FUZZY REASONING FOR PCB INSPECTION

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Abstract:

Using the concept of fuzzy reasoning, we developed an automated visual inspection system to detect defects of PCB (printed circuit boards) inner layer. The algorithm consists of two major processing phases. At the first phase, preprocessing is performed to eliminate noise and to reduce the number of potential candidates of PCB defects. At the second phase, features of PCB defects are obtained by image subtraction and defect boundary analysis processes. The results of the proposed fuzzy linguistic method are compared to well-known noise elimination algorithms. They are found to be of comparable quality with less computational complexity.

Keywords:

Fuzzy linguistic; Noise elimination; PCB; Defect inspection

1. Introduction

Automatic optical inspection (AOI) of printed circuit boards (PCB) manufacturing is an important application, nowadays. A large number of PCB inspection algorithms have already been proposed. Moganti and Ercal [7] grouped these algorithms into three categories: (1) reference based inspection, (2) non-reference inspection and (3) hybrid inspection. Image subtraction method is a classical image comparison technique in reference based inspection group. Moganti and Ercal [7] pointed that this method is simple, quick and effective to find defects, and it is easy to be implemented by hardware. Although, most defects can be detected by this method; however, it suffers from a serious inspection error problem when a noise occurs, which could be introduced by environment or information transformation.

Image quality improvement is an important issue, when a system executes image inspection process. Translation noise from the environments of image capturing affects the inspection result especially on image subtraction process. In this research, the fuzzy reasoning is used to avoid this problem. In addition, fuzzy reasoning is often used for clustering objects and obtaining properties from images.

Based on similarities between fuzzy set theory and mathematical morphology, Grobert et al. [2] proposed a fuzzy morphology based on the fuzzy integral. Fast implemental definitions for erosion and dilation based on the fuzzy integral were given. Molina et al. [8] proposed a fuzzy reasoning system, which incorporated the expert knowledge about the images, to defect image boundary. Moganti and Ercal [7] developed a PCB inspection, which could handle all of the defects at PCB inner layer manufacturing process. Tolias [10] proposed a novel approach for enhancing the results of fuzzy clustering by imposing spatial constraints for solving image segmentation problem. Li et al. [4] introduced a fuzzy logic method on inspection of contamination and plating quality of lead frame. Liew [5] presented a spatial fuzzy clustering algorithm that exploited the spatial contextual information in image data. Guo et al. [3] proposed an intelligent image agent based on soft-computing techniques for color image processing. Aureli [1] presents a framework for the segmentation of multi-dimensional images, e.g., color, satellite, multi-sensory images, based on the employment of the fuzzy integral, which undertakes the classification of the input features.

This research proposed a fuzzy linguistic synthesis method to avoid the noise problem in image subtraction process. Section 2 will describe the proposed method in this research. Section 3 is the defect inspection and the performance of proposed method is discussed in section 4. Finally, the conclusion is described in section 5.

2. Proposed Fuzzy Reasoning Method

This research proposed a PCB defect inspection method with image subtraction method. Before doing image subtraction process, it should make a well binary image. It is not good enough to separate object and background by using a threshold value. This research proposed a fuzzy reasoning method to avoid the noise

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problem in image subtraction process.

Fuzzy logic allows data examination of human knowledge represented as a set of fuzzy rules or definition of fuzzy sets. The advantage of fuzzy logic in image processing results form two reasons, the possibility to overcome the special features of pattern descriptions as they can be used for algorithms and the inclusion of human intentions in the process of algorithm goal formulation.

The proposed image binary process by fuzzy reasoning method includes for steps:

(1) Calculate pixel value histogram and threshold value of source image
(2) Search peak values of object and background clusters
(3) Calculate LD (light dark threshold) and LB (light bright threshold)
(4) Excite Fuzzy linguistic synthesis method to make binary image data

The histogram of PCB inner layer inspected image will present as Figure 1 (a). The background and object are two clusters in histogram. In this research uses iterative threshold finding method to decide the threshold value for inspected image. In general both of object and background clusters will have one peak value. Darkmax means the peak value of background cluster, and Brightmax means the peak value of object cluster. Using threshold, Darkmax, and Brightmax to calculate LD (light dark symbolic value) and LB (light bright synbolic value) by function (1) and (2). Therefore, the input of fuzzy linguistic synthesis membership function will obtain, which is shown as Figure 1 (b). Every pixel value of gray scale source image will belong to one of Dark, Light Dark, Light Bright, and Bright sets.

$$LD = (Dark_{msx} + Threshold)/2 \quad (1)$$

$$LB = (Bright_{\max} + Threshold)/2 \quad (2)$$

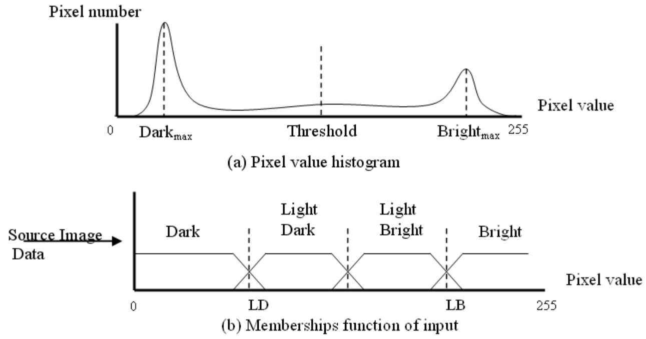

Figure 1. Histogram of source image and memberships function input of fuzzy linguistic synthesis method

In this study, we propose a rule system to modify the binary image, which is obtained by only one threshold value, and the rules is described as follow:

IF ($F_c(x,y)$ IS Dark) AND ($S(x,y)$ IS Background) THEN ($B(x,y)$ IS Background)

IF ($F_c(x,y)$ IS Dark) AND ($S(x,y)$ IS Object) AND($F_1(x,y),F_2(x,y),F_3(x,y),F_4(x,y$ IS Bright Environment)THEN ($B(x,y)$ IS Object) ELSE ($B(x,y)$ IS Background)

IF ($F_c(x,y)$ IS Bright) AND ($S(x,y)$ IS Object) THEN ($B(x,y)$ IS Object)

IF ($F_c(x,y)$ IS Bright) AND ($S(x,y)$ IS Background) AND ($F_1(x,y),F_2(x,y),F_3(x,y),F_4(x,y)$ IS Dark Environment) THEN ($B(x,y)$ IS Background) ELSE ($B(x,y)$ IS Object)

IF ($F_c(x,y)$ IS Light Dark) AND ($S(x,y)$ IS Background) THEN ($B(x,y)$ IS Background)

IF ($F_c(x,y)$ IS Light Dark) AND ($S(x,y)$ IS Object)AND ($F_1(x,y),F_2(x,y),F_3(x,y),F_4(x,y)$ IS Light Bright Environment OR Bright Environment)THEN ($B(x,y)$ IS Object) ELSE ($B(x,y)$ IS Background)

IF ($F_c(x,y)$ IS Light Bright) AND ($S(x,y)$ IS Object) THEN ($B(x,y)$ IS Object)

IF ($F_c(x,y)$ IS Light Bright) AND ($S(x,y)$ IS Background) AND ($F_1(x,y),F_2(x,y),F_3(x,y),F_4(x,y)$ IS Light Dark Environment OR Dark Environment)THEN ($B(x,y)$ IS Background) ELSE ($B(x,y)$ IS Object)

Where F(x,y) is the input of linguistic synthesis fuzzy memberships function. Fc(x,y) is the center of a 3×3 mask, and F1(x,y), F2(x,y), F3(x,y), F4(x,y) are 4-neighborhoold of the 3×3 mask. They are present as Figure 2.

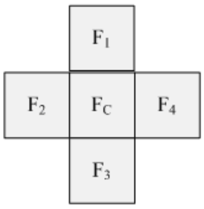

Figure 2. 4-neighborhood of a 3×3 mask

S(x,y) is the input reference image data for linguistic synthesis fuzzy operation. In this case it is the PCB design image data. Object and background are two states of PCB design image data. Besides, there are four environments are define for fuzzy linguistic synthesis rules.

Bright Environment:
F1(x,y),F2(x,y),F3(x,y),F4(x,y) are 4 Brights
Or F1(x,y),F2(x,y),F3(x,y),F4(x,y) are 3 Brights and 1

Light BrightDark Environment:
F1(x,y),F2(x,y),F3(x,y),F4(x,y) are 4 Darks
Or F1(x,y),F2(x,y),F3(x,y),F4(x,y) are 3 Darks and 1

Light DarkLight Bright Environment:
F1(x,y),F2(x,y),F3(x,y),F4(x,y) are more then 1 Bright

Light Dark Environment:
F1(x,y),F2(x,y),F3(x,y),F4(x,y) are more then 1 Dark

The method output is the state of the central pixel B(x,y) that is a binary result image data. The modify binary operation can effectively avoid the problem on image subtraction operation. Therefore, the noise will be removal and the defect will be preserved.

3. Defect Inspection

Inner layers after etching process is the most important inspection stage, and Mognati and Ercal [7] defined defet types occuring at inner layer manufacturing process as shown in Figure 3.

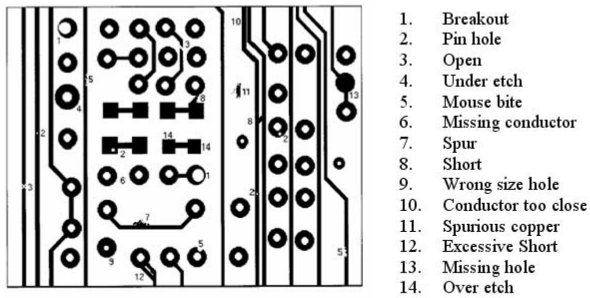

Figure 3. PCB defect type classification

The automated visual inspection system proposed in this research is to detect defect on a PCB inner layer. This system includes six major is showed as Figure 4.

This research makes two ideal images: expansion (Figure 5 (b)) and contraction (Figure 5 (c)) from the original design image (Figure 5 (a)) for image subtraction process. Expansion image is used for detecting excess pixels defect such as short, spur, excess copper. Contraction image is used for detecting lack pixels defects such as open, mouse bite, pin hole, and missing conductor.

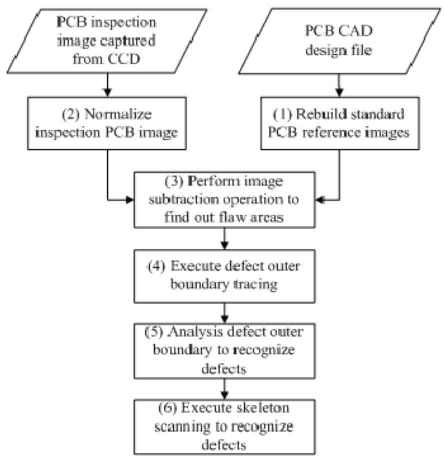

Figure 4. PCB inspection stages

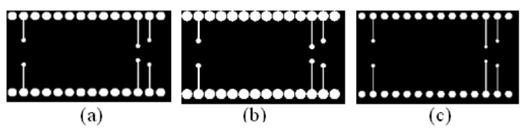

Figure 5. Rebuilt ideal image (a) design image; (b) expansion image; (c) contraction image

Image normalization process is a really important stage for PCB inspection. In this process, some reference points should be searched first, and then the inspection image could be mapped on the ideal image by these reference points. Sonka [9] pointed out three geometric transformations that are rotation, scaling and shifting operations for image normalization process.

Image subtraction method is one of the reference-based inspection methods, and it is simple, quick and effective to find defect. The resultant images can be separated into two groups: lack pixels and excess pixels after image subtraction operation with expansion and contraction of ideal reference images. The image group of lack pixels $Lack(x,y)$ defects includes open, mouse bite, pinhole, and missing conductor. The image group of excess pixels $Excess(x,y)$ defects includes short, spur, and excess copper.

Sonka [9] developed an easy outer boundary-tracing algorithm, which uses a 4-connectivity logic operation to find out the outer boundary of objects in a binary image. After the defects outer boundary tracing process, the defects can be classified by boundary analysis process, which can detect eight types of defects. Boundary analysis process tracks the defect outer boundary and checks the state of boundary, which is either the object or background; then count number of state transition (NOST) for classifying defect types. Defect boundary state transition counting is shown as Figure 6.

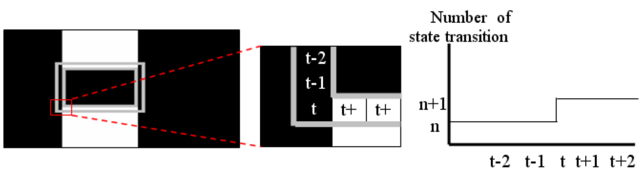

Figure 6. Defect boundary state transition counting.

The centroid and number of state transition will obtain after doing defect outer boundary analysis process. The type of defects can be grouped into two sets whether the centroid is inside defect area. For example centroids of some over etch and under etch defects are not inside defect areas.

Several defects have their unique characteristic in this defect outer tracing process, but some defects not. Those unknown defect should execute pattern skeleton analysis process to recognize defect types. The result of this defect recognition process is presented in Table 1.

Table 1. Result of defects classification by boundary analysis process

Defect type	Number of state transition (NOST)	Lack	Excess	Centroid inside defect area
Open	4 or 3	√		√
Short	4 or 3		√	√
Missing conductor	0(all in background)	√		√
Excess copper	0(all in background)		√	√
Pin hole	0(all in object)	√		√
Under etch	0	√		
Over etch	0		√	
Unknown	2 or 1			√

Simplifying the radial matching algorithm [6], this study proposes a pattern skeleton scanning method, which includes 3 steps:

(1) Calculate the skeleton of a PCB image from a CAD design file
(2) Calculate tolerance for skeleton scanning process
(3) Recognize defect type by the statistical data of skeleton scanning

The skeleton scanning process is shown as Figure 7, and the result of this process is presented in Table 2.

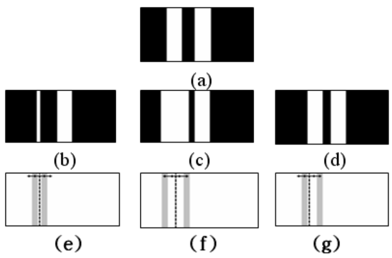

Figure 7. Pattern skeleton scanning: (a) standard image; (b) over etch image; (c) under etch image; (d) conductor too close image; (e) over etch skeleton scanning; (f) under etch skeleton scanning; (g) conductor too close skeleton scanning.

Table 2. Result of defect classification by skeleton scanning

Defect type	Lack	Excess	Both side defect
Mouse bite	√		
Spur		√	
Over etch	√		√
Under etch		√	√
Conductor too close	√	√	√

Pattern skeleton scanning process can recognize the defect types that can not be recognized in outer boundary analysis process. Therefore, all defect types of inner layer etching process can be detected.

4. Implementation and Discuss

There are so many methods proposed to improve image quality before. Classically, closing and opening operation of morphological transformation are going to removal noise. Dilation and erosion are two primary operations of morphological transformation. Grobert et al. [2] pointed out a dilation operator D is every operator that commutes with the maximum operation, and erosion E is every operator that commutes with minimum operation.

If I(x) acts like N×N → {0, 1}, I is call a binary image, the associated morphology is called binary morphology. In this research the mask M is a 3×3 mask. The function of dilation and erosion are presented as function (3) and (4).

$$D_M \circ I = \bigcup_{\{x|I(x)=1\}} M(x) \tag{3}$$

$$E_M \circ I = \bigcap_{\{x|I((x)=1\}} M(x) \tag{4}$$

If I(x) is a function N×N→G, where G is a finite subset of N (mostly the values 0, 1, 2, …, 255 representing gray values), it is called grayscale morphology. Therefore, the function of dilation and erosion are presented as function (5) and (6).

$$D_M \circ I = \max_{i \in M} (I(x_i)) \tag{5}$$

$$E_M \circ I = \min_{i \in M} (I(x_i)) \tag{6}$$

Closing operation is dilation followed by erosion, and opening operation is erosion followed by dilation. Closing and opening operations can removal small area noise effectively, but they are also removal the defect information away. For example, when a pin hole defect is not big then 3×3 area, it will not be detected by inspection system after doing opening and closing operation.

Another quality improvement method of image inspection process is the nearest neighbor filter, which is an adaptive vector weighted filter. A general form of filters is given as a vector weighted filter. The filter's output at the mask center is presented as function (7), and the nearest neighbor filter's weighted coefficients are determined by function (8).

$$y = \frac{\sum_{j=1}^{n} w_j x_j}{\sum_{j=1}^{n} w_j} \tag{7}$$

$$w_j = \frac{d_{\max} - d(j)}{d_{\max} - d_{\min}} \tag{8}$$

Where d_{max} is the maximum distance with center pixel value in the filtering mask, and the d_{min} is the minimum distance. d (j) means the 8-neighborhood distance with center pixel value.

The nearest neighbor filter is useful to improve image quality on gray scale image, but there are still some noise can not be removal. The residue noise might make false defect in inspection system.

The above described method has been tested with image form the PCB inner layer defect inspection system. Table 3 show the false defect alarm number in the PCB inspection system by different image preprocess before doing image subtraction process.

Table 3. False defect number of PCB inspection result

Pixel value space	Iterative threshold	The nearest neighborhood filter	Binary Morphology	Grayscale Morphology	Fuzzy linguistic Synthesis
0	14	12	7	5	0
1	9	11	4	2	0
2	6	8	3	1	0
3	5	5	2	0	0
4	4	4	1	0	0
5	2	3	0	0	0
6	2	2	0	0	0
7	1	0	0	0	0
8	0	0	0	0	0

The binary image are make by those five method: (1) iterative threshold, (2) the nearest neighborhood filter with iterative threshold, (3) binary morphology, (4) grayscale morphology, and (5) fuzzy linguistic synthesis method, and the partial binary image of those method is shown as Figure 8 and the Figure 9 shows the pin hole defect image inspection result by those methods.

Binary morphology and grayscale morphology are not good enough methods, if the inspection system wants to move noise but keep the information of small defects. The nearest neighborhood filer has really good performance of noise removal process in grayscale image, but it is also not good enough to make a well binary image for inspection system by image subtraction process.

This research proposes a fuzzy linguistic synthesis method can easy remove noise away, and preserve the information of small defect. The fuzzy linguistic synthesis method can make a good enough binary for image subtraction process, and the experiment shows the performance of this method. Although, it has good performance to recognize object and background of an image, the fuzzy linguistic synthesis method is only suitable for the image, which only has two clusters.

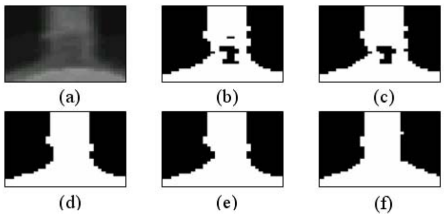

Figure 8. (a) Source image, (b) iterative threshold, (c) the nearest neighborhood filter, (d) binary morphology, (e) grayscale morphology, and (f) fuzzy linguist synthesis

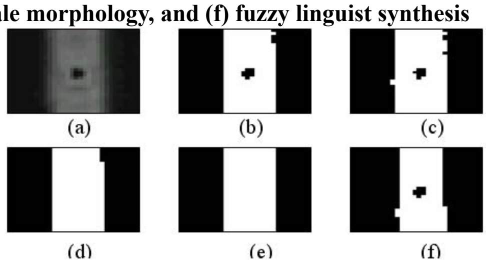

Figure 9. (a) Source image, (b) iterative threshold, (c) the nearest neighborhood filter, (d) binary morphology, (e) grayscale morphology, and (f) fuzzy linguist synthesis

5. Conclusion

Image subtraction process is a fast and easy method to find defect, but it needs a well binary image. The proposed fuzzy linguistic synthesis method can avoid the problem at image subtraction process. In this research, the real PCB images were tested by the inspection system with the fuzzy linguistic synthesis method. It makes the PCB inspection system detect defects without any false alarm. Meanwhile, the results of the proposed fuzzy linguistic method were compared to well-known noise elimination algorithms. They are found to be of comparable quality with less computational complexity.

Acknowledgments

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