Proceedings of the World Congress on Engineering 2011 Vol II
WCE 2011, July 6 - 8, 2011, London, U.K.

Detection of Bare PCB Defects by Image Subtraction Method using Machine Vision

Ajay Pal Singh Chauhan, Sharat Chandra Bhardwaj

Abstract— **A Printed Circuit Board (PCB) consists of circuit with electronic components mounted on surface. There are three main steps involved in manufacturing process, where the inspection of PCB is necessary to reduce the defects. First step is printing, second step is the components fabrication over the PCB surface and third is the components soldering. In this paper Machine Vision PCB Inspection System is applied at the first step of manufacturing, i.e., the making of bare PCB. We first compare a standard PCB image with a PCB image to be inspected, using a simple subtraction algorithm that can detect the defected regions. Our focus is to detect defects on printed circuit boards. Typical defects that can be detected are over etchings (opens), under-etchings (shorts), holes etc.**

Index Terms— **Machine vision, PCB defects, Image subtraction, PCB inspection, Particle analysis**

I. INTRODUCTION

NOWADAYS Machine Vision inspection process [1], [2] is necessary to improve the quality of PCB. In manufacturing industry there are defects, misalignment, and orientation error so automated inspection [3], [4] is required. The defects can be analyzed by machine vision using algorithms developed for it. So machine vision provides a measurement technique for regularity and accuracy in the inspection process.

These systems have advantage over human inspection in which subjectivity, fatigue, slowness and high cost is involved. In recent years, the PCB industries require automation due to many reasons. The most important one is the technological advances in PCB's design and manufacturing. New electronic component fabrication technologies require efficient PCB design and inspection method with compact dimension [5]. The complex and compact design causes difficulties to human inspection process. Another important factor is necessity to reduce the inspection duration. These factors lead to automation in PCB industry. Nowadays automated systems are preferred in manufacturing industry for higher productivity.

II. MATERIAL AND METHODS

A. Machine vision

Machine vision is the science and technology of machines that "See". It is the science in which a computer is programmed to process and understand images and video [2]. It can be assumed as signal processing applied to images, videos. Machine vision is concerned with the theory behind artificial systems that extract information from images and sequence of images. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner.

On a technical ground, it is necessary to implement the proposed theory and method to construct a machine vision system. Machine vision can be implemented for the system involving following processes.

- Automated Inspection process
- Process control
- Data base collection and indexing
- Modeling of system and environment

B. Bare PCB Defects

During the manufacturing there are some defects commonly found on PCB. These defects are divided into two categories, potential and fatal defects. Short-circuit and open-circuit defects are in fatal defects category. Breakout, under etch, missing hole, and wrong size hole fall in potential defects category [6], [7], [8]. Fatal defects are those in which the PCB does not meet the objective for which it is designed, while the potential defects are those which compromise the PCB performance during utilization. During etching process, the anomalies occurring on bare PCB could be largely classified in two categories: the one is excessive copper and missing copper. The incomplete etching process leaves unwanted conductive materials and forms defects like short-circuit, extra hole, protrusion, island, and small space. Excessive etching leads to open-circuit and thin pattern on PCB [7], [8]. In addition, some other defects may exist on bare PCB, i.e. missing holes, scratch, and cracks.

There are many ways to designate PCB errors as shown in Table I.

TABLE I
PCB ERRORS CLASSIFICATION

FATAL	1 Breaks	1.1 Fracture
		1.2 Cut
		1.3 Scratches
		1.4 Cracks
	2 Shorts/bridges	
	3 Missing conductor	
	4 Incorrect hole dimension	
	5 Missing hole	
POTENTIAL	6 Partial Open	6.1 Mouse bit
		6.2 Nicks
		6.3 Pinholes
	7 Excessive spurious	7.1 Specks
		7.2 Spurs/protrusions
		7.3 Smears
	8 Pad violations	8.1 Under etching
		8.2 Over etching
		8.3 Breakout
	9 Variations between the printed lines	9.1 Small thickness wiring
		9.2 Large conductors
		9.3 Excessive conductors
		9.4 Incipient short (conductor too close)

Ajay Pal Singh Chauhan is with Electronics and Communication Engineering Department, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India, Phone: +91-94171-06644, e-mail: ajaypal_singh@yahoo.com
Sharat Chandra Bhardwaj is with Electronics and Communication Engineering Department, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India, e-mail: bhardwaj.sharat@gmail.com

Fig. 1 (a) and (b) show the examples of reference PCB image and defective image. Each defect shown in Fig.1 (b) is a representative example of certain defects as listed in Table I, though the shape and the size of the defects may vary from one occurrence to another.

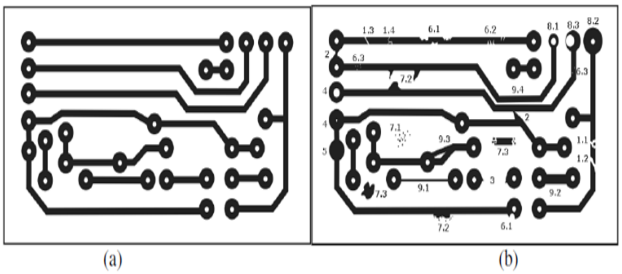

Fig.1 PCB without error (a) PCB with error (b)

C. *Concepts of logic Operator for Image*

An arithmetic or logic operation between images is a pixel-by-pixel transformation. It produces an image in which each pixel derives its value from the value of pixels with the same coordinates in other images [9].
If *A and B* are the images with a resolution *XY*, and *Op* is the operator, then the image *N* resulting from the combination of *A* and *B* through the operator *Op* (fig.2) is such that each pixel *P* of the resulting image *N* is assigned the value
pn = (*pa*)(*Op*)(*pb*) ; where *pa* is the value of pixel *P* in image *A*, and *pb* is the value of pixel *P* in image *B*.

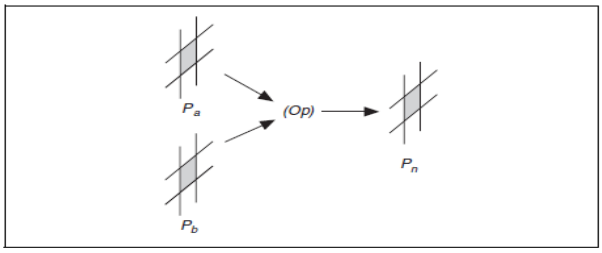

Fig. 2 Operator Concept

D. *Logic and Comparison Operators*

Logic operators are bitwise operators listed in Table II. They manipulate gray-level values coded on one byte at the bit level [9]. In the case of images with 8-bit resolution, logic operators are mainly designed to combine gray-level images with mask images composed of pixels equal to 0 or 255 (in binary format 0 is represented as 00000000, and 255 is represented as 11111111), or to combine or compare images with a binary or labeled content (after thresholding the image).

TABLE II
LOGICAL OPERATORS

Logical Operators	Operator Equation
AND	pn = pa AND pb
NAND	pn = pa NAND pb
OR	pn = pa OR pb
NOR	pn = pa NOR pb
XOR	pn = pa XOR pb
Logic Difference	pn = pa AND (NOT pb)

III. IMPLEMENTATION OF METHOD

To implement the image subtraction logic some software tools are required. There are various tools available for implementation. Here NI Vision Assistant is being used as a development tool.

A. *Vision Assistant 2009*

Vision Assistant is a tool for prototyping and testing image processing applications. Build custom algorithms with the Vision Assistant scripting feature [9] are used to prototype an image processing application. The scripting feature records every step of the processing algorithm. After completing the algorithm, we can test it on other images to make sure it works. The algorithm is recorded in a Builder file, which is an ASCII text file that lists the processing functions and relevant parameters for an algorithm that we prototype in Vision Assistant.

B. *Inspection flow chart*

The PCB inspection using Image subtraction method [7], [10], [11] is performed in steps. As shown in flow chart (fig. 3) the first step load a reference image, second step buffers the reference image so that it can be used for subtraction operation. The third step loads the image which is going to be inspected. To find the PCB error, inspected image is XORed with reference image; this process is also called Image subtraction.

C. *Image Subtraction Operation*

Image subtraction operation is performed in order to get the differences between two images [3], [4]. The images are the reference image and the inspected image. The method compares both images pixel-by-pixel using XOR logic operator [7], [9], [12]. The resulting image obtained after this operation contains defects (fig.4).

The subtraction operation will produce either negative or positive image, '1' represents white pixel and '0' represents black pixel in a binary image.

Two rules exists for image subtraction operation
Rule 1: If 1-0 = 1 then it gives positive pixel image
Rule 2: If 0-1 = -1 then it gives negative pixel image

Fig. 3 Inspection flow chart

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

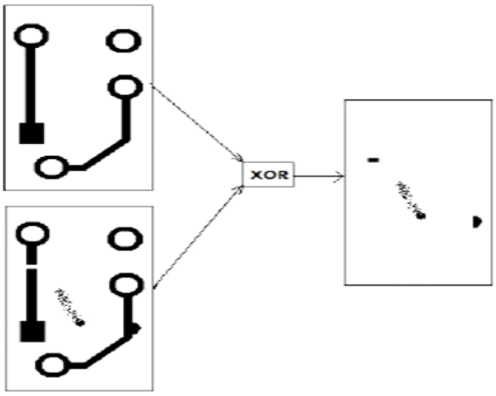

Fig.4 Image subtraction operation

In fig. 5 and 6, corresponding reference and inspected PCB images are shown. These images are converted into grayscale and added into image buffer before subtraction process. The conversion of image into grayscale is needed for obtaining binary image and this image is further processed for measurement purposes.

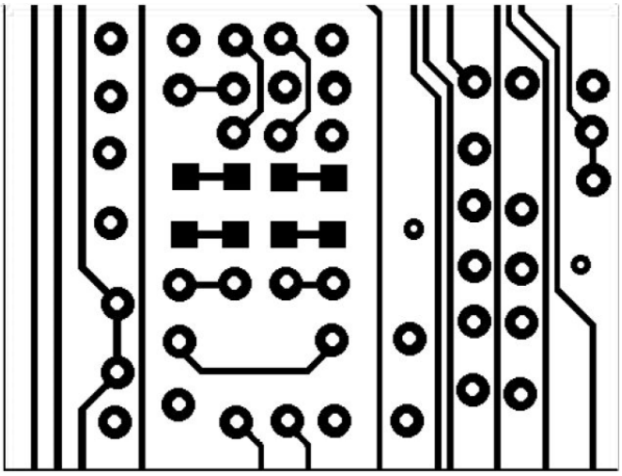

Fig. 5 Reference image

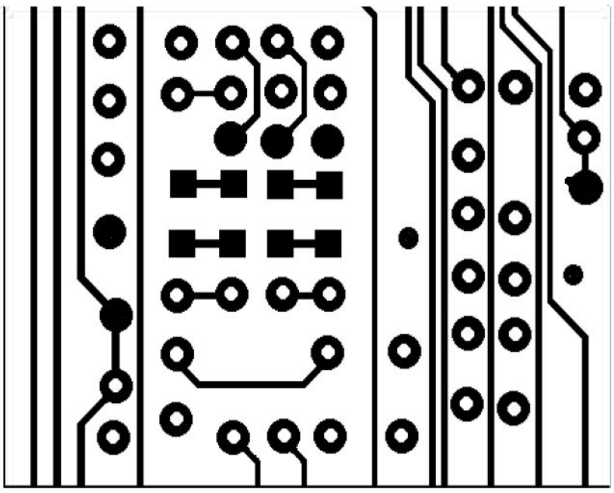

Fig.6 Image for inspection: - Missing holes

For the image subtraction operation it is required that both images has same size in terms of pixels. The logical XOR operation gives defects in inspected image as compared with reference image. Fig.7 shows the resultant image and also some other steps are shown in same image which are required in order to perform image subtraction. These steps are shown in icon form.

The resultant image is further processed for thresholding as shown in fig. 8 in order to convert the resultant image in binary form. The binary form of image shows the resultant area into '1'and '0' form. The image area which contains information is represented by '1' and rest of portion is considered as'0'.

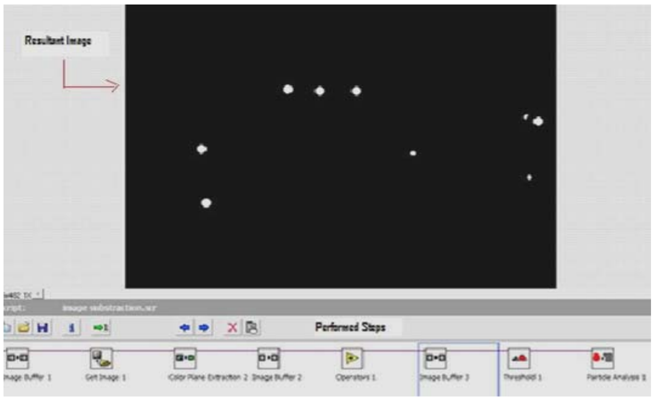

Fig.7 Resultant image after subtraction operation

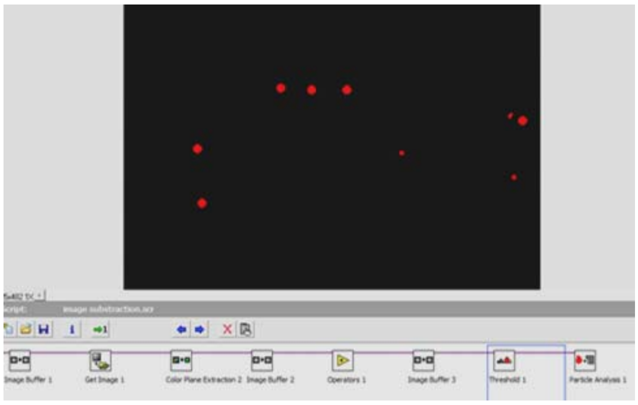

Fig.8 Resultant image after thresholding

For the measurement purpose 'Particle Analysis' function of the NI Vision Assistant is used [9]. This 'Particle Analysis' is applied on the obtained defected area of PCB and outputs are represented in terms of parameters such as area, orientation, X and Y coordinate etc. All measurements can be done in terms of pixel or system calibrated units. Here pixel is being used as a unit for measurement. In fig.9 the image is shown after 'Particle Analysis' and corresponding measurements are given in table III. The parameters for measurement in table III such as X and Y pixels shows the position of defect in image area, Hydraulic radius shows the size, Area represents the area of defected object, Orientation gives the angular position of defects and last one gives the percentage defected area.

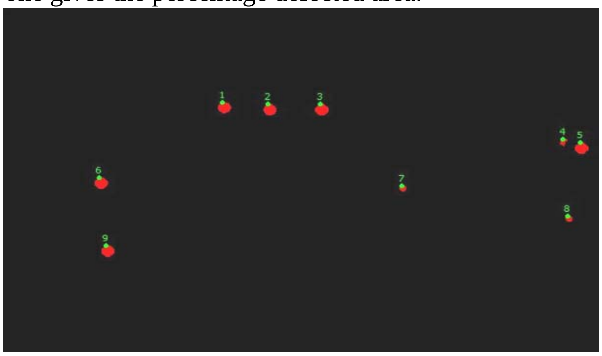

Fig.9 Image after Particle Analysis

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE III
MEASUREMENT OF DEFECTED OBJECT IN RESULTANT IMAGE

Obje ct #	First Pixel X	First Pixel Y	Hydraulic Radius	Area	Orientation	% Area/Image Area
1	237	126	3.15657	140	73.23927	0.04574
2	284	128	3.26468	141	95.19179	0.04607
3	338	128	3.3144	147	64.26647	0.04803
4	588	171	1.51631	40	62.10365	0.01307
5	606	175	3.35801	145	39.82985	0.04737
6	110	218	3.23436	144	86.26726	0.04705
7	422	228	1.80509	41	135	0.0134
8	593	265	1.76106	40	104.297	0.01307
9	117	301	3.22703	141	84.71497	0.04607

The above discussed methods namely Image subtraction, Image Thresholding and Image Particle Analysis are repeated for other defects and corresponding figures and measurements are as given below

1. Missing Circle (Fig. 10, Fig.11 and Table IV)
2. Under Etching (Fig. 12, Fig.13 and Table V)
3. Over Etching (Fig. 14, Fig.15 and Table VI)

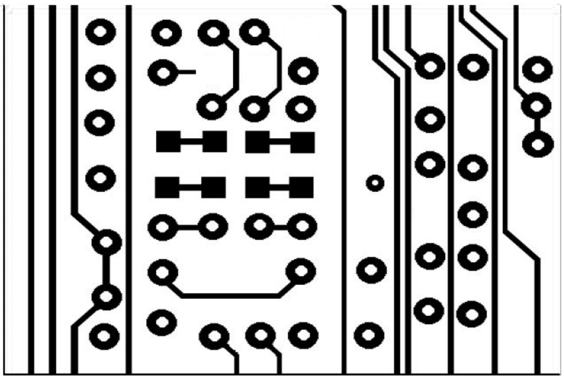

Fig10. Missing circles

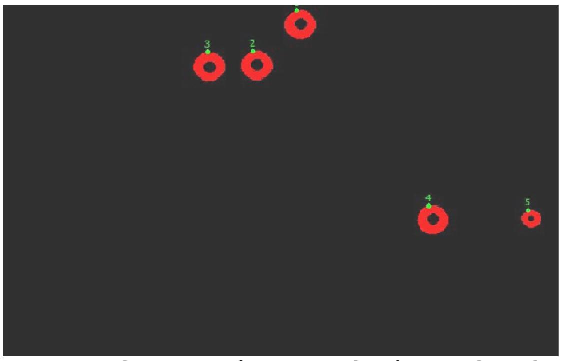

Fig11. Resultant Image of Missing circles after Particle Analysis

TABLE IV
MEASUREMENT OF MISSING CIRCLES

Objec t #	First Pixel X	First Pixel Y	Hydraulic Radius	Area	Orientation	% Area/Imag e Area
1	335	21	7.16103	782	175.8629	0.2555
2	287	69	7.03816	792	118.9301	0.25876
3	237	70	7.2236	796	0.90421	0.26007
4	481	253	7.13164	786	145.3381	0.2568
5	591	258	4.40511	297	177.4269	0.09704

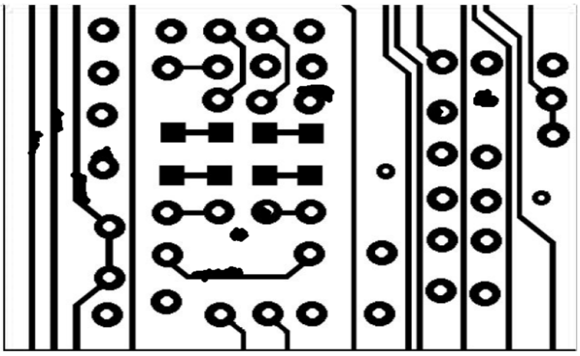

Fig12. Under etching

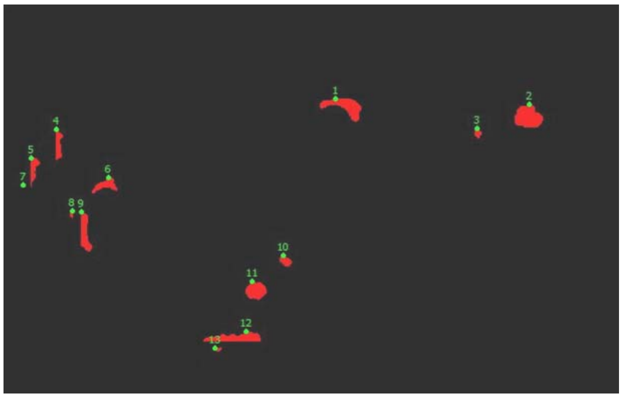

Fig13. Resultant Image of Under etching after Particle Analysis

TABLE V
MEASUREMENT OF UNDER ETCHING

Obje ct#	First Pixel X	First Pixel Y	Hydraulic Radius	Area	Orientation	% Area/Im age Area
1	341	112	3.92964	454	160.9356	0.14833
2	534	118	5.84762	519	159.1196	0.16957
3	482	144	1.85472	52	98.70858	0.01699
4	63	145	2.11688	156	89.92514	0.05097
5	38	176	2.05739	147	83.21509	0.04803
6	115	197	2.59926	189	17.64021	0.06175
7	30	205	0.41886	3	90	0.00098
8	79	233	0.99288	18	90	0.00588
9	88	234	2.91444	281	94.98278	0.09181
10	289	281	2.60645	95	138.103	0.03104
11	258	309	4.66598	304	5.37413	0.09932
12	252	363	3.17572	399	2.86564	0.13036
13	221	381	1.17503	22	0	0.00719

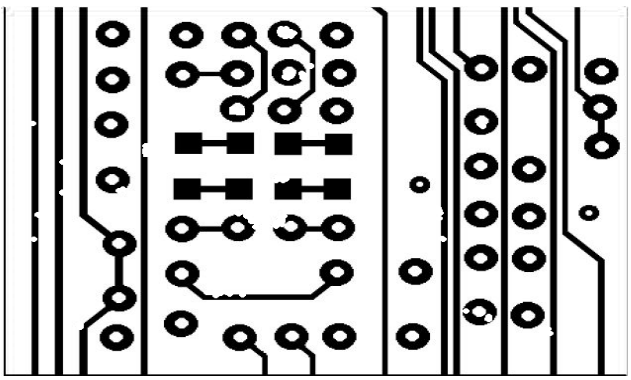

Fig14. Over etching

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

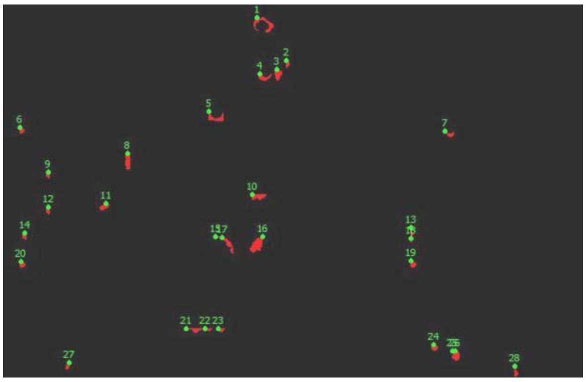

Fig15. Resultant Image of Over etching after Particle Analysis

TABLE VI
MEASUREMENT OF OVER ETCHING

Object#	First Pixel X	First Pixel Y	Hydraulic Radius	Area	Orientation	%Area
1	282	26	1.30644	116	154.1259	0.0379
2	313	74	1.29642	26	90	0.00849
3	303	84	2.05769	69	87.4019	0.02254
4	285	89	1.42436	57	178.7164	0.01862
5	231	131	1.35834	77	169.4399	0.02516
6	31	149	1.4275	29	90	0.00947
7	481	153	1.01505	31	164.3084	0.01013
8	145	178	1.87745	81	90.09171	0.02646
9	61	199	1.27232	22	90	0.00719
10	277	224	1.91409	72	4.92401	0.02352
11	122	234	1.75838	49	30.88693	0.01601
12	61	238	1.29642	26	90	0.00849
13	445	261	0.86366	21	94.44627	0.00686
14	36	267	1.25307	24	91.22265	0.00784
15	238	271	0.81528	8	0	0.00261
16	288	271	2.833	149	55.4278	0.04868
17	245	272	1.33758	67	122.1898	0.02189
18	445	273	0.76935	8	90	0.00261
19	445	298	1.69796	38	105.0594	0.01242
20	32	299	1.66832	34	90	0.01111
21	207	374	1.07835	43	177.1994	0.01405
22	227	374	0.92879	16	176.5585	0.00523
23	241	374	1.17503	22	0	0.00719
24	469	392	1.71757	37	0	0.01209
25	489	399	0.32979	2	45	0.000653
26	492	399	2.21096	69	84.64742	0.02254
27	83	412	1.13215	23	69.76584	0.00751
28	555	416	1.05435	30	96.11076	0.0098

IV. LIMITATIONS

1) Some of the Bare PCB defects such as open circuit, short circuit, incorrect dimensions, missing conductor etc. cannot be detected by this Image Subtraction method.
2) Image subtraction method requires same size of reference and inspected PCB image.
3) Orientation of inspected image must be the same as the reference image.

V. CONCLUSION

The bare PCB is analyzed and the defects of PCB are extracted in terms of various parameters. These parameters can be taken as referential data base for further analysis to fabricate defect free PCB and can assist in making an automated system for inspection. In order to use this method in an industrial application some improvements need to be done. Future work consists of inspecting and analyzing a PCB with Surface Mounted Devices.

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