Faculty of Electrical Engineering

COMPUTER VISION INSPECTION AND CLASSIFICATION ON PRINTED CIRCUIT BOARDS FOR FLUX DEFECTS

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DECLARATION

I hereby declare that the work in this thesis is my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……..

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Doctor of Engineering.

Signature : …….....

Supervisor Name : …….....

Date : …….....

DEDICATION

To my beloved mother, Madam Kok Mooi Yin, beloved father, Mr. Ang Chor Kok, wife, Ms. Lee Feuy Feuy, daughter, Ang Shin Yii and son, Ang Yee Kae.

ABSTRACT

The manual inspection of Printed Circuit Boards (PCB) is labor intensive and slow down the production line. During the assembly process, the defective PCBs with flux defects if not detected and remove, it can create corrosion and cause harmful effects on the board itself. As such, an automated inspection system is very much needed to overcome the aforementioned problems in PCB production line. The main objective of this work is to develop a real-time machine vision system for quality assessment of PCBs by detecting defectives PCBs. The proposed system should be able to detect flux defect on PCB board during the re-flow process and achieve good accuracy of the PCB quality checking. The proposed system is named as An Automatic Inspection System for Printed Circuit Boards (AIS-PCB), involves design and fabrication of a total automation control system involving the use of mechanical PCB loader/un-loader, robotic pneumatic system handler with vacuum cap and a vision inspection station that makes a decision either to accept or reject. The decision making part involves classifier training of PCB images. Prior to ANN training, the images need to be processed by the image processing and feature extraction. The image processing system is based on pattern matching and color image analysis techniques. The shape of the PCB pins is analyzed by using pattern matching technique to detect the PCB flux defect area. After that, the color analysis of the flux defect on a PCB boards are processed based on their red color pixel percentage in Red, Green and Blue (RGB) model. The red color filter band mean value of histogram is measured and compared to the value threshold to determine the occurrence of flux defect on the PCBs. The texture of the PCB flux defect can also be extracted based on line detection of the gradient field PCB images and feature indexing by using Radon transform-based approach. The feed-forward back-propagation (FFBP) model is used as classifier to classify the product quality of the PCBs via a learning concept. A number of trainings using the FFBP are performed for the classifier to learn and match the targets. The learned classifier, when tested on the PCBs from a factory's production line, achieves a grading accuracy of coefficient of efficiency (COE) greater than 95%. As such, it can be concluded that the developed AIS-PCB system has shown promising results by successfully classifying flux defects in PCBs through visual information and facilitates automatic inspection, thereby aiding humans in conducting rapid inspections.

ABSTRAK

Pemeriksaan secara manual bagi Papan Litar Bercetak (PCB) memerlukan tenaga kerja yang intensif dan melambatkan aliran pengeluaran. Dalam proses pemasangan, PCB yang rosak jika tidak dikesan dan diasingkan, keadaan ini boleh menghasilkan kakisan dan menyebabkan kesan buruk terhadap PCB tersebut. Maka, pemeriksaan secara pemeriksaan penglihatan automatik yang sistematik adalah sangat diperlukan bagi mengatasi masalah yang dinyatakan di atas didalam aliran pengeluaran. Oleh itu, objektif utama kajian ini adalah untuk membangunkan satu sistem penglihatan mesin masa nyata untuk penilaian kualiti PCB dengan mengesan kecacatan pada flux PCB. Sistem yang dicadangkan didalam kajian ini akan berupaya mengesan kecacatan fluks pada papan PCB semasa proses aliran semula dan memperolehi ketepatan yang tinggi terhadap pemeriksaan kualiti PCB. Sistem yang dicadangkan, dinamakan sebagai Sistem Pemeriksaan Automatik bagi Papan Litar Bercetak (AIS-PCB), melibatkan reka bentuk dan fabrikasi sistem kawalan automasi yang melibatkan penggunaan PCB mekanikal 'loader'/'un-loader', pengendalian sistem pneumatik robotik dengan topi vakum dan stesen pemeriksaan penglihatan yang membuat keputusan sama ada diterima atau ditolak. Proses membuatan keputusan ialah melibatkan latihan pengkelasan imej PCB. Sebelum latihan, semua imej perlu melalui pemprosesan imej dan proses pengekstrakan ciri-ciri. Sistem pemprosesan imej adalah berdasarkan kepada corak yang hampir sama dan teknik analisis warna imej. Bentuk pin PCB dianalisia menggunakan teknik corak yang hampir sama untuk mengesan kawasan kecacatan fluks PCB. Selepas itu, teknik analisisa warna bagi kecacatan fluks papan PCB diproses berdasarkan peratusan piksel berwarna merah di dalam model Merah, Hijau dan Biru (RGB). Penuras warna merah bermaksud nilai histogram diukur dan dibandingkan dengan nilai ambang untuk menentukan sama ada berlakunya kecacatan fluks pada PCB. Tekstur kecacatan fluks PCB juga boleh diekstrak berdasarkan pengesanan garis medan kecerunan pada imej PCB dan ciri pengindeksan dengan menggunakan pendekatan terubah Radon. Model propagasi-belakang suapan-hadapan (FFBP) digunakan sebagai pengkelas untuk mengklasifikasikan kualiti PCB melalui konsep pembelajaran. Beberapa latihan menggunakan FFBP dilaksanakan bagi pengkelas untuk belajar dan memadankan dengan sasaran. Rangkaian pengelasan ini apabila diuji terhadap PCB dari aliran pengeluaran kilang telah didapati mencapai ketepatan pekali kecekapan (COE) melebihi 95%. Oleh itu, kesimpulan dapat dibuat bahawa sistem AIS-PCB yang dibangunkan ini telah memberikan keputusan yang memberangsangkan dengan keupayaan mengklasifikasikan kecacatan flux PCB melalui maklumat penglihatan dan memudahkan proses pemeriksaan secara automatik, dengan itu ia berupaya membantu manusia melaksanakan pemeriksaan secara pantas dan tepat.

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LIST OF ABBREVIATIONS

AF	Auto Focus
AIS	Automatic Inspection System
ANN	Artificial Neural Network
AOI	Automatic Optical Inspection
API	Application Program Interface
ASIC	Application-Specific Integrated Circuit
AUC	Area Under The Curve
AVI	Automated visual inspection
BIOS	Basic Input/output System
BGA FET	Ball Grid Array Field-effect Transistor
BNC	Bayonet Neill-Concelman
BW	Black And White
CAGR	Compound Annual Growth Rate
CB	Clear Image Border
CCD	Charge-Coupled Device
CCIR	Consultative Committee For International Radio
COE	Coefficient of Efficiency
CMM	Coordinate Measuring Machine
CMYK	Cyan, Magenta, Yellow, Key
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CVBS	Composite Video Baseband Signal
DAQ	Data Acquisition
DIO	Digital I/O
ED	Edge Image
ELCB	Earth Leakage Circuit Breaker
FCT	Functional Testing
FDS	Flux Defect Segmentation
FFBP	Feed-Forward Back -Propagation
FN	False Negative
FP	False Positive
FPGA	Field-Programmable Gate Array
FS	First Subtraction
GA	Genetic Algorithm
GLPF	Gaussian Low-Pass Filter
GUI	Graphical User Interface
HPC	High-Performance Computing
HSB	Hue, Saturation, Brightness
HSL	Hue, Saturation, Lightness
HSV	Hue-Saturation-Value
I/O	Input/output
IC	Integrated Circuit

ICT	In-Circuit Test
LED	Light-Emitting Diode
LM	Levenberg-Marquardt
LPT	Line Print Terminal
LUT	Look-Up Table
MAE	Mean Absolute Error
MCB	Miniature Circuit Breakers
MExG	Modified Excess Green
MExR	Modified Excess Red
MI	Manual Insert
MIL	Matrox Imaging Library
MLP	Multi-Layer Perceptron
MO	Morphological Opening
NGC	Normalized Gray Scale Correlation
NTSC	National Television System Committee
OCR	Optical Character Recognition
PAL	Phase Alternative Line
PC	Personal Computer
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PCI	Protocol Control Information
QA	Quality Assurance
RBF	Radial Basis Function
RCA	Radio Corporation Of America
RGB	Red, Green, Blue
RMSE	Root Mean Square Error
ROC	Receiver Operating Characteristic
ROI	Region Of Interest
RT	Radon Transform
SATA	Serial ATA
SCG	Scaled Conjugate Gradient
SIMD	Single Instruction Multiple Data
SMT	Surface Mount Technology
SS	Second Subtraction
SSEx	Streaming SIMD Extensions
TN	True Negative
TP	True Positive
TTL	Transistor-Transistor Logic
WYSIWYG	What You See Is What You Get
Y/C	Luminance/Chroma

LIST OF SYMBOLS

bpp	-	Bits per pixel
D	-	Dimension
GB	-	Gigabyte
GHz	-	Gigahertz
hex	-	Hexadecimal
m	-	Meter
MB	-	Megabyte
MHz	-	Megahertz
rpm	-	Revolution per minute
TB	-	Terabyte
V	-	Volt

LIST OF PUBLICATIONS

Ang Teoh Ong, Zulkifilie Bin Ibrahim, Suzaimah Ramli (2013). Computer Machine Vision Inspection on Printed Circuit Boards Flux Defects, American Journal of Engineering and Applied Sciences 6(3): 263-273, 2013.

Ang Teoh Ong, Aouache Mustapha, Zulkifilie Bin Ibrahim, Suzaimah Ramli, Boo Chai Eong (2015). Real-Time Automatic Inspection System for the classification of PCB Flux Defects. American Journal of Engineering and Applied Sciences, 2015.

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Image Processing Based Method For Printed Circuit Boards Flux Defects Detection.
Main Hall UTeM, Melaka, 17 - 18 December 2014.

CHAPTER 1

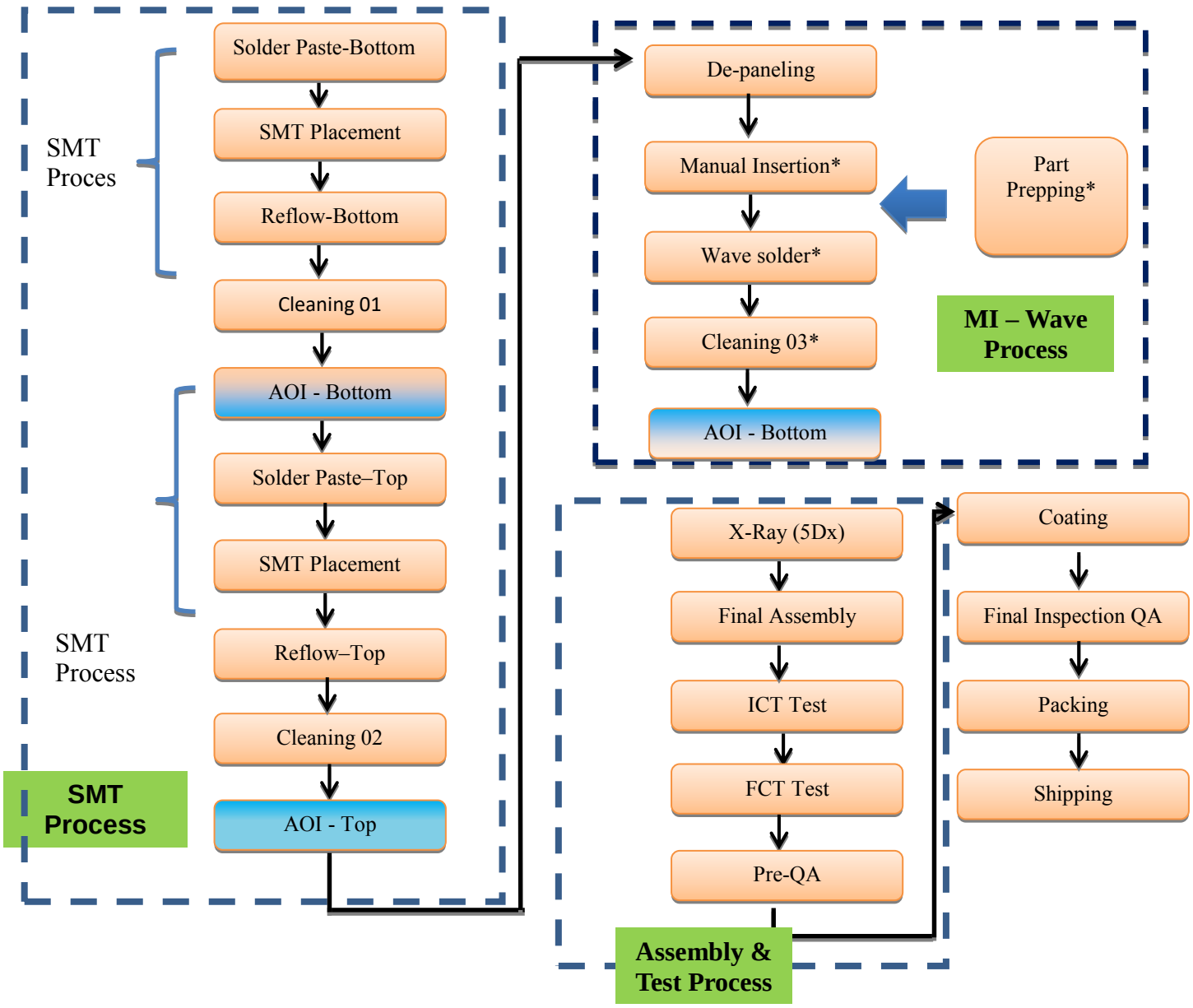
INTRODUCTION

1.1 Background

PC-Based vision technology has been developed and utilized as a part of a wide range of industry territory applications. One of the vision inspection applications is machine vision inspection on detect of the printed circuit board (PCB). Machine vision inspection is critical because it evacuates the deformities subjective elements and gives quantitative, quick and dimensional evaluations. PCBs typically contain complicated and definite format pattern designs; with this reason manual visual inspection is extremely exhausting and can caused many human errors. On the other hand, automatic machine vision systems are very consistent, accurate, fast and do not get exhausted.

PCB mechanically supports as well as electrically connection for electronic components using conductive tracks etched the copper sheets laminated onto a non-conductive substrate. However, more complex PCB consists of components like resistors, capacitors and other electronic components in the substrate. PCB is expensive to design but allows automated manufacturing and assembly providing potentially more reliable, cheaper to manufacture and faster in production. Automated PCB defects machine vision inspections require the features extraction of data information from the defective appearance area. The purpose of this vision inspection process is to recognize and allocate the potential defects, which these defects will affect the quality and the PCB final products

functionality. Figure 1.1 below show the PCBA (Printed Circuit Board Assembly) general process flow chart in PCB industry manufacturing sector. The process involved SMT process for bottom and top level, MI (Manual Insert) process and finally assembly and test process. This research main focus is machine vision inspection algorithm technique on PCB flux defects, which has been applied in process AOI - Bottom, AOI - Top and Manual Insert AOI - Bottom.



Remark: * Depend on the board design

Figure 1.1: PCBA general process flow chart

Initially, PCB's artwork generation was a full-time manual process performed on clear Mylar sheets at a scale of generally 2 or 4 times the desired size. Modern practice comprises computers that handle almost every task automatically and less labor intensive. Pattern-matching method is the most commonly image processing technique used in the machine vision application. Due to the rapid development in computer technology, this method became practicable and affordable. In addition, frame grabber was used to transmit the images from camera to computer and follow by image processing analysis.

The manual inspection of PCB defects might cause labor intensive and subjects to human error and inconsistent grading which can be solved by automatic inspection process with "Computer Machine Vision Inspection". This system applies a connectivity approach to detect the fatal defects such as PCB board printing and labelling, circuit bridging and scratches. Furthermore, this system is able to identify the marking of the components, components orientation, missing components, and so on.

Consequently, a computer machine vision system is proposed for image detection, localization, segmentation and classification of flux defect on PCBs with different orientation. Total Automation Control System is implemented in this design which includes the mechanical PCB loader/un-loader, pneumatic robotic arm with vacuum cup, vision inspection station and final classification station to determine the acceptance of the allowable PCB flux. This research has been well designed by utilizing all the combined knowledge of mechanical, electrical, electronic, communications and software engineering to develop an integrated machine to identify and monitor the flux defects on PCB. As a results, this automated machine can be used to separate the PCBs defects board from good ones.

1.2 Computer Vision System

Computer technology is in progress and becoming more powerful, computer vision equipment is presently moderately economical. Computer vision system basically requires a camera, a frame grabber and a computer. Now days, a basic computer vision system can be supported with personal computers which including a camera and others interface components. Never the less, there are also high performance computer vision system which can be very costly.

Automatic visual inspection of PCB boards is developed by using computer vision techniques to evaluate the performance and various PCB board defects. The fault detection strategy is very critical in this design and it is based on referential inspection method where the board artwork or a manufactured board without errors is chosen as a benchmark. The PCB defects can be classified into two main categories, the fatal defects (reject units) and no defects (accept units). This system is very effective to detect the fatal defects by subtracting the reference board image from the tested board image using image comparison technique and subsequently separates the good and defect boards.

The computer machine vision inspection system investment in the PCB manufacturing processes, not only could prevent problematic boards from escaping to the field, but also prevent catastrophic failure on the aerospace vehicles and the loss of human life. The fluxes must be detected and cleaned before the PCB been coated and sent for final inspection. Once the PCB been coated, the PCB need to be reworked with additional side effect onto the PCB quality.

1.3 Motivation for Research

The motivation for this research is to overcome the problems at the existing inspection on PCB flux defects, which was done in manual system by operator. This manual inspection is slow and brings more mistakes due to human error. Automatic computer vision inspection makes the inspection process faster and more consistent than manual inspection. In addition, the cost will be reduced significantly in long run with the return of investment less than two years period. Since the percentage of PCB flux defects is high, there subsists a prospect of introducing and implementing a computerized PCB inspection system to remove the subjective aspects rather than manual inspection. At the same time, the automated PCB examination system provides real time assessment of the PCB quality inspection.

1.4 Problem Statement

The main disadvantage of manual inspection of PCB defects are human mistakes, labour intensive and inconsistent result in evaluating. Problem statement might be varied depending on the inspection components and their respective features. In this case the inspection is carried out after all the PCB components have soldered. The problem statement together with error, components feature and solution applied is summarise in the table below.

Table 1.1: PCB inspection problem statements

PCB Inspection Problem Statement Summary			
To Inspect	**Errors**	**Features/Properties**	**Solution Suggested**
Pads	• Missing • Degraded • Polarity(+ve/-ve) • Orientation/Position	• Metallic lustre • Shape	• Diffuse illumination • Thresholding • Pattern Matching • Position