Jurnal
Teknologi

Full Paper

TEMPLATE BASED DEFECT DETECTION OF FLEXIBLE PRINTED CIRCUIT

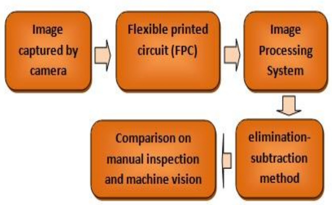
Zuliani Zulkoffli[a]*, Elmi Abu Bakar[b]

[a]School of Mechanical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[b]School of Aerospace Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia

Article history
Received
20 July 2013
Received in revised form
24 July 2015
Accepted
15 December 2015

*Corresponding author
zulianizulkoffli@gmail.com

Graphical abstract



Abstract

This study presented a research on machine vision inspection to define defects on flexible printed circuit (FPC). The images were subjected to image processing system where an elimination-subtraction method used. In this algorithm, 7 types of FPC defects defined and simulated in the system using Specimen 1 and processing time taken for both side inspection was 3.3s. Then, the commercial patent design of FPC was tested as specimen 2 to define short circuit defects on it. The processing time taken by this algorithm on specimen 2 was 0.28s. Comparison on manual inspection and machine vision implementation were carried out and greatly resulted on shorten inspection time to 59.7%. This result shows significant contribution in increasing the efficiency of FPC inspection process.

Keywords: Visual inspection, flexible printed circuit (FPC), image elimination-subtraction, image acquisition, defect classification

Abstrak

Kertas kerja ini membentangkan kajian pemeriksaan terhadap litar elektronik bercetak fleksibel (FPC) melalui kaedah visi komputer. Fokus pengimejan pemprosesan imej dimana kaedah penyingkiran-penolakan digunapakai. Di dalam algoritma yang digunakan, 7 jenis kecacatan FPC dikenalpasti dan disimulasi di dalam sistem dinamakan Spesimen 1 dan masa pempropsesan yang diambil terhdap pemeriksaan permukaan atas dan bawah litar adalah sebanyak 3.3s. Kemudian, litar elektronik bercetak lain yang berpaten komersil diuji dan dinamakan Spesimen 2 diuji menggunakan kaedah yang sama. Masa pemprosesan yang diambil oleh algoritma ini bagi Spesimen 2 adalah 0.28s. Pebandingan terhadap pemeriksaan manual dan penggunaan visi komputer dijalankan dan menunjukkan keputusan yang memberangsangkan terhadap pengurangan masa pemeriksaan sebanyak 59.7%. Keputusan ini menunjukkan sumbangan yang signifikan terhadap peningkatan keefisyenan proses pemeriksaan FPC.

Katakunci: Visi komputer, litarelektronik bercetak fleksibel, penyingkiran-penolakan imej, perolehan imej, pengkelasan kecacatan

1.0 INTRODUCTION

Flexible printed circuit board (FPC) is a basic component used as connectors in the electronic product system. A common application of flex circuits is in personal computer motherboard [1], medical devices [2], electronic product for power cellular telephones [3], cameras, calculators etc. In electronic product manufacturing, inspection process plays an important role in guaranteed the final electrical product performance [4, 5]. Human visual inspection is prone to tiredness and inconsistency due to repeated task for hours [6]. Furthermore, the advance complexity of FPC brings high difficulties in this inspection task. Machine vision technology seems as a potential alternative which can be used in unfavorable condition where the complex inspection information can be stored easily for analysis and low cost in implementation [7].

In recent years, the use of machine vision systems in FPC inspection has been in increasing trend, and the methods used can be categorized into three main types [8], which are reference comparison, non-reference method, and hybrid techniques respectively [9-13]. In the reference comparison method, an image of circuit board with no defects will be stored in the system memory, where it serves as the standard board. Then, on production line FCB for inspection will go through scan process and its image will be compared pixel by pixel to that standard board in the system memory to identify the defects. Template matching method implemented a simple learning algorithm by classification of unknown samples by comparing them to known prototypes, or templates and it's able to achieve strong performance in recognizing objects. This study proposes template matching using Boolean logic subtraction-elimination method [14].The algorithm employs a subtraction operation between inspected image and template image. The subtracted image will contain defects, where they will be further classified into 7 types of different defects by using elimination operation. This paper proposes machine vision inspection system that involves two major stages:

Stage1: Image Acquisition System, the image of FPC is first captured by using camera in appropriate scene constraints.
Stage 2: Image Processing System, the concept of subtraction-elimination suggested by Wu *et al*., [4] is employed. It is based on three indices, which are (i) type of object detected, (ii) the difference in object numbers, and (iii) the difference in background number between template and inspected image.

2.0 EXPERIMENTAL

2.1 Image Acquisition Setup

Final image acquisition setup is shown in Figure 1. Main components used in this setup were; a) Toshiba Teli Fire Dragon camera series (IEEE 1394) model CSFV90BC3-B. This camera is a black and white camera with VGA resolution (640 x 480 pixels), b) Tamron lens, model 20HC, c) 2 pieces Flex Placers (top and bottom), d) Perspex Holder and e) Camera stand.

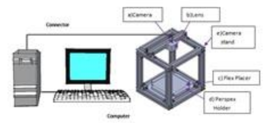


Figure 1 Final Image Acquisition Setup

2.1.1 Image Acquisition Operation Procedures

Procedural activity for this image acquisition system was sandwich structure formation of flex placer (bottom) - FPC – flex placer (top). This sandwich structure was placed on the Perspex holder in the prototype. Then, sandwich structure top surface is captured by using camera that connected to the computer. Surface capturing image was done on both up and bottom side of FPC by changing the sandwich structure placement and images were sent to the computer. After acquiring the images of both sides of the FPC, the sandwich is separated to remove the FPC. This acquisition process is repeated for another FPC inspection.

2.2 Image Processing System

2.2.1 Defect Detection

A standard FPC image is stored in the main system using MATLAB platform programming system as reference template. The images are converted to binary image in order to reduce the amount of information process and to reduce processing time needed. Inspected image go through direct subtraction followed by an elimination procedure to filter the actual defects. The defects were recognized by subtracting the difference between inspected PCB (Specimen 2) and the reference template (Specimen 1). Three outcomes are assigned to the subtracted image, as shown in Table 1, which were: i) Equal (E), ii) Positive (P) and iii) Negative (N).

Table 1 Possible outcomes of subtracting the template from the inspecting image

Template Image	Inspected Image	
	Object	**Background**
Object	E (Equal)	N (Negative)
Background	P (Positive)	E (Equal)

Captured image contained noise appearance from the environment and elimination action were carried out before further image processing analysis. The following step is to eliminate P and N pixels caused by noise appearance. If the area of the defects is smaller than allowance of 50 pixels, then the pixels are considered not defective.

This would result in greater or equal to the allowance. If it so, it would be maintained, and this considered as defects. Otherwise, if it was smaller than allowance, then the pixel was considered as an E-pixel, and was eliminated from the subtracted image. The image is known as residual image after the elimination procedure. Portion area containing P and N pixels are define as defect, and classified according to their type.

2.2 Defect Classification

The defined defects area were classify by using 8-connectivity concept of Huffman Coding, the P-pixels (or N-pixels) which are 8-connectivity to each other in the residual image are defined as P-object (or N-object). Seven types of defects were classified as shown in Figure 2. There are three indices are used to classify them; a) type of N-object and P-object detected, b) difference between inspected image and template in object number (Δ_{ON}) and c) difference between inspected image and template in background numbers (Δ_{BN}).

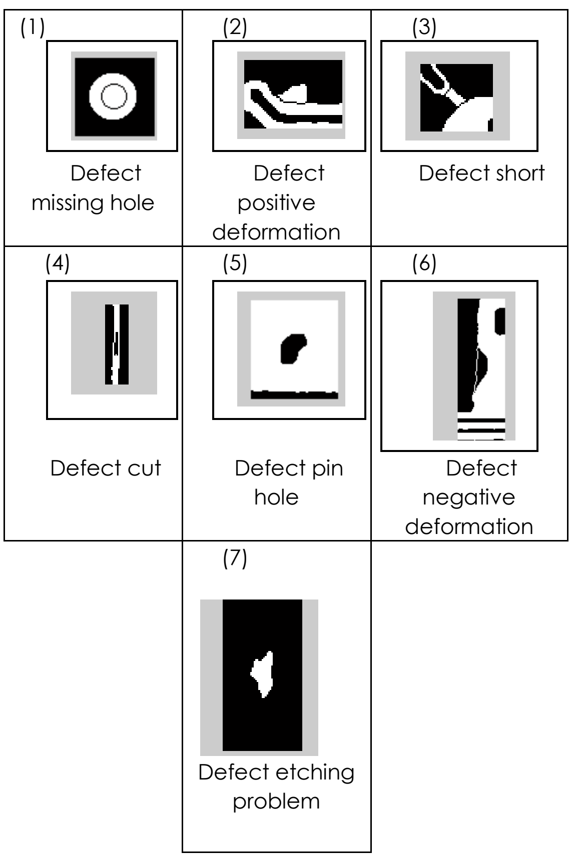


Figure 2 Classification of 7 types of defects [4]

The obtained Δ_{ON} and Δ_{BN} results in a small rectangular region of inspected image were classified as defected product. Otherwise, object background number in the same region of the template is considered achieved the template product perfect status and no further action taken on the image.

2.3 Algorithm Flow Chart

The algorithm was divided into two section of image processing and part classification. In image processing, the template image and standard parameter was set in the main system. The overall process flow algorithm used in this research is shown in Figure 3. The inspected FCB product will be converted to binary image for comparison analysis. The analysis on residual image by elimination-subtraction method taking action and further step on search object on that residual image applied. Then, object detection was compared to standard product and define 7 types of classified defects. In part classification algorithm, the comparison on number, and type of defects were analyzed till the defects marked.

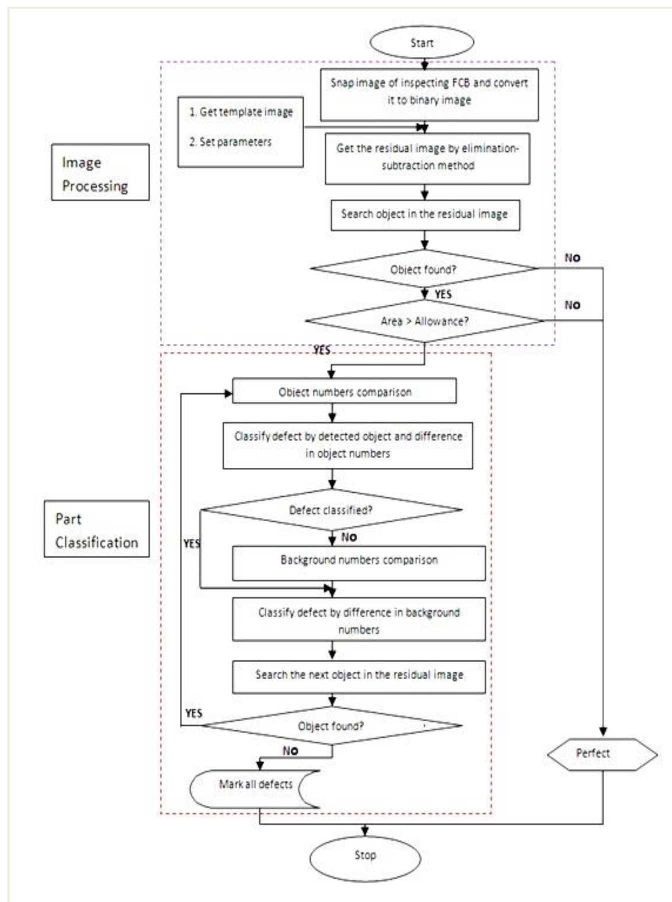


Figure 3 Process flow algorithm FPC defect detection and classification

3.0 RESULTS AND DISCUSSION

The FPC product tested is a small and tiny component printed circuit that contained a few types of material such as gold, stiffener and FR4. The circuitry design of this product included round plate with holes, continuous metal connector line in same width shape in straight line and round line, rectangular space and also rectangular dots in grids form. The FPC machine vision algorithm in was tested. Discussion on simulated defect, misalignment error and result comparison on inspection time for manual inspection and machine vision visual inspection implementation were carried out on the actual projection image of FPC product.

3.1 Stage 1: Simulated Defect on FPC Product (Specimen 1: Template image)

The template resolution image of 537 x 517 pixels was stored in the system. This image was then simulated to define 7 types of defects contained in inspected product. The individual windows based on type of defects shown in Figure 4. These two images were then subjected to the algorithm of image processing system. Figure 5 and Figure 6 shows the stages taken and raw data changes for image analysis of defects detection.

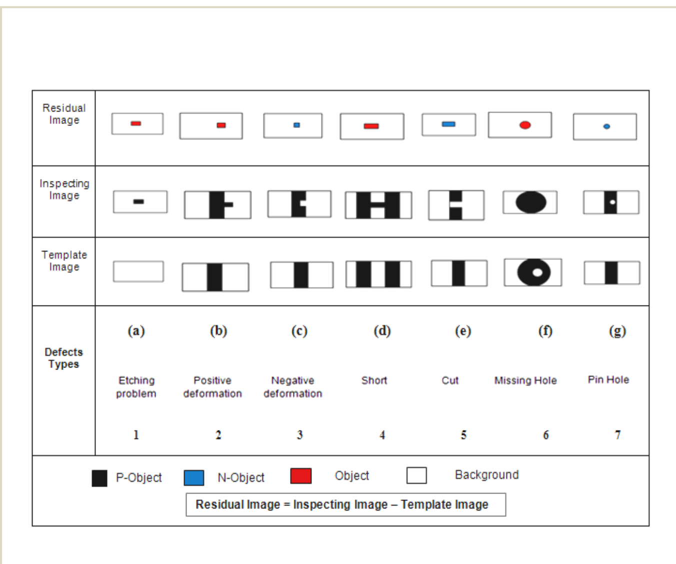


Figure 4 Individual defects in their respective windows

Figure 5(a) show the input data flow, while Figure 6(a) shows its input image. The FPC product set template image shown in Figure 6(b). Further analysis of binarize image of input image and template image shown in Figure 6(c) and (d). Finally, the subtracted image with noise filtered and defective pixels of defects outlined in Figure 6(e) and (f).

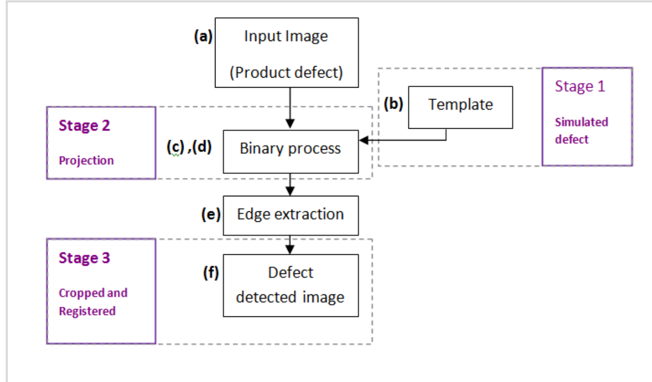


Figure 5 Flow stages in simulated defect processing image

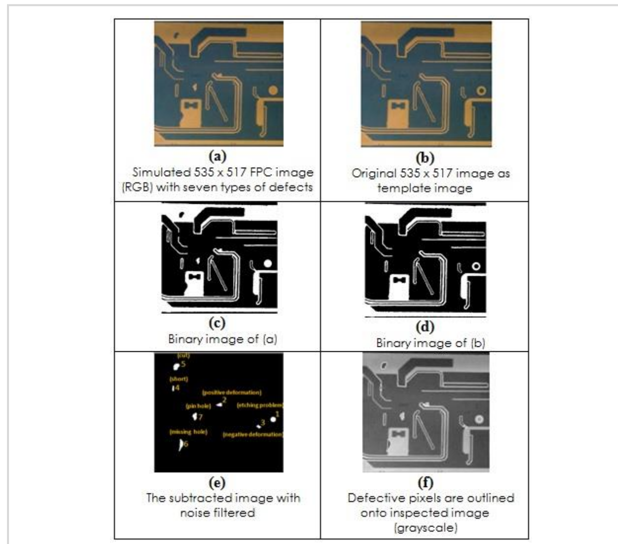


Figure 6 Defect detection procedures based on flow stages

3.2 Stage 2: Actual Projection Image on Defect (Specimen 2, Defect: Short Circuit)

This stage uses an actual patent FPC product contained defects. The image size is 640 x 480 pixels. The actual defect location is shown in red circle in Figure 7(c). The RGB type image is converted to grayscale and binary type images as shown in Figure 7. The analysis on binary form data is efficient in reading the defect type stored in system. Figure 7(c). The RGB type image is converted to grayscale and binary type images as shown in Figure Figure 7. The analysis on binary form data is efficient in reading the defect type stored in system.

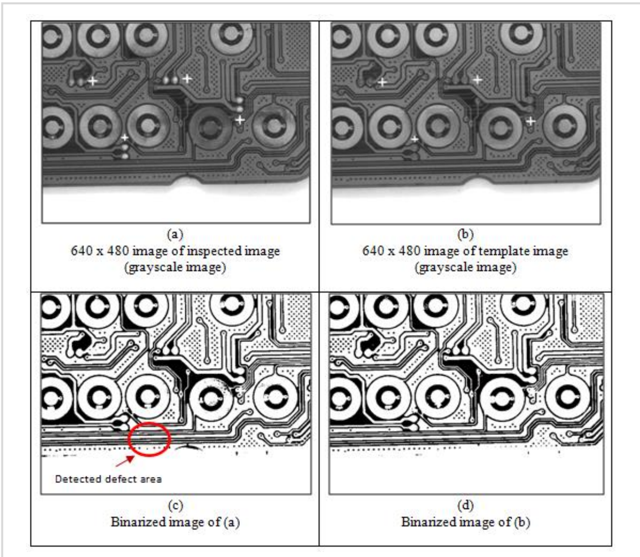


Figure 7 Turning grayscale image to binary form in Image Processing Sequence for Specimen 2. The + sign in (a) and (b) referred to image reference point

4.3 Stage 3: Cropped and Registered FPC (Specimen 3, Defect: Short Circuit)

The images are registered in MATLAB platform for crop function to overcome the misalignment error in inspection image. The processed image is then subjected to image processing stage for the validity of algorithm, this result shown in Figure 8. These figures explain the grayscale image and the value of grayscale distribution in the histogram. The binary image data show design features in the image and comparison on Figure 8(c) and (d) taking action. Positive subtracted image of Figure 8(a) and (b) shown in Figure 8(e). Negative Subtracted Image shown in Figure 8(f). Both images in Figure 8(e) and (f) contained noise. To define the defects area, the noise was eliminated by the algorithm. Figure 8(g) shows clearly the defect area after Subtracted image in Figure 8(e) to the noise. Smooth black area after removing the noise was created on the template image as shown in Figure 8(h). Figure 8(i) shows Short circuit defect area outlined on inspected image and Figure 8(j) shows the individual window on location of short circuit area. Based on result proven, FPC machine vision visual inspection is feasible applicable. The final image size is 70 x 61 pixels, and the processing time taken in MATLAB is 0.28s.

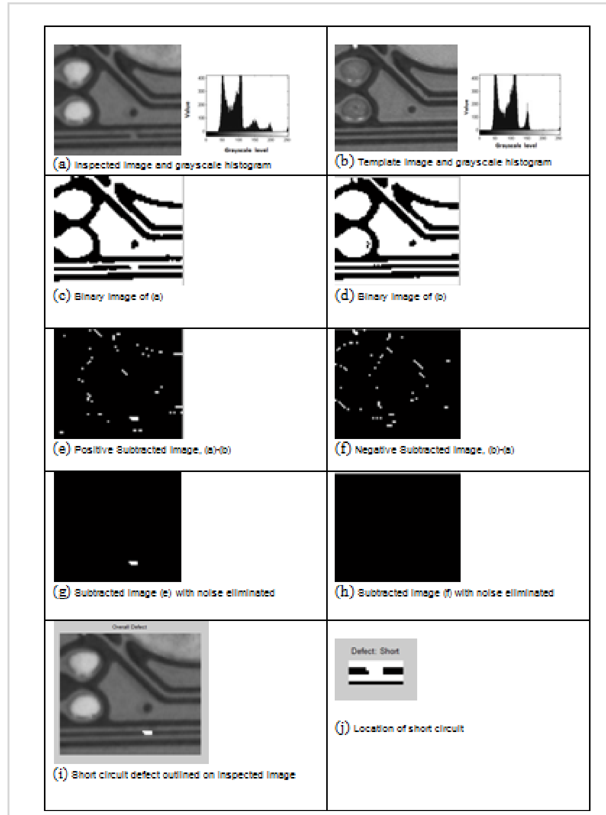


Figure 8 Specific results of image processing for Specimen 3

4.4 Manual Inspection and Implementation of Machine Vision Visual Inspection

For conventional manual inspection on FPC model Product A, the inspection is carried out under microscope with 10x magnification, and the total inspection time required can be categorized in Table 2.

Table 2 Inspection time with total manual inspection compared to machine vision visual inspection implementation

Inspection Criteria	Manual inspection time	Implementation machine vision inspection time
Gold	10	10
Stiffener	1	1
Placing Hole + Visual	11+15	3.3
FR4	1	1
Total Inspection Time (s)	38	15.3

inspection was 38s. By combining machine vision implementation, total time needed was reduced to 15.3s. This shows large contribution on shorten the inspection processing time to 59.7%. Graph comparison ratio on the comparison inspection time before and after machine vision visual inspection implementation shown in Figure 9.

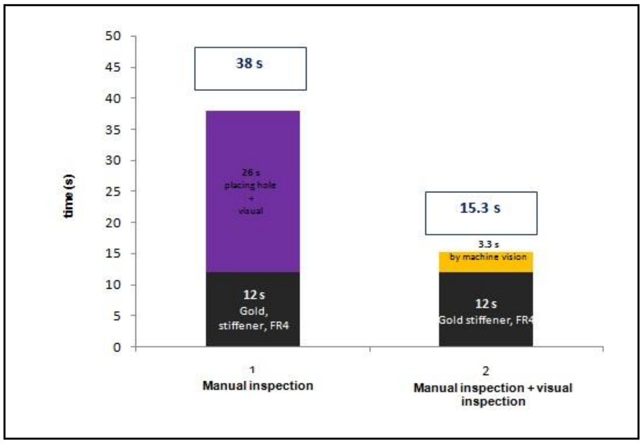


Figure 9 Comparison chart on inspection time before and after machine vision visual inspection implementation

4.0 CONCLUSION

Research on FPC machine vision visual inspection has been carried out. Image acquisition system surrounded office structure cool white fluorescent lamp as illumination source is located far from the prototype. This purposely reduces noise of shadow and reflection on the inspected surface of FPC. Image processing system was implemented subtraction-elimination method algorithm to simulated defects type on the FPC template and FPC specimen. The algorithm works greatly shorten to 59.7% overall inspection processing time by machine vision visual inspection implementation. However, this research only detects the 7 type defects stored in system to recognize the circuitry problem. Further defect identification development on gold plating, stiffener and FR4 position error should be carry out in the future in fully utilize machine vision technology.

Acknowledgement

The authors would like to express gratitude to Universiti Sains Malaysia (USM) for the facilities and their technical supports. A warm compliment is dedicated to Malaysia Ministry of Higher Education (MOHE) for MyBrain15 study sponsorship.

References

[1] Bozkurt, A. and A. Lal. 2011. Low-cost Flexible Printed Circuit Technology Based Microelectrode Array for Extracellular Stimulation of the Invertebrate Locomotory System. *Sensors and Actuators A: Physical*. 169(1): 89-97.

[2] Kima, S. H., H. Y. Cha, C. M. Miesse, J. H. Jang, Y. S. Oh and S. W. Cha. 2009. Air-Breathing Miniature Planar Stack Using the Flexible Printed Circuit Board as a Current Collector. *International Journal of Hydrogen Energy*. 34(1): 459-466.

[3] Moganti, M., F. Ercal, C. H. Dagli and S. Tsunekawa. 1996. Automatic PCB Inspection Algorithms: A Survey. *Computer Vision and Image Understanding*. 63(2): 287-313.

[4] Wu, W. Y., M. J. J. Wang and C. M. Liu. 1996. Automated Inspection of Printed Circuit Boards Through Machine Vision. *Computers in Industry*. 28(2): 103-111.

[5] Leong, W. C., M. Z. Abdullah and C. Y. Khor. 2012. Application of Flexible Printed Circuit Board (FPCB) in Personal Computer Motherboards: Focusing on Mechanical Performance. *Microelectronics Reliability*. 52(4): 744-756.

[6] Drury, C. G. 2000. Human Factors in Aircraft Inspection. Proceedings of the Aging Aircraft Fleets. *Structural and Other Subsystem Aspects, November 13-16. Sofia, Bulgaria*. 7: 1-7:11.

[7] Yannick, C. 2010. Inspection of Complex Surfaces by Meansof Structured Light Patterns. *OPTICS EXPRESS*. 18(7): 6642-6660.

[8] Shirvaikar, M. 2006. Trends in Automated Visual Inspection. *J. Real-Time Image Process*. 1: 41-43.

[9] Charette, C., S. Park, R. Williams, B. Benhabib and K.C. Smith. 1988. Development and Integration of a Micro-Computer Based Image Analysis System for Automatic PCB Inspection. *Proceedings of the IEEE International Conference on Computer Integrated Manufacturing, May 23-25. Troy, NY., USA*.129-135.

[10] Forsyth, D. A. and J. Ponce. 2003. *Computer Vision a Modern Approach*. Prentice Hall: USA.

[11] Chauhan, A. P. S. and S. C. Bhardwaj. 2011. Detection of Bare PCB Defects by Image Subtraction Method Using Machine Vision. *Proceedings of the World Congress on Engineering, Volume 2, July 6-8, London, UK*. 1597-1601.

[12] Ibrahim, Z., S. A. R. Al-Attas and Z. Aspar. 2002. Model-Based PCB Inspection Technique using Wavelet Transform. *Proceedings of the 4th Asian Control Conference, September 25-27, Singapore*. 2026-2029.

[13] Farooq, U., T. King, P.H. Gaskell and N. Kapur. 2004. Machine Vision Using Image Data Feedback for Fault Detection in Complex Deformable Webs. *Transactions of the Institute of Measurement and Control*. 26(2): 119-137.