minimum Inertia ratio of 0.009.

Drawing Keypoints

After the blobs are marked, then the Keypoints are drawn on the blobs to make sure the blob detection is working as expected. The drawKeypoints() function is used to draw the circles around the detected blobs. For the final part of the system, Keypoints are also drawn on the Inspected PCB image to show the user where are the defective parts are.

III. THEORETICAL FOUNDATION

PCB Quality Inspection

Quality inspection in general, is an activity that is done to check the product's quality which is applied to manufacturing processes and organizations analysis. [3]

PCB or Printed Circuit Board is a thin board manufactured from laminate materials such as fiberglass with conductive pathways etched onto the board which connects different components embedded on the PCB such as transistors, resistors, and integrated circuits. These components are soldered into the PCB to the conductive tracks which will allow them to work together. In the PCB manufacturing industry, a quality inspection is essential in the production process in order to avoid any defective parts existing on each board as any defective parts found within the PCB can cause a design misalignment which can results in a non-working PCB. Moganti in 1996, proposed that there are three types of PCB inspection algorithm, which are Referential approaches consisted of image comparison technique, Non-referential approach based on general design rules for PCB components, and the Hybrid approach which combines the Referential and Non-referential approach. [4]

There are several methods or solution that can be used to conduct a PCB Inspection using the referential approach, one of the methods is using an Automated Optical Inspection. Automated Optical Inspection (AOI) system is by its name, an automated visual inspection of a Printed Circuit Board (PCB) or other electronical components production where a Camera is used to autonomously scan the surface of products for quality defects and sort out the defective products from the rest of production. AOI system in general, works within the Computer Vision discipline which is a branch of Artificial Intelligence field of study.

PCB Defects

For a PCB panel, there are various defects that can affect the pattern printed on the PCB. Several types of the defects can be categorized as functional defects and visual defects.

Functional Defects critically affects the PCB's functions as they damage the PCB to the extent of malfunction due to misalignment of design and product. On the other hand, Visual Defects, just as stated in its name, are just small defects that are not harming the PCB in the short time. In long period however, Visual Defects will also affect the PCB's functionality since misalignment between design and current product can leads into potential defects. Therefore, an inspection to make sure the PCB does not have any kind of defect is vital.

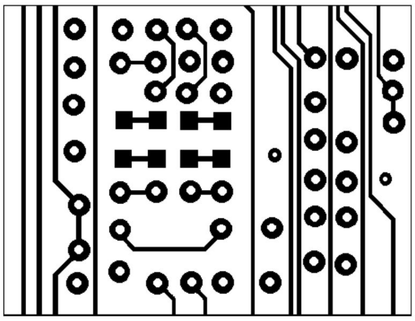

Fig. 4. Good PCB

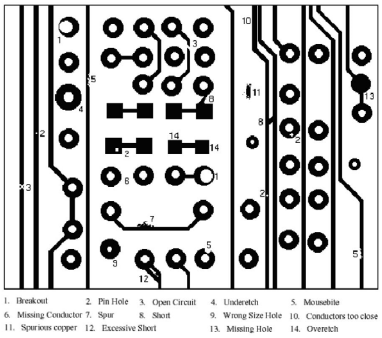

Fig. 5. Defects in PCB

Within a defective PCB, various defects can be found as stated within Figure5, in which defects are classified into the following types:

1. Breakout	8. Short
2. Pinhole	9. Wrong Size Hole
3. Open	10. Conductor too close
4. Under etch	11. Spurious Copper
5. Mouse bite	12. Excessive Short
6. Missing conductor	13. Missing Hole
7. Spur	14. Overetch

Image Processing

Image processing, in its essence, is a process to extract visual information required to do image manipulation, detection, navigation, and recognition. It is a process that a system will be required to do, sometimes in exact order, to get the additional information which can be acquired from the input images. [5]

Gaussian Blur or Gaussian Smoothing is a technique or method that is commonly used within Image Processing. The main goal of applying a Gaussian Blur to a Digital Image is to smoothen rough edges, reducing image resolution, and also to reduce noise. [6]

Within the 2D plane scenario, the function's equation will create a surface using concentric circles to be the contours of the image. Then, the Gaussian distribution is applied starting from the center point and then create values, which forms a convolution matrix. The matrix is then applied to the reference image. This new matrix contains several pixel values, which are weighted average of the neighboring pixels. The original pixel that is affected by the Gaussian function will have the heaviest weight contributed to the highest Gaussian value while the smaller weights are loaded to its neighboring pixels in an increment to the distance to the original pixel. [7]

Image **Thresholding** is one of the simplest methods of Image Segmentation process in Computer Vision. Thresholding is a process where a grayscale image will be inserted into the process as an input image and then processed to create a binary image. [8]

The way it works is that since the grayscale image only contain a single value ranging from 0 to 255 per pixel, a constant which is called T will be used as a base to modify the image based on the current value contained within the pixel compared to the T value. It will return 0 value (black color) if the image intensity I(i,j) is less than the T value and on the opposite, will return 255 value (white color).

Binary **Image Morphology** is an Image Processing method which is used to process Binary Images using a structuring element. Structuring element itself is a referential or base binary image that is used to process the input image to get the desired result image. Image Morphology is used to process or morph a Binary Image into several shapes or blobs in order to extract new information from an Image. While there are several shapes of structuring elements, the most used shapes used in Binary Image Morphology are Box and Ring shapes. [5]

Image subtraction is an algorithm or process where the system takes two images as an input and then produces an output of a result image which its pixel values are gained from simply the first image's pixel value subtracted by the second image's pixel value. [9]

There are several ways to do image subtraction, with strictly subtracting the pixel values within the two images, which are to simply subtracting the value of pixels contained within the Image or by calculating the absolute difference of both image.

IV. RESULTS

Two kinds of Images are used to test the performance of the system, which are a low-resolution image under 720p image resolution, and a high-resolution image which is 720p or above. The images are obtained from an online repository with artificial defects applied on the images for testing purposes.

Low-resolution Image (447x385 pixels)

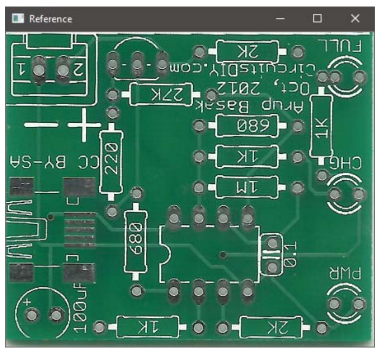

Fig. 6. Reference Image (Low-Res)

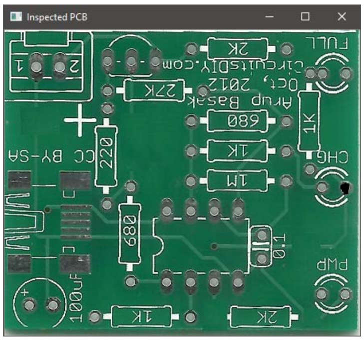

Fig. 7. Inspected Image (Low-Res)

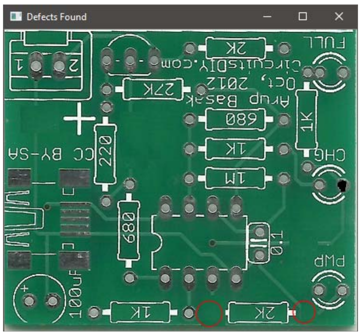

Fig. 8. Defects Detected (Low-Res)

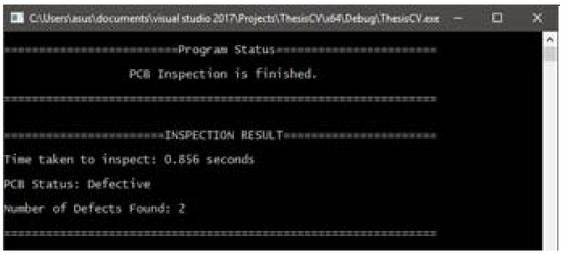

Fig. 9. System Report

High-resolution Image (1748x931 pixels)

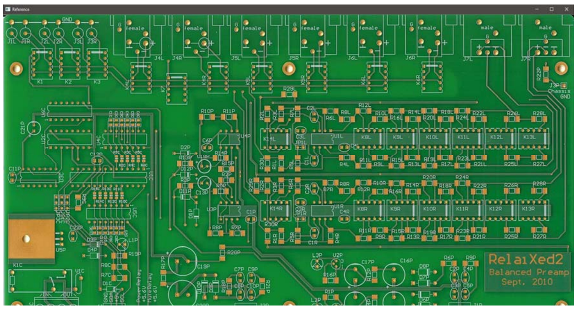

Fig. 10. Reference Image (High-Res)

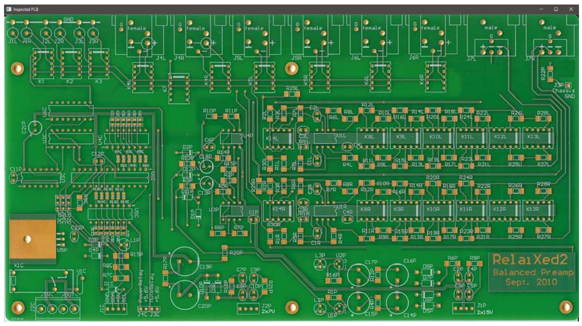

Fig. 11. Inspected Image (High-Res)

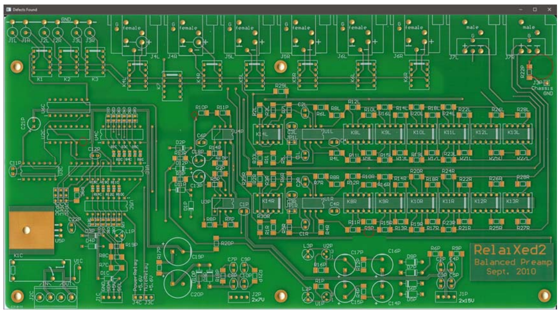

Fig. 12. Defects Detected (High-Res)

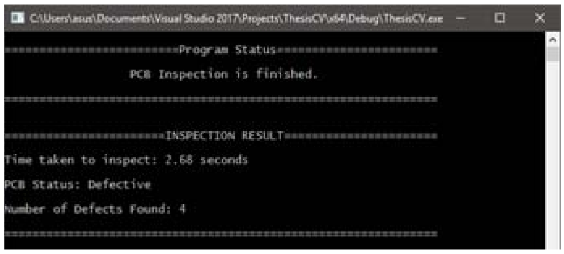

Fig. 13. System Report

Result Analysis

From the two tested images, below is the result from the defect detection system.

TABLE I. TESTING RESULT

Image	Size	Time	Accuracy	Status
Low-Res	447x385	0.856s	40%	Detected
High-Res	1748x931	2.68s	80%	Detected

From the data above, the current method of using image subtraction to detect defective parts on a PCB is proven done in a really fast pace, ranging from 0.856 seconds for Low-resolution image to 2.68s for High-resolution which is faster compared to a manual inspection done by humans.

The size of the image represents how long each inspection is done as the bigger the image, the more pixels that are processed, will take longer time to finish the inspection process. Accuracy of the system is also represented by the image size or resolution, as the more accurate or higher the resolution of the image, the accuracy of the program will also increase.

The system was able to detect defective parts on all the boards tested which is the main objective of the project.

V. CONCLUSION

The PCB inspection system is able to detect a defective PCB in a very fast pace using Image Subtraction Method, reaching from 0.856 to 2.68 seconds depending on the size of the processed Digital Image source. The accuracy of using image subtraction method for an PCB Inspection on Etched boards is not satisfying despite being able to spot a defect in every single tested board, this will be critical if there are lots of boards with copper trail or circuit defects. However, from the result of the testing we can conclude that the resolution of the Images directly affects the accuracy, as the higher the image size, the accuracy of the detection is also higher.

Testing results shows that the system needs to be improved to increase the accuracy of defect detection. Below are some recommendations that can be done to improve the system and overcome the limitations:

1. Improve the algorithm of Blob Detection and Morphology to further raising the accuracy of the system.
2. Apply a Hough-Transform process and Image Segmentation for Images in order to increase accuracy and reduce the necessity of having both Reference and Inspected image to be at the same size and alignment.
3. Implement an Image Segmentation method in order for the system to be able to process images which have larger resolution compared to the system's hardware specification.
4. Research another method which can enhance the capability of the system.

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