Machine Vision algorithm for PCB Parameters Inspection

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ABSTRACT
An Automated Optical Inspection (AOI) algorithm for printed circuit board (PCB) inspection system proposed in this paper. The proposed method detect holes defect that occur during PCB etching process during manufacturing. The object of PCB inspection algorithm is to develop a more reliable and faster visual inspection system. The inspection process contains two stages, namely, measurement stage and detection stage. In the first stage, only one image feature is measured from the examined image and is used for detection of defects.

General Terms
Image inspection, Image processing, Parameter Extraction

Keywords
AOI, PCB Defects, Image Morphology, Particle analysis, Particle measurement

1. INTRODUCTION
Automated optical inspection (AOI) technology is making significant progress as PCB designs continue to pack in more circuitry per square inch and create new inspection challenges. The common goal among AOI system manufacturers is to improve lighting, computing power, and vision software. These improvements make AOI products more intelligent, flexible, and with far more repeatable results that are superior to human visual inspection.

For finding of errors in PCB many algorithms are proposed by authors. There are many different errors in printed circuit boards. Automatic optical inspection (AOI) systems are widely adopted in industrial applications [1-3].

There are many algorithms, techniques, and approaches developed in the area of automated visual PCB inspection. By Moganti et al. [4], these can be broadly classified into three categories: referential, rule based, and hybrid approaches. The referential approaches consist of image comparison algorithms. Image comparison technique simply compares the tested PCB image to the reference PCB image using simple XOR logic operator [5].in the Model-based technique, PCB image is matched by using a predefined set of referential data base [6]. Rule-based approache looks for the design rule of PCB to detect whether PCB trace fulfills the required dimensions or not. Also mathematical morphological operation is used where dilation and erosion are basic operation [7]. Lastly, the hybrid inspection approaches combines the referential and design rule approaches to overcome the shortcomings of each approach.

2. PCB DEFECTS
In the manufacturing process of PCB, there are some defects commonly present. During the first process that is etching the anomalies occurring on bare PCB. These defects can be classified into two categories, potential and fatal defects. Fatal defects are those in which the PCB does not fulfil the design rules or specifications, while the potential defects are those which compromise the PCB performance during utilization. In fatal defects category short-circuit and open-circuit defects are there. Breakout, under etch, missing hole, and wrong size hole fall in potential defects category. 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 [8], [9]. In addition, some other defects may exist on bare PCB, i.e. missing holes, scratch, and cracks [10].

3. METHODOLOGY FOR PCB INSPECTION

3.1 Extraction of Color Planes from RGB image
The number of planes in an image corresponds to the number of arrays of pixels that compose the image. A greyscale or pseudo-color image is composed of on plane. A true-color image is composed of three planes- one each for red component, green component and blue component i.e. the color component intensities of a pixel are coded into three different values. Thus, a color image is the combination of three arrays of pixels corresponding to red, green and blue in an RGB image. The following equations convert an RGB image into a grayscale image on a pixel-by-pixel basis [11]. Grayscale value = $0.299R + .587G + 0.114B$
An alternative conversion from RGB to grayscale is a simple average: grayscale value = (R + G + B) / 3

3.2 Pre-processing using Image filters
Please Filters are used to prepare an image for processing so we can extract only the information needed from the image. Most of these filters apply a kernel across the image. A kernel represents a pixel and its relationship to neighboring pixels. The weight of the relationship is specified by the coefficients of each neighbor [11]

- Smoothing-Low pass: Low pass filtering. smooth images by eliminating details and blurring edges.
- Smoothing-Local Average: Local averaging of the image pixels based on the kernel.
- Smoothing-Gaussian: Gaussian filtering based on the kernel. Attenuate the variations of light intensity in the neighborhood of a pixel.

3.3 Conversion of image from Grayscale to Binary
To convert grayscale image into binary, thresholding of image is done. Thresholding consists of segmenting an image into two regions: a particle region and a background region. This process works by setting to 1 all pixels that belong to a gray-level interval, called the threshold interval, and setting all other pixels in the image to 0. Use thresholding to isolate objects of interest in an image [11]. Thresholding converts the image from a grayscale image, with pixel values ranging from 0 to 255, to a binary image, with pixel values of 0 or 1. Thresholding enables to select ranges of pixel values in grayscale and color images that separate the objects under

consideration from the background. A threshold is applied when we have to isolate features for analysis and processing, or to remove unnecessary features. The image after Thresholding shown in Fig. 1

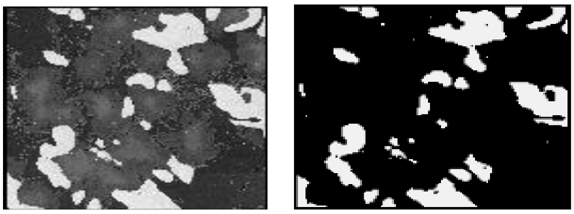

Image (a) Before thresholding (b) After thresholding

Fig. 1 Effect of Thresholding

In contrast to manual thresholding, these methods do not require the minimum and maximum light intensities. These techniques are well suited for conditions in which the light intensity varies. Depending on our source image, it is sometimes useful to invert (reverse) the original grayscale image before applying an automatic threshold function, such as moments and entropy. This is especially true for cases in which the background is brighter than the foreground. Clustering is the only multi-class thresholding method available. Clustering operates on multiple classes so we can create tertiary or higher-level images. The other four methods (entropy, metric, moments, and inter class variance) are reserved for strictly binary thresholding techniques. The choice of which algorithm to apply depends on the type of image.

3.4 Image Morphology

Morphological transformations extract and alter the structure of particles in an image. They fall into two categories:

- Binary Morphology functions, which apply to binary images
- Grayscale morphology functions, which apply to gray-level images

3.4.1 Binary Morphology: Binary morphological operations extract and alter the structure of particles in a binary image. Because thresholding is a subjective process, the resulting binary image may contain unwanted information, such as noise particles, particles touching the border of images, particles touching each other, and particles with uneven borders. By affecting the shape of particles, morphological functions can remove this unwanted information, thus improving the information in the binary image [11].

3.4.2 Greyscale Morphology*:* In greyscale morphology, a pixel is compared to those pixels surrounding it in order to keep the pixels whose values are the smallest (in the case of erosion) or the largest (in the case of dilation) [11]. Greyscale morphology functions are used to filter or smooth the pixel intensities of an image. Applications of greyscale morphology include noise filtering, uneven background correction, and gray-level feature extraction. The gray-level morphology functions apply to gray-level images. These functions can be used to alter the shape of regions by expanding bright areas at the expense of dark areas and vice versa. It also smooth gradually varies patterns and increases the contrast in boundary areas.

3.5 Inspection Algorithm

Inspection process of bare PCB is shown in flow chart (Fig.2). In this chart different steps and methodology are used for defect detection. At first, image (Fig.3) is selected for inspection from the location where captured image are stored. To enhance the image for detection filters are used. Here low pass filter and highlight detail filter are used and grayscale image converted into binary one by applying thresholding. For the detection of defects algorithms are applied on the enhanced image. Advanced Morphology is used to remove the boarder object in the binary image. This process removes unwanted portion of image. On the resultant image Particle Analysis functions i.e. circle detection and Particle measurement are applied. Output of these functions gives the desired results in terms of specified parameters. For other defects some steps may change but basic pre-processing steps e.g. filtering, thresholding are same.

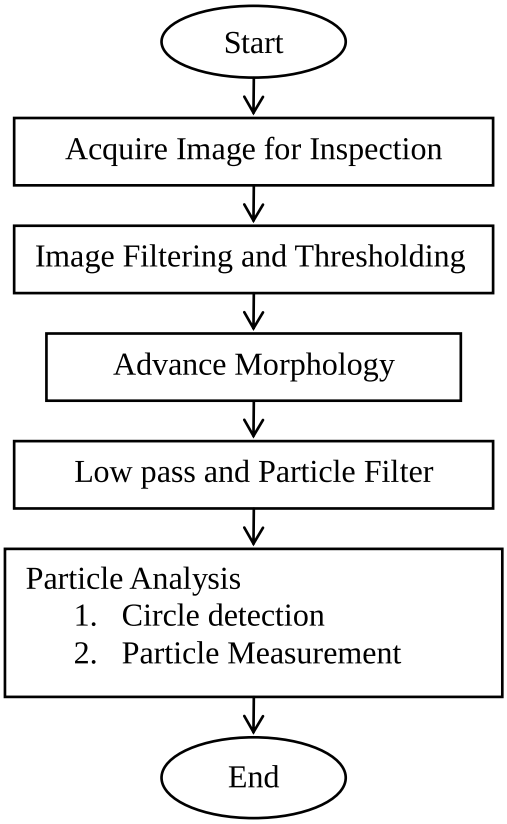

Fig.2 Inspection Flow Chart of Bare PCB

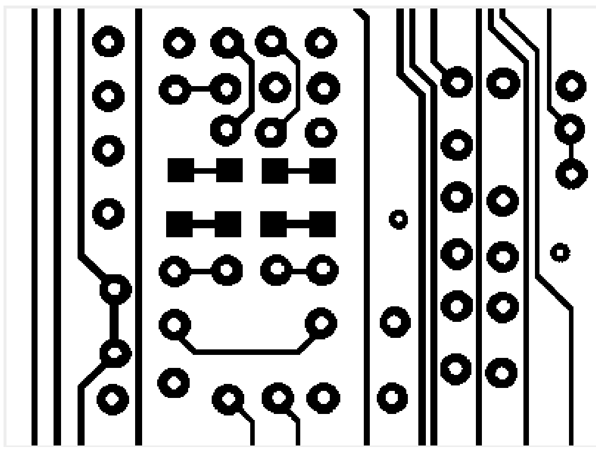

Fig.3 Template image of bare PCB

4. DETECTION OF HOLES AND MEASUREMENT OF DIMENSION

4.1 Filtering and Thresholding of a Grayscale Image

The acquired image is from IEEE monochrome camera and the image is greyscale format so no need of image conversion. The image is pre-processed using filters or by other image processing tools such that the required inspection can be implemented effectively. Here 'Highlight Detail' filter is being used to enhance the image. After filtering the image is converted into binary image using Threshold. As shown in fig. 4 red highlighted image contains required portion of image. The Red portion represents '1' and rest of portion taken as '0' in the binary image. Here Manual Thresholding Method is being used for converting the filtered image in binary one.

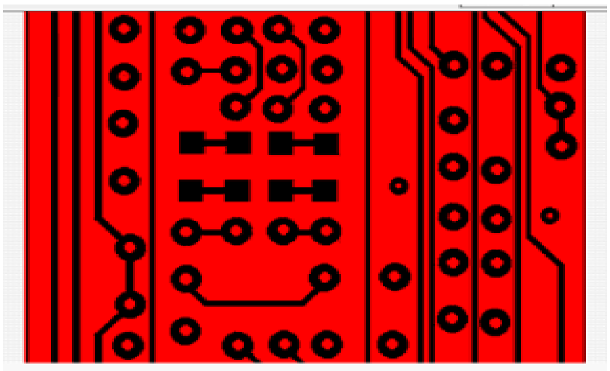

Fig 4 Image after thresholding

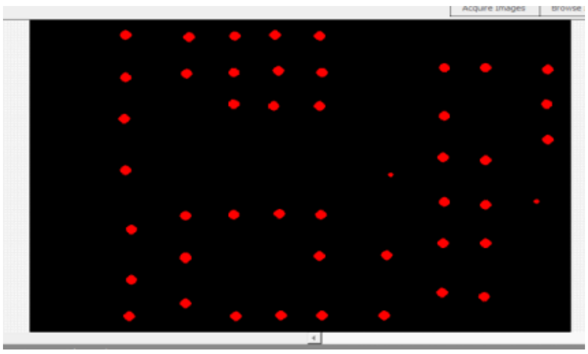

Fig.5 Image after Advance Morphology

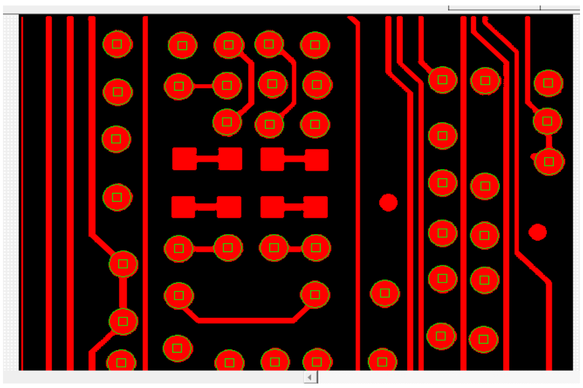

Fig. 6 Outer circle measurement of holes

4.2 Performing a Particle Analysis

Particle Analysis function is used to calculate measurements for every particle in the image and it displays the results (Fig. 5). There are various parameters; the results are displayed in terms of these parameters. Here only required measurement parameters such as Perimeter, Radius, Area and Orientation are chosen. The portions detected are inner holes of pad. In the table the measurements are given and further processed for defect detection. This algorithm is dedicated to convex objects, and may find and return multiple circles in a single non-convex object. In this step the PCB hole are detected as a circle. By this step measure the area, radius of the circle (Fig. 6) are measured. These data are compared for further defect detection such as missing circle, over etched holes, under etched holes, extra copper on the PCB

5. RESULTS AND ANALYSIS

5.1 Particle Analysis results for Inner Hole

Particle analyses are done after detection of defects. The output of inner holes detection is shown in Red portion of resultant image (Fig. 5). These are outcome of Inner Holes detection steps as explained previously. In fig. only inner holes are extracted on which 'Particle Analysis' is performed. Measurements of Particle Analysis are given in table 2. In the table 'Perimeter', 'Radius', 'Area', gives the measurement of holes in terms of pixels and Orientation gives the angular position of holes. These are outcomes of Reference PCB and are compared with inspected image outputs for the detection for defects.

5.2 Outer circle detection of Pads and its Measurement

In the Fig. 6 the output of outer circle detection is shown. In the fig the pads are detected as a circle. In design of PCB the dimension of pads are provided. After measurement of pads result are analyzed in terms of pad radius and its position (x, y co-ordinates). The measurements are given in table 3. In the table "Center X, Center Y" gives the co-ordinates of center position of pads and "Radius" gives its value of radius. These all measurements are done in terms of 'Pixels', but can be represented in terms of real world co-ordinates (Centimeter, Inches) by doing" System Calibration". These measurements are of Reference PCB so these data are compared to the measurements of inspected PCB for the detection of defects. If any pad having measurements differ from certain limits then defect is present.

Table 1 Particle measurement

Obj	Perimeter	Radius	Area	Obj	Perimeter	Radius	Area
1	42.104	3.301	139	24	18.883	1.74	33
2	42.104	3.230	136	25	41.276	3.246	134
3	41.748	3.185	133	26	21.208	1.65	35
4	40.846	3.207	131	27	42.178	3.224	136

5	42.772	3.249	139	28	42.342	3.164	134
6	40.521	3.109	126	29	41.276	3.294	136
7	42.018	3.165	133	30	42.608	3.144	134
8	42.104	3.277	138	31	42.018	3.189	134
9	42.104	3.206	135	32	41.276	3.246	134
10	41.857	3.081	129	33	42.104	3.253	137
11	41.514	3.227	134	34	42.104	3.230	136
12	42.608	3.168	135	35	42.104	3.253	137
13	43.276	3.096	134	36	42.104	3.230	136
14	43.189	3.218	139	37	45.276	3.489	158
15	42.685	3.115	133	38	41.276	3.222	133
16	42.448	3.109	132	39	42.104	3.230	136
17	41.674	3.263	136	40	43.010	3.069	132
18	41.27	3.246	134	41	42.104	3.206	135
19	42.17	3.176	134	42	42.104	3.206	135
20	42.10	3.23	136	43	42.104	3.230	136
21	42.10	3.253	137	44	42.772	3.202	137
22	42.10	3.301	139	45	42.104	3.230	136
23	42.60	3.191	136	46	42.178	3.224	136

Table.2 Measurements of outer circle

Circle	Center X	Center Y	Radius	Circle	Center X	Center Y	Radius
1	112	36	16	23	112	225	16
2	286	36	16	24	485	269	16
3	240	37	16	25	533	272	16
4	339	37	16	26	239	287	16
5	187	38	16	27	292	287	16
6	485	80	16	28	340	287	16
7	534	81	16	29	183	288	16
8	606	84	16	30	119	307	16
9	290	85	16	31	485	325	16
10	341	86	16	32	533	327	16
11	238	87	16	33	419	343	16
12	183	88	16	34	339	345	16
13	113	95	16	35	183	346	16
14	605	131	16	36	119	378	16
15	238	132	16	37	483	396	16
16	287	135	16	38	532	400	16
17	339	135	16	39	181	411	16
18	485	149	16	40	293	428	16
19	111	153	16	41	341	428	16
20	607	181	16	42	416	428	16
21	485	207	16	43	117	429	16
22	534	211	16	44	241	429	16

6. CONCLUSION

In PCB inspection, captured image is preprocessed using filter, threshold, Morphology, Particle Analysis and Circle Detection function and the defects are detected and measured in terms of specific parameters. The inspection carried out on the basis of referential database. This referential database is made using the inspection of reference PCB. The parameter results are compared for the defect detection

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