Defect Solder Classification in Print Circuit Boards using Machine Learning

Watcharin Tangsuksant[1], **Jiraphan Inthiam**[2], **Hattapat Silangren**[3], **Phattharaporn Iamcharoen**[4], **Wisanu Jitviriya**[5]
Center of Innovation Robotics and Advanced Precision System: iRAPs,
Faculty of Engineering, King Mongkut's University of Technology North Bangkok,
1581 Pracharat 1 Road, Wongsawang, Bangsue
Bangkok, 10800, Thailand
E-mail: watcharin.t@eng.kmutnb.ac.th[1], jiraphan.i@eng.kmutnb.ac.th[2], hattaphat22642@gmail.com[3],
phattharaporniamcharoen@gmail.com[4] wisanu.j@eng.kmutnb.ac.th[5]

Abstract

This research proposes the solder inspection using the digital image processing technique and machine learning base with our machine vision prototype. There are five classes of classifying solder, including acceptable, short circuit, insufficient, blow hole and too much of solder. Automatic Optical Inspection (AOI) is used for the light source in the designed prototype and industrial camera which are installed on the mini-CNC. For the algorithm, this research applies the scanning line of binary image for detecting short circuit defection and the Random Forrest model for classifying other defects. According to the experiments, the system can classify the defect types for two classes (acceptable and unacceptable types) and five classes as 89% and 71% of accuracy, respectively.

Keywords: solder classification, solder defect, solder inspection, inspection machine

1. Introduction

Although, there have been developed automation system for the various tasks in the production line, soldering inspection on the Printed Circuit Boards (PCB) is still an important topic. There are many defected types occurring after wetting the solder, For example, solder bridging, insufficient solder, too much solder and blowhole. There defects result in damage to circuit on PCB. Moreover, the size of solders are very small that is quite hard for human vision and take a long time to inspect them, manually. The soldering inspection with the machine vision systems are proposed in the various solutions such as x-ray captured image [1], InSb IR camera [2]. Although, these are quite precise, the devices are expensive and complex. Another common solution is digital microscope capture that acquire the images from light source reflection. According to the light source types using for soldering inspection system, they can be categorized into two main types such as white and RGB light.

Based on white light reflection and digital microscope capture [3-8], there are different proposed method using digital image processing and some other machine learning techniques. For example, the YOLO is the real-time object detection that applies to detect the solder joint defects [3-4]. In 2020, Yu-Ting Li and *et al.* [3], YOLOv2 was used for detecting the foreground of the solders, then the 6 defect patterns was classified by using the ResNet-101. The accuracy was measured as 96.73% with 15 seconds per image. The updated version of YOLOv4, the algorithm processing time was faster than YOLOv2, was also applied for automatic inspection system for PCB solder joint by Ayhan Caliskan and *et al.* [4]. The 4,000 images approximately were train for increase accuracy as 97% with 4 seconds per image. Moreover, the Convolution neural network (CNN) is another option for object classification. According to the research of Shijia Gao et al. [5], the solder images were categorized into two classes as normal and abnormal. Then, the Support vector machine classifier (SVM) with the feature of Histogram of Oriented Gradient (HOG) was compared with the CNN solution. The result shown that the CNN had the higher accuracy as 85%. In addition, the traditional solution of image processing with OpenCV library such as image subtraction and blob detection are still usable, by Fa'Iq Raihan and Win Ce in 2017, [6] for the automated inspection system. Another interesting solution for the white light reflection, B.C. Jiang and *et al.* [7] proposed the machine vision and background remover-based that classified the solder defect such as the normal, short, open and no-solder. Analyzing the basic statistical values from the gray-level image for each defect types, using mean, median, range, standard deviation, and etc. The result was shown the 97.30% accuracy, but the feature selection and overlapped area of feature values problem were still difficult.

In order to add more information for light source reflection to the camera, the 3-color hemispherical LED array light source consisting of red, green and blue have been applied on many researches [9-12]. The various patterns of its reflection can be appeared on the image that depends on the curve and shape of solders. In 2020, Wenting Dai and *et al.* [9] applied the YOLO to detect the position of solder joint and semi-supervised learning for defect and non-defect classification of solders. The result is quite good for only 2-class by 1.5% error rate. Moreover, Yu Ting Li and Jiun In Guo [10] proposed the Faster RCNN model for PCP inspection using VGG16 as a pre-trained which result shown the mAP as 60% for the average of defect classification. In addition, the features can be extracted from each defect types. For example, place features, shape features such as color, occupancy ratio of area, center of gravity and continuous pixels [11]. Although, this proposed earned the good result, the case of solder joint fills with gas cavity within solder was still difficult and challenge. Ziyin Li and Qi Yang [12] designed the hardware prototype including illumination module, image acquisition module, motion control unit, PC, graphic display and operation unit. The prototype can detect many defects such as short and open circuit, wire gaps, voids, and scratch with around 95% of success rate.

This paper intent to present a system for detecting the solder defects on PCB that consists of a part of prototype design and classification algorithm. There are five types for classifying such as non-defect, short circuit, blowhole, insufficient solder, too much solder. The paper is organized as the follow. The proposed system including prototype design and classification is in the section 2. The experiments and results are in the section 3. Conclusion and discussion will be shown in section 4.

2. Proposed System for Solder Defects Inspection On PCB

The overview of system will be shown in Fig. 1, which have three main parts such as the vision, control, and classification in the personal computer (PC). All devices communicate to PC with the different protocol such as the GigE connecting the CMOS camera and USB for connecting the Automatic Optical Inspection (AOI) light source and controller.

The vision part consists of the AOI light source and GigE Industrial camera with 20 MP. Moreover, the AOI light source is an adjustable color-light mode between white and RGB color. The control part consists of the controller board, stepper motor driver and mini-CNC. This control part will be received the command as X, Y position from the PC for moving to the solder position on PCB. The process of classification, command and communication are done by PC.

2.1. *Prototype Design for Image Acquisition*

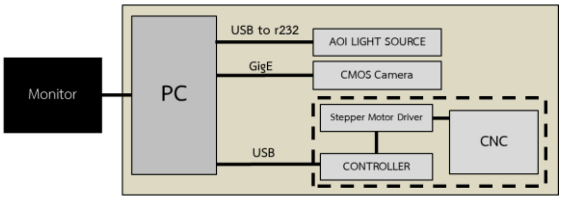

Fig. 1. Hardware system diagram

To acquire the solder images, this research designs the prototype as shown in Fig. 2. The position of each solder is saved on the PC initially. Then, the mini-CNC, that consists of three stepper motors for controlling moment along X, Y and Z axes, is commanded from PC as the position of X, Y position of solder on PCB via the Arduino UNO module. When the mini-CNC reaches the acquired position, the AOI light source and GigE Industrial camera, which are mounted on the Z-axis of the mini-CNC, will be worked as PC received command.

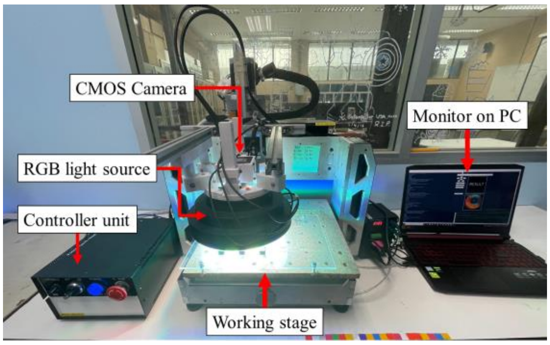

Fig. 2. Prototype design for Images acquisition

First is the camera will be captured the image with the white light for detect the short circuit defect. Then, the AOI is changed to RGB light mode and camera will capture the images for other defect type classification on PC.

2.2. *Solder Defects Classification*

This research categorizes the solder into five types, including the acceptable type. The solder types are acceptable, short circuit, insufficient, too much solder and blow hole as shown in Fig. 3. The proposed classified method is seperated into two solutions. Firstly, the basic techniuqe of image processing will be applied for detecting the short circuit defect. Second is to detect other defect types by using machine learning base.

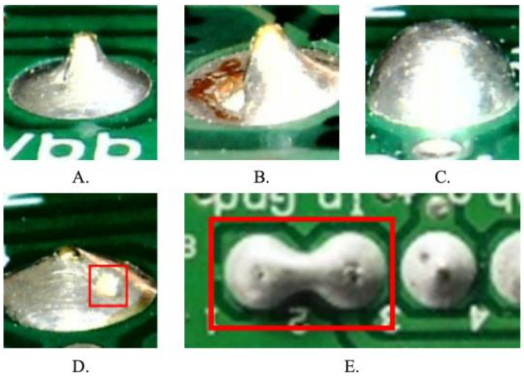

Fig. 3. Four solder defect types and acceptable type (A. acceptable, B. Insufficient, C. Too much, D. Blow hole, E. Short circuit.)

In case of short circuit defect, the image is captured by white light mode. Then, the image thresholding and morphology techniuqe are used for pre-processing process. Then, the connected area of each solder will be checked by using contour techniuqe. Clearly, the short

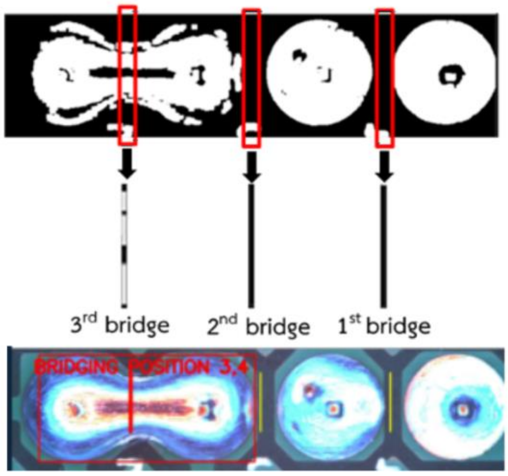

Fig. 4. Short circuit detection

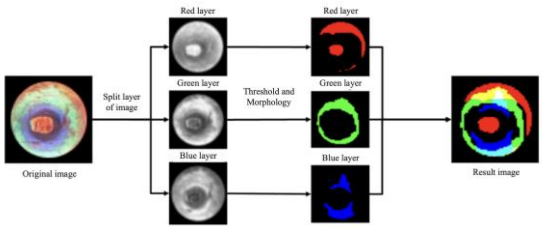

Fig. 5. Feature extraction of the solder image

circuit area, in the image, is shown the huge connected area for comparing to the other solder pattern. Moreover, the position of short circuit will be detected by scanning the white pixel area of binary image between solder and its neighbor as shown in Fig. 4. If the summation of scaning line is greater than 200, that position will be defined for short circuit.

Then, other defect types, including insufficient, too much and blow hole, are detected by machine learning techniuqe. This research apply the RGB light of AOI for more information whlie extracting features process. Fig.5 shows the feature extraction of solder image as the first step is seperation of image layer to red, green and blue. Then, thresholding value is set for segmenting each layer. Finally, these three layers are merged as the the feature for machine learning.

In order to extend the dataset of training process for machine learning. All merged images are augmented by rotating the angle from 20 to 340 degree, totally 408 new sample images are the dataset. Then, intensity values of the image size by 26×26 pixels. are preparing as the 676 vector feature and its lable.

3. Experimental Results

In the experiment, 7 print circuit boards are used as testing board, each board has 4 position solder pads. All circuit boards consist of acceptable type and defect type (Short circuit, Insufficient, Blow hole, and Too much).

3.1. *Verification I*

First verification of this proposed research is the comparison of classifier models using machine learning. The objective score is expressed in Eq. (1) which was used to evaluate the effective of classifier methods, where $\boldsymbol{\sigma}$ is the hyper-controlling factor ($\boldsymbol{\sigma} = \mathbf{0.04}$).

$$Objective\ score = \%\ Accuracy \times \left(\frac{Target\ time}{Process\ time} \right)^{\sigma} \tag{1}$$

Table 1. The comparison of classifier methods.

Classifier Methods	Accuracy (%)	Target Time (s)	Processing Time (s)	Objective score (%)
k-NN (k = 4)	87	0.3	0.39	86
k-NN (k = 1) with PCA	67	0.3	0.28	67
SVM	81	0.3	0.13	84
Decision Tree	73	0.3	0.75	70
Random Forest	**90**	**0.3**	**0.59**	**88**

From the experimental results in the Table 1, Random Forest had the maximum value of the objective score (88%). Therefore, It was selected as the classifier method in this research.

3.2. *Verification II*

The confirmation of the suitable model was presented with the average accuracy of the system, including the confusion matrix. The experiment was repeated 10 times for all testing boards. In this research, the efficiency of solder defect classification was compared with 2-class classification (acceptable and unacceptable types) and 4-class classification (acceptable type and 3 defect types).

- **2-class classification**

The average accuracy of the system was 89%, F1-score accuracy was 0.79 and the confusion matrix is shown in Fig. 6.

- **4-class classification**

The average accuracy of the system was 71%, F1-score accuracy was 0.48 and Fig.7 presents the confusion matrix.

Actual Class (columns) / Predicted Class (rows)

	Unacceptable class	Acceptable class
Unacceptable class	65.5%	0%
Acceptable class	34.5%	100%

Fig. 6. Confusion matrix of 2-class classification

Actual Class (columns) / Predicted Class (rows)

	Acceptable class	Blow hole class	Insufficient class	Too much class
Acceptable class	88%	45%	60%	30%
Blow hole class	0%	45%	20%	25%
Insufficient class	12%	10%	20%	0%
Too much class	0%	0%	0%	45%

Fig. 7. Confusion matrix of 4-class classification

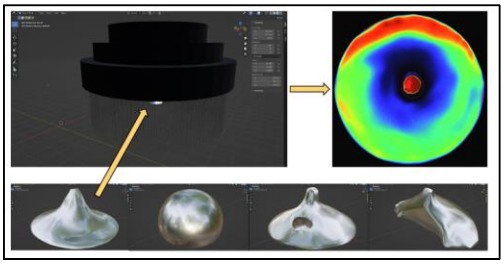

Fig. 8. The sample synthetic dataset

4. Conclusion and Discussion

From the experimental results, when Random Forrest was used to test the defect solder classification, it was found that the 2-class solder classification had higher percentage accuracy and F1-score than the 4-class classification. The non-defect type (or acceptable type) was the most accurate for the prediction, and the insufficient solder was the least accurate. The part of short circuit detection was used the morphology scanning pixels methods that is highly accurate because these types of defects are clear and distinction. For the future work, we aim to raise the accuracy of the inspection system using the synthetic dataset. In Fig. 8 shows the sample synthetic dataset that is created from Blender3D software.

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Authors Introduction

Dr. Watcharin Tangsuksant

He is a lecture of Department of Production and Robotics Engineering at King Mongkut's University of Technology North Bangkok, in Thailand. He received his D. Eng. degree in Graduate School in 2019. His research interest is Asistive Devices/Application with Artificial Intelligence and Machine Learning.

Dr. Jiraphan Inthiam

He is a lecture of Department of Instumentation and Electronics Engineering at King Mongkut's University of Technology North Bangkok, in Thailand. He received his D. Eng. degree in Graduate School in 2019. His research interest is Robotics fields and Artificial Intelligence and Machine Learning.

Mr. Hattapat Silangren

He received his Bachelor of Engineering Program in Robotics engineering and Automation System from the Faculty of Engineering, King Mongkut's university of technology North Bangkok, Thailand, in 2022. He is currently a master's degree student at Kyushu Institute of Technology Iizuka Campus, Japan.

Ms. Phattharaporn Iamcharoen

She received her Bachelor of Engineering Program in Robotics engineering and Automation System from the Faculty of Engineering, King Mongkut's university of technology North Bangkok, Thailand, in 2022.

Asst. Prof. Dr. Wisanu Jitviriya

He is a lecturer in Department of Production and Robotics Engineering, King Mongkut's University of Technology North Bangkok, Thailand. He received his D. Eng. degree in Graduate School in 2016. His research interest that covers the design and analysis of robotic system combined with an artificial neural network