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A PRINTED CIRCUIT BOARD INSPECTION SYSTEM WITH DEFECT CLASSIFICATION CAPABILITY

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ABSTRACT. *An automated visual printed circuit board (PCB) inspection is an approach used to counter difficulties occurred in human's manual inspection that can eliminates subjective aspects and then provides fast, quantitative, and dimensional assessments. In this study, referential approach has been implemented on template and defective PCB images to detectnumerous defects on bare PCBs before etching process, since etching usually contributes most destructive defects found on PCBs. The PCB inspection system is then improved by incorporating a geometrical image registration, minimum thresholding technique and median filtering in order to solve alignment and uneven illumination problem. Finally, defect classification operation is employed in order to identify the source for six types of defects namely, missing hole, pin hole, underetch, short-circuit, mousebite, and open-circuit.*

Keywords: Automated Visual Inspection System; Image Subtraction; Thresholding; Image Registration; Printed Circuit Board

1. Introduction. 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 approachesconsist of image comparison and model-based technique. Non-referential approaches or design-rule verification methodsare based on the verification of the general design rules that is essentially the verification of the widths of conductors and insulators. Lastly, 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.

In literature, only Wu et al. (1996), Rudi Heriansyah and Abu-Bakar (2004), Rau and Wu (2005), and Ibrahim et al. (2011) have proposed PCB inspection systems in classifying defects. In this paper, a new PCB inspection system on real PCB images has been proposed by adapting similar algorithm that comes from (Ibrahim et al., 2011). Image subtraction must be used to detect defects on the PCBs. However, image subtraction operation that has been utilized to detect defects between defective and template images cannot be used directly as it contributes unwanted noise due to misalignment and uneven binarization and thus, the accuracy of the defect detection could be decreased. Since the nature of real PCB images is different compared to computer generated PCB images, an image registration must be employed at first in order to get well-aligned defective image against template image.Then, all pixels in the template image are subtracted against the registered defective image to get two output images known as positive and negative images. Next, by applying image thresholding and filtering techniques, noise free positive and negative images are produced. Starting from here, the two images can be used as inputs for defect classification.

2. Defect on Bare Printed Circuit Board. The source of defects is come from printing process which is done before the etching process. Short and open-circuit fall in fatal defects category. Meanwhile, the other defects such as pinhole, underetch, mousebite, and missing hole, fall in potential defects category. Note that fatal defects are those in which the PCB does not attend the objective they are designed for, while the potential defects are those compromising the PCB during the utilization. Figure 1(a) and Figure 1(b) show real PCB images for template image and defective image in RGB format, respectively.

3. Flow Process of the PCB Inspection System. Figure 2 depicts the PCB inspection system developed in this research for detecting and classifying defects on PCB which includes six stages. The stages are image acquisition, image registration, defect detection, thresholding, filtering, and defect classification.

3.1. Image acquisition. In this study, real PCB images are captured using a high resolution 1620 x 1236 pixels UNIQ monochrome charged coupled device (CCD) camera. Height in between the CCD camera and the inspected PCBs is set to 34 cm as this is the highest available distance for the camera stand that can be set up such that CCD camera can grab the entire PCB images. A PC2-Vision frame grabber has been used to digitize and store the images into computer. Two bars of LED are used in the illumination part. Detection and classification algorithms are developed and tested in MATLAB 7.7.0 environment by employing Image Processing Toolbox, on Windows Vista platform, with Pentium Intel® Core™ 2 personal computer, 1.86 GHz and 2 GB RAM (Random Access Memory). Figures 3shows the image acquisition system used in this research. Figures 4, 5, and 6 show the CCD camera, the PC2 vision frame grabber, and two bars of LED respectively used in this research.

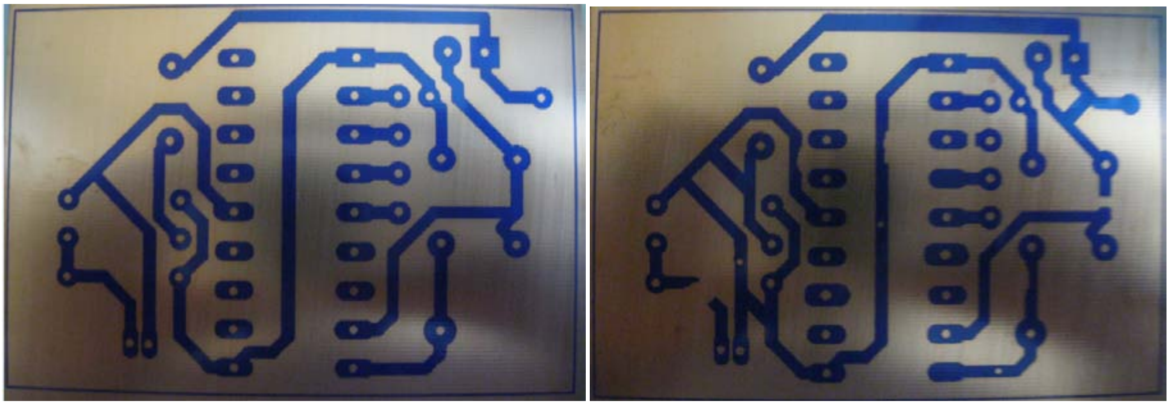

FIGURE 1. (a) A template bare PCB image, (b) A defective bare PCB image

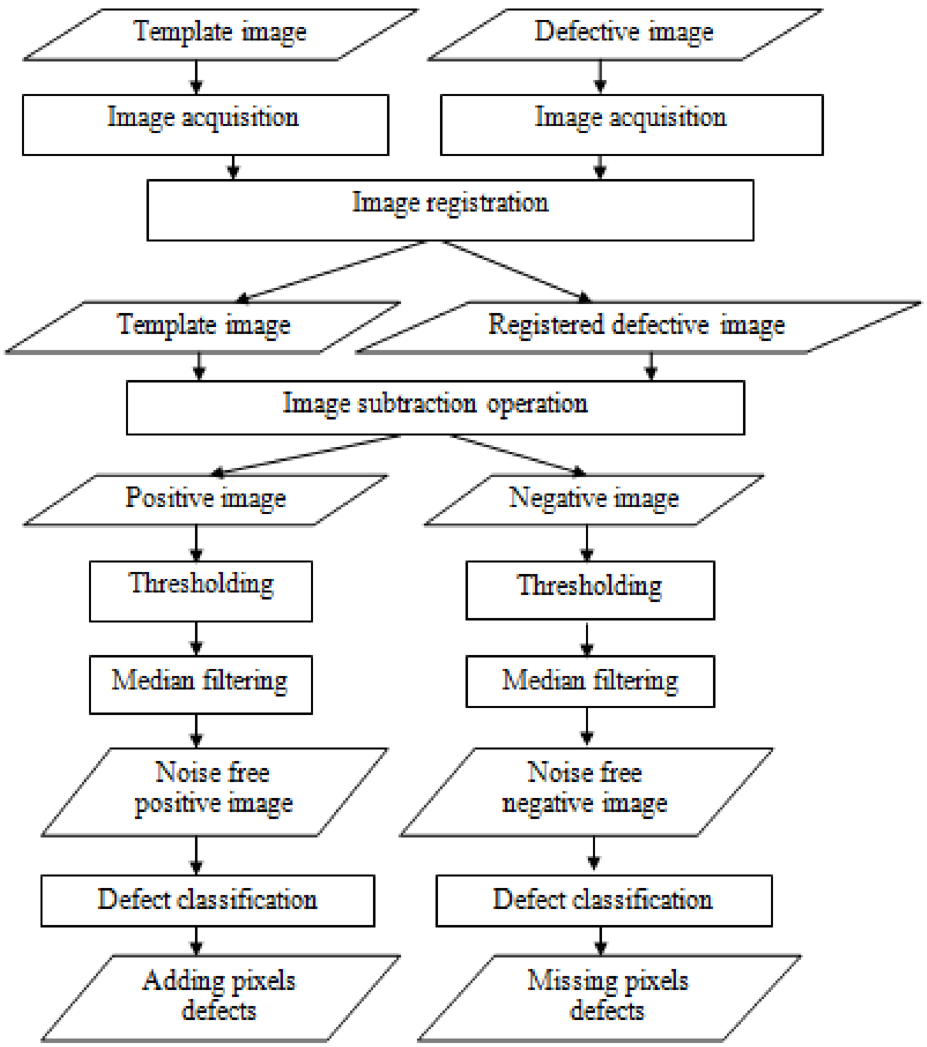

FIGURE2. Block diagram of the PCB inspection system

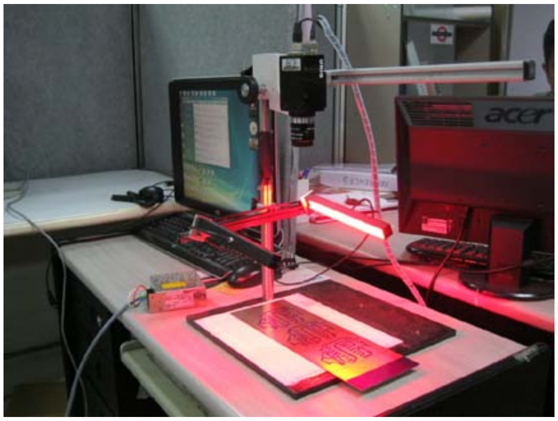

FIGURE 3. Image acquisition system

FIGURE 4. A monochrome CCD

FIGURE 5. A PC2-Vision frame grabber

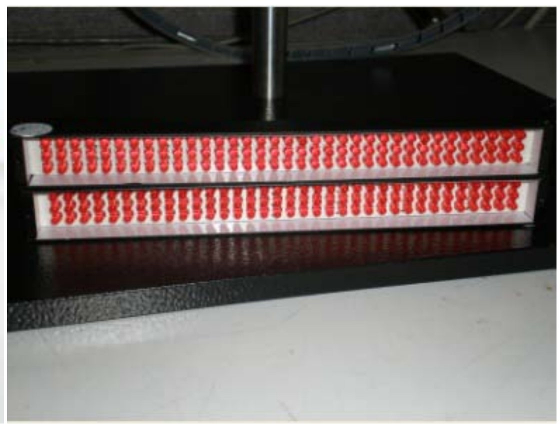

FIGURE 6. Two bars of LED

3.2. Image registration. Defective image is registered by software according to the template image. At first, geometric transformation will align the defective image to the template image. The geometric transformation method used for this study is based on an affine transform. An affine transform is a linear coordinate transformation that includes typical geometric transformations such as translation, rotation, scaling, stretching, and skewing. An affine transform has six degrees of freedom. Two of the degrees, t_x and t_y belong to translation. The remaining four degrees, that are a_{11}, a_{12}, a_{21}, and a_{22} are used to calculate scaling and shearing between two images. In this study, a globally affine and smooth transformation model added with intensity variations which were established by Periaswamy and Farid (2006), is used by including two new parameters; a_{31} for contrast and a_{32} for brightness. The affine transform equation can be formulated as in equation 1.

$$a_{31} f(x,y,t) + a_{32} = f\left(a_{11}x + a_{12}y + t_x, a_{21}x + a_{22}y + t_y, t-1\right) \quad (1)$$

where $f(x,y,t)$ and $f(\hat{x},\hat{y},t-1)$ represent template and defective images, respectively.In image resampling, the image values in noninteger coordinates are computed by the appropriate interpolation technique. In this study, a bi-cubic interpolation method has been employed for digital image transformation to detect image deformation over the entire image area.

3.3. Image subtraction. Image subtraction operation is executed after image registration operation. It is primarily used to discover the differences by comparing every pixel valuebetween two images. The difference between two images $f(x, y)$ and $h(x, y)$ is expressed as in equation 2.Consideration of outputs used are just in negative and positive pixel image, since zeros values of data do not affect the output of the operation.

$$g(x, y) = f(x, y) - h(x, y) \tag{2}$$

3.4. Thresholding. In order to convert the positive and negative images to be binary, and eliminate noise on the images, threshold operation is executed to both images. Minimum thresholding technique (Prewitt and Mendelsohn, 1966) is chosen.Threshold value, T is chosen such that $h_{T-1} < h_T \leq h_{T+1}$, where $h$is the number of pixels in the image with the certain gray-level. In this paper, threshold values, T, for the positive and negative images, are 165 and 157, respectively. As a result, the thresholded positive and negative images are produced.

3.5. Filtering. The template of size 3 x 3 of median filter (Gonzalez and Wintz, 1987) is employed to remove small noise in the both thresholded images.

3.6. Defect classification. Defect classification used is a combination of several image arithmetic and morphological operations that put at particular places in its algorithm (Ibrahim et al., 2011).

4. Experimental results. Several experiments were performed to validate the performance of the PCB inspection system.Defects that have been classified are depicted in Figure 7 and Figure 8.The overall computational time for this system is about 17.95 seconds. Computational time could be improved further by implementing the inspection on high performance computing platform or using small dimension of PCB samples.

5. Conclusion. This research studies automated PCB inspection system for detecting and classifying defects on bare printed circuit board. After images have been captured, image registration is executed to obtain a well-aligned defective image. Then, image subtraction operation, minimum thresholding and median filtering are used to get noise-free positive and negative images.Next, defect classification algorithms that have been taken from (Ibrahim et al., 2011). are employed to classify six printing defects as mentioned in Figure 7 and Figure 8. The system was proven to be an alternative way to efficiently detect and classify defects. Furthermore, the system is cheap as mechanical alignment facility is no need to purchase.

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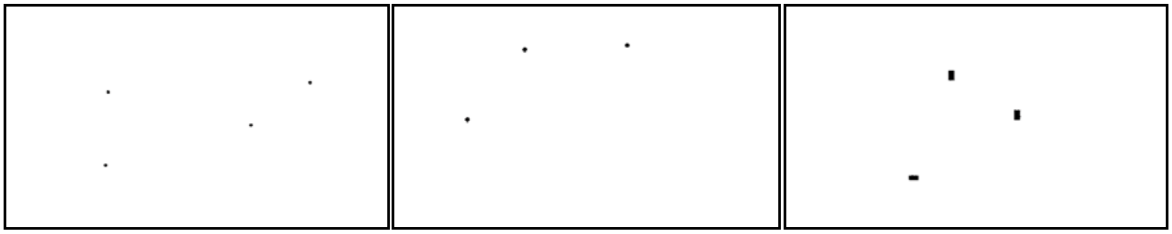
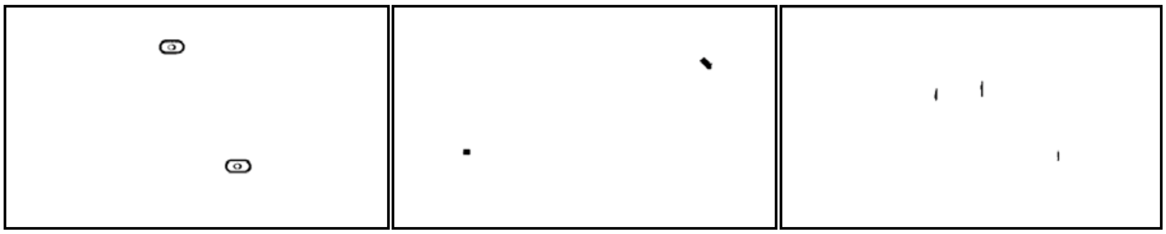


(a) (b) (c)

FIGURE 7. (a), (b), and (c) show pin hole, missing hole and short-circuit defects



(a) (b) (c)

FIGURE 8. (a), (b), and (c) show underetch, open-circuit, and mousebite defects

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