THROUGH HOLE SOLDERING SYSTEM WITH AUTOMATIC OPTICAL INSPECTION

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Degree of Master of Philosophy

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

Machine vision has been widely deployed in many applications in various sectors like industrial, medical, manufacturing, agricultural, surveillance etc. Such applications consist of numerous algorithms to fulfil the ultimate requirement of the end product. The role of automatic vision for classifying the quality of solder joints in the Electronics Manufacturing Services (EMS) industry has become significant because the increasing cost of labour, skill dependency, attitudes, time variance of human operators have narrowed down the quality of their service. Several major companies develop stand-alone Automatic Optical Inspection (AOI) systems with proprietary algorithms that contains multiple cameras operating inside a specific lighting environment for the inspection of Surface Mount Devices (SMD) and Through-Hole Technology (THT) components. However, the accuracy and maturity level for the automatic inspection of the quality of solder joints have yet to reach its ultimate goal due to the complex appearance of solder joint surface. Even though, many AOI systems are available, no vision system has been developed to integrate with a soldering robotic system to provide quality classification of solder joints in real time without prior teaching of individual joints and enclosed chambers with specific lighting to operate.

In this research, a THT soldering system with an AOI and Computer Aided Design (CAD) tool has been developed to classify the quality of THT solder joints without prior teaching and specific lighting requirements. The design consists of three main stages:

- AOI system for quality classification of THT solder joints (Major Research)
- CAD tool for extracting physical parameters of each component (Minor Research)
- THT Soldering system to perform automatic soldering (Minor Research)

The AOI system mainly operates in three stages. The first stage involves with precise alignment of the Printed Circuit Board (PCB) to the origin of the THT soldering system using feature extraction and template matching techniques. This approach provide a reliable and robust PCB verification and alignment capability compared to Hough transform based alignment method proposed by Nang Seng Siri Mar. Furthermore, this methodology rendered a better outcome even in distinguishing between vias, pads and test-points in addition to conventional fiducial markings. The identification of the solder pad and the verification of the component availability is performed prior to soldering in the second stage. The automatic identification of solder pad regardless of its plated colour and surrounding solder mask colour made a significant improvement over the methodology proposed by T. Y. Ong, Z. Samad and M. M. Ratnam, based on prior teaching of individual pads using artificial neural networks. In addition to that, the implemented methodology provides online positioning accuracy calibration which is not available in any commercial soldering robotic systems. The component availability is assured by precisely segmenting the component lead top from the identified solder pad. The developed algorithms could render a better outcome even for component leads which possess a minimum colour dissimilarity with their surrounding drill-hole region. No commercial soldering robotic system is capable of verifying component availability prior to soldering. Further, the segmented lead is used to establish a relationship between prior and post soldering stages of the solder pad in order to provide a robust solder quality classification capability. The classification of the soldering quality for short circuit (solder bridging), voids inside the drill-hole, voids on solder pad and excess solder, is carried out after soldering during the third stage. The implemented algorithms could render an improved recognition rate even with applied flux, illuminated pad regions, uneven illumination distribution and shadows on the solder joint surface. Such a widely distributed quality inspection capability is

not covered in any of the reported studies. Neither commercial AOI systems nor soldering robotic systems perform real time inspection of soldering quality just after the soldering of THT components. Moreover, the precise localization of defective areas inside the solder joint, enables the robotic system to perform automatic reworking on defective solder joints adhering to IPC regulations with minimum user interaction. Such automatic reworking capability is not available with any commercial soldering robotic system in the market today.

The CAD system extracts the geometrical information of components and their pads such as the component location, its orientation, size of the solder pad and drill hole, height of nearby components, the width of the connected PCB track to the solder pad from the respective CAD file and visualize the 2D view of the PCB to the user in a Graphical User Interface (GUI). This information enhances the intelligence and the situational awareness of both robotic system and AOI.

The THT soldering system is a four-axis robotic platform that performs soldering on selected solder pads through the CAD system GUI. Its operation is mainly controlled by the vision system and the information acquired from the CAD system. The implemented THT soldering system together with integrated AOI and CAD tool provides a new concept in the EMS industry by replacing the manual inspection of THT solder joints with automatic inspection and providing automatic rework capability on defective solder joints within a single platform.

The performance of the complete system was evaluated under different illumination levels, flux residues, different types of component leads, colour combinations of solder pads and solder mask colours, wide variety of solder pad neighbourhoods and a range of solder pad sizes. Each stage of the AOI was able to provide a significant improvement over the reported studies and commercial systems. The automatic identification of solder pad and the verification of component availability could provide nearly a 98% of recognition rate for both cases. However, the existence of highly illuminated pad regions and overheated solder joints surfaces degrades the performance of the classification of not soldered regions by 2% and excess solder detection by 5% respectively (subjected to a sample size of 200 solder joints). Even though, a slight performance reduction is there due to such extreme conditions, the proposed approach provides an automated solution for soldering and quality assurance within a single platform while solving several problems in the reported studies and commercial systems effectively.

Keywords:

Automatic Optical Inspection, Solder Quality Classification, Localization of Component Lead inside a THT Solder Joint for Solder Defects Classification, Fiducial Verification

To my parents, wife and sister

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Even though, it is a single name that is attributed as the author of this work, there are many people without whom it could never been completed. Firstly, I am immensely grateful to my family members who encouraged me throughout the period of this immense work.

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List of Abbreviations

AOI	Automatic Optical Inspection
BRIEF	Binary Robust Independent Elementary Features
CAD	Computer Aided Design
CCOEFF	Correlation Coefficient
CIE	Commission Internationale de I'Elcairage
CV	Connection Validation
DCT	Discrete Cosine Transform
DMA	Direct Memory Access
DoG	Difference of Gaussian
DWT	Discrete Wavelet Transform
EDA	Electronic Design Automation
EMS	Electronics Manufacturing Services
FAST	Feature Accelerated Segment Test
FCM	Fuzzy C-Means
FLANN	Fast Library for Approximate Nearest Neighbour
FOV	Field of View
GPU	Graphical Processing Unit
GUI	Graphical User Interface
ICA	Independent Component Analysis
IPC	Institute for Interconnecting and Packaging Electronics Circuits
LoG	Laplacian of Gaussian
MCU	Module Control Unit
MST	Minimum Spanning Tree
NPI	New Product Industrialization
OCP	Over Current Protection
PC	Principle Curvatures

PCA	Principle Component Analysis
PCB	Printed Circuit Board
PUS	PCB Under Solder
ROI	Region of Interest
SD	Standard Deviation
SIFT	Surface Invariant Feature Transform
SMD	Surface Mount Devices
SMT	Surface Mount Technology
SPI	Serial Peripheral Interface
SQDIFF	Squared Difference
SURF	Speed-Up Robust Features
THT	Through Hole Technology