Research on Image Segmentation Algorithm Based On Area Array Camera PCB Automatic Optic Inspection

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Abstract. In this paper, a fast and accurate image segmentation algorithm is studied in this paper, which is based on the automatic optic inspection (AOI) equipment device of the experimental prototype surface array camera printed circuit board (PCB), which is built in the laboratory. In the search for “ridge lines” in the “topography” watershed, three thinning algorithms, skeleton algorithm, watershed algorithm and so on are used for image morphological processing. The experimental comparison shows that the improved watershed algorithm, which combines the related morphological processing, has a remarkable effect on image segmentation, and it can lay a good foundation for the detection and detection of the following PCB board defect recognition.

1. Introduction
Image segmentation is the basis of image analysis and target recognition. It has developed in the 1960s. There are thousands of segmentation algorithms proposed by scholars at home and abroad. However, a universal segmentation algorithm that is suitable for all images has not been developed so far. The commonly used classical image segmentation algorithms include edge detection, threshold segmentation, and region segmentation. With the advent and development of some other special theoretical techniques in recent years, a large number of Chinese and foreign scholars have devoted themselves to the study of new methodologies applied to image segmentation. The segmentation algorithm based on mathematical morphology has been widely used and developed [1]. The watershed algorithm is a newer region-based segmentation algorithm based on mathematical morphology. The method realizes image segmentation by selecting target pixels to merge pixels in different regions to obtain better image segmentation results, which is suitable for complex image segmentation. However, this method is susceptible to noise interference and the segmentation result is easy to lose important edge information. When the noise content is large, “over-segmentation” and “under-segmentation” are more prominent [2].

In this paper, aiming at the limitations of the traditional watershed algorithm, in order to improve the image segmentation effect, an image segmentation method based on improved watershed algorithm is proposed based on the processing of related image morphology. The test proves that this method is ideal for image segmentation, effectively solves the phenomenon of “over-segmentation”
and “under-segmentation” and quickly, accurately and completely finds the “ridge line” in the “topography” watershed.

2. Area camera image acquisition system

Based on the existing scientific research basis, the inspection equipment was redesigned, processed, and improved for the detection requirements of the PCB automatic optic inspection equipment (AOI). According to the conventional PCB defect detection process, the system adopts the idea of module design, which mainly includes an image acquisition module, an image transmission module, an image processing module, and a terminal display module. The PCB defect inspection equipment development platform was set up in time to conduct comprehensive experiments. Through the continuous debugging of the performance of different modules, the appropriate structural design was checked for the rationality and efficiency of the relevant algorithms, and relevant improvement measures were put forward based on relevant experimental results.

This system adopts the idea of modular design and coordinated work of each module. Compared to the traditional PCB automatic optical inspection system, this paper proposes an innovative solution for image capture of array camera arrays, and cooperates with the two-dimensional motion platform designed and processed independently. Effectively improve the detection efficiency and detection accuracy. Figure 1 shows the structure of the PCB automatic optical detection system.

![Figure 1. PCB automatic optical inspection system overall structure diagram](image-url)
3. Image Mathematical Morphology Processing

In this paper, the target area of PCB board is extracted by the laboratory image acquisition system, and the Geber file is drawn and parsed. According to the unit (inch) of the Gerber data and the scanning precision (1/1000 inches), it is very easy to determine the corresponding relation between the unit of the Gerber data and the unit of the standard image (pixel). The standard image matching the scanned image is obtained. It is found that there are more local white structure elements in the Geber graph after the resolution processing, resulting in incomplete image. This will have a great impact on image segmentation. Therefore, in order to solve this problem, this paper uses image corrosion and expansion method to do digital morphological processing [3].

The following is defined as follows:

Let $A$ be a one-dimensional plane target area $(x, y)$, $D$ as the structure element of the specified size and shape, defined in the $(x, y)$ coordinates of the $D$ region as $D(x, y)$, the expression of corrosion for $A$ is:

$$\{(x,y) | (x,y) \in A, D(x,y) \cap A = \emptyset \}.$$  

(1)

Expansion and corrosion is the operation of duality, expansion is the integration of all the structural elements connected with the object into the object, and the process of expanding the boundary of the image to the outside. It can fill the small holes in the image and the small hollow parts at the edge of the image. The mathematical definition is as follows:

Let $A$ be a one-dimensional plane target area $(x, y)$, $D$ as the structure element of the specified size and shape. The region defined by $D$ in the coordinates of $(x, y)$ is $D(x, y)$, the expansion expression for $A$ is:

$$\{(x,y) | (x,y) \in A, D(x,y) \cap A \neq \emptyset \}.$$  

(2)

By choosing appropriate structural elements and parameter size, the two valued images are first corroded, expanded and re expanded.

Figure 2. PCB original diagram

Figure 3. After processing PCB images
4. Image segmentation algorithm

4.1. Skeleton algorithm

The so-called “skeleton” refers to a fine curve, which is consistent with the connectivity and topology of the original shape, as an ideal expression of an object expression simply, is a simplified figure that is located inside an object, and can reflect its shape characteristics. It has the function of describing the branch of a convex object, and also describing the void inside the object [4]. In the two-dimensional space, the skeleton is a curve.

4.1.1. Theoretical basis of morphological skeleton extraction algorithm based on axis transformation.

Axis transformation is the most common way to describe the skeleton of objects. The middle axis (Middle-Axis) can be regarded as an exact skeleton. It was first formally proposed by Blum in the form of “surface fire” in 1961: imagine a meadow with the same shape and size of the target object, ignition at the periphery of the whole edge of the whole grassland, the fire spreading to the interior, and the track of the fire front meeting point forward is the middle axis, which is the surface fire (grass-fire) [5].

The concept of the largest disc is a more formal and broad definition:

It is assumed that a disc with arbitrary diameter can be changed, and the connecting component can be described by a series of largest discs. The largest disk is tangent to the contour of the connecting component, and the skeleton of the connecting component is the line of the series of the largest tangent disc center [6]. The disk with these points on the skeleton satisfies two condition:

The circle is completely inside the image.
The radius of the circle is the largest.

Through the above model conditions, we can see that the following two conditions should be satisfied when seeking the skeleton of an image:

The image should be regularly reduced in the Process of skeletonization.
The connectivity of the image should be kept Constant during the gradual reduction of the image.

Next, we use mathematical morphology to describe the skeleton process.

The largest disk in the image \( f \) is defined as \( A_r \). The set of the largest circle \( R \) of \( A_r \) is \( \text{Sk}(F,I) \), \( i = 1, 2, 3 \). By skeleton definition, skeleton contains all skeleton subset and skeleton subset is skeleton:

\[
\text{Sk}(f) = \{\text{Sk}(f;1) \cup \text{Sk}(f;2) \cup \text{Sk}(f;3) \ldots \cup \text{Sk}(f;i), i = 1, 2, 3, \ldots\}
\]

Taking \( Y \) as the set of \( P \) in Euclidean space, the skeleton \( Sr(Y) \) of \( Y \) is a subset of \( S(Y) \), \( r \) is the largest inscribed circle radius of \( Y \). The mathematical morphology description is as follows:

\[
S(Y) = U\{(Y \Theta A) - ((Y \Theta A) \circ B)\}.
\]

The \( A \) in the formula is the largest inscribed circle with discrete radius \( r \), and \( B \) is the structural element in the Euclidean space. It represents the corrosion calculation of \( Y \) for successive \( r \) times. And the next iteration is the first time that the structural element \( B \) is corrupted to an empty collection, \( R \) times.

\[
K = \max \{r \mid (Y \Theta Br) \neq \emptyset, r = 1, 2, 3, \ldots\}.
\]

In this paper, we use skeletonization to process images. By calculating the maximum domain value of each pixel, the template is set as the comparison interval of \( 5 \times 5 \), and the specified area is traversed to determine whether the range center is the maximum distance value point. The pixel that obtains the center point is the maximum distance value point that is the skeleton point. Figure 4 below (Black:
substrate area, white: copper clad area, blue: copper covered area skeleton) for skeletonization of images.

**Figure 4.** Skeleton processing of images

From Figure 4, it can be seen that the method based on distance transformation has obvious advantages on the accuracy of the skeleton points, but this method is difficult to ensure the connectivity of the skeleton, and the branches are multiple and messy, which will affect the expression of the skeleton topology. Obviously not the ideal result.

### 4.2. Thinning algorithm

Image thinning generally refers to skeletonization of two value images, and the information contained in the image is minimized under the premise of preserving the original image geometry. Looking for the skeleton or central axis of the target image, replacing the original image with a single pixel skeleton, the process of eliminating the redundant information in the image is a preprocessing method in the image processing. It can reduce the redundant information of the original object as much as possible while maintaining the shape information of the original object, and quickly extract the feature of the image [7]. The effect of image thinning directly affects the effect and accuracy of later image processing. After thinning, the skeleton should be in the center of the original image, and preserve the topology, connectivity and detail features of the original image.

According to different needs, there are many algorithms and judgments for image thinning, but the following two criteria should be followed:

- Thinning of images cannot shorten the length of image skeletons.
- Refinement cannot decompose images into different parts.

At the same time, we must satisfy the requirements in judging these two criteria:

- The number of visible pixels in 8 directions in the current pixel field is calculated. If less than 2 pixels are less than 2 pixels, the deletion of this pixel will shorten the length of the skeleton of the image; if more than 6 pixels, the pixel will be deleted to change the geometry of the image skeleton.
- Calculate the number of regions in the neighborhood of the current pixel. If there are 1 more redundant pixels, the center pixel will be decomposed into different parts.

#### 4.2.1. Theoretical introduction of thinning algorithm

The region a of 3 in an image, the name of each point is labeled $P_i$ ($i=1,2,3,4,5,6,7,8$). Figure 5 shows several forms of neighborhood. If the central pixel in the b is deleted, the length of the image skeleton will be shortened. If the central pixel in the c is deleted, the geometric shape of the image will be affected. If the center pixel in the d is deleted, it will be deleted [8].
In this paper, on the basis of morphology, the thinning of two value images is shown as shown in Figure 5 (Black: substrate area, white: copper cladding area, blue: skeleton of copper clad area). Although the processing effect has been improved significantly compared with the previous skeleton algorithm, there is still a small number of branches still exist for the local area refinement and the inaccuracy of judging the location. So it is still an undesirable result.

**Figure 5.** Domain judgment in refinement: (a) The region $a$ of $3 \times 3$; (b) If you delete P1, the skeleton length of the image will be shortened; (c) If you delete P1, it will affect the geometry of the image; (d) If P1 is deleted, the image will be split

|   | P3 | P2 | P9 |
|---|----|----|----|
| P4 | P1 | P8 |
| P5 | P6 | P7 |

|   | 1  | 0  | 0  |
|---|----|----|----|
| 0 | P1 | 0  |
| 0 | 0  | 0  |

|   | 1  | 1  | 1  |
|---|----|----|----|
| 1 | P1 | 1  |
| 0 | 0  | 0  |

|   | 1  | 1  | 0  |
|---|----|----|----|
| 1 | P1 | 1  |
| 0 | 1  | 1  |

**Figure 6.** Image thinning
4.3. Image segmentation with improved watershed algorithm

4.3.1. Traditional watershed algorithm. Watershed transformation algorithm is a region growing image segmentation method based on geographical morphology [9]. In the field of image processing, there are many methods to calculate the watershed algorithm. One of the most classical methods is the “immersion simulation” method. The basic idea of the algorithm is that the image is regarded as a high and low topographic map.

The height of each point corresponds to the gradient value of every point in the topographic map. The high gradient of the image corresponds to the mountain peak, and the low gradient corresponds to the valley. Such an image is made up of a number of depressed basins and protruding ridges between adjacent basins. The bottom of each basin is bound to have an extremely small area, which is pierced in this polar area, assuming that there is water flowing from the polar area to the basin. As the water level rises, the water of the two adjacent basins will be connected over the ridge. In order to prevent the connectivity of the two basins, the embankments and dams are built at the top of the ridge between the two basins. As the water level rises, it becomes higher. Finally, when the water level reaches the highest ridge, the water stops rising and the algorithm terminates. A number of ponding basins surrounded by dams are the final separated regions, and the dykes are the final separated boundaries. They are called “watershed” or “water line”.

Figure 7. Watershed and water accumulating basin sketch map

4.3.2. Implementation process of improved watershed algorithm. Although the watershed algorithm is used to segment [10] images, the effect is ideal and outstanding. However, there are still some obvious defects, such as the segmentation migration caused by image noise sensitivity, easy to lose important contour for low contrast image, and easy to produce “over segmentation” and “under division” and other common problems. In the actual image segmentation algorithm, for the solution of these three problems, the first two can be based on the knowledge of digital image morphological processing, through the use of the relevant functions in the MATLAB tool to complete the adjustment of image contrast and filtering de-noising. The problem of image excessively segmentation is mainly due to the local minima caused by noise, the texture details in the region and the error of correlation quantization. When these minimum values are accumulated to a certain number, there will be a large number of fine cell domains in the image segmentation, resulting in the excessive segmentation of the image.

In order to solve this problem, this paper first starts with the pixel area, and takes the smallest closed area as the marking object, and finally provides the target object for the watershed transformation. The concrete steps are as follows:

Region of interest extraction - through the analysis

Of the edge information and structure information, combined with the image traversal theory, obtain the minimum corresponding contour, so as to determine the related area markers.
Effective pixel detection using threshold set and threshold segmentation to acquire relevant effective pixel information.

Distance computation and extreme value search

Element search the extremum value of the marked region by the gray scale map after the distance transformation, and obtain the set of relative extreme points.

Through the analysis of the copper cladding area and substrate area of the PCB board, it is found that there is a certain useless area (the area that needs to be cut off in the later process), the unrelated area (because of the stains produced in the process, but insignificant) and the false edge. By extracting the features of the target area, the algorithm can reduce the complexity of the algorithm, reduce redundancy and improve the recognition efficiency. The main extraction methods are described as follows:

Euler number. In many applications, Euler number $K$ is used as a topological feature to recognize objects. The Euler number $E$ is defined as the difference between the number $C$ of a connected object and the number of holes $H$ in the object.

$$K = C - H.$$  \hspace{1cm} (6)

Among them, the Euler number $K$, $H$ and $C$ are all a topological characteristic component. As long as the image is not split, their numbers do not change because of the deformation of the graphics.

Area characteristics

The area characteristic of target area $S(I)$ is the description of the size of the area. The size of the region is represented by the statistics of the number of pixels in the target area $W(x,y)$.

$$S(I) = \sum_{i} G(x_i, y_i).$$ \hspace{1cm} (7)

Among them, $S(I)$ represents the total number of pixels in the region, $I \in W(x, y)$, $G(x_i, y_i)$ representing the gray value in the region. In the region $W(x, y)$, the threshold is set by itself to mark.

After extracting the target area of the image, the region part of the above method is processed by gradient edge processing, and the further detection of the target area is completed [11]. Then the processed image is two valued, and the two value map (base area and copper overburden region) through the Euclidean distance transform can get the distance between the target pixels in the region and the nearest background pixels, so as to obtain the regional extreme points.

The concept of distance transformation of two value images is proposed by Rosenfeld and Pfaltz in 1966. The main idea is to transform the two value images into gray images by recognizing the distance between the points of the space (the target point and the background point).

For pixels $p(x, y)$, $q(s, t)$, $D(p, q)$ is used to represent the distance between pixels $p$ and $q$, and the mathematical definition of Euclidean distance transformation between pixels is as follows:

$$D(p,q) = \sqrt{(x-s)^2 + (y-t)^2}.$$ \hspace{1cm} (8)

The Euler distance transformation of each pixel in the target region of the two valued image is obtained by using the Euclidean distance transformation to get the $Di (i=1,2,3\ldots)$ of the distance point, then through compare and calculate each distance set $Di$ and finally get the extreme point set $Si$ of the $Di$.

The algorithm uses ergodic form to obtain the Euler distance transform and the maximum point set $Si$ for the target calibration area, so that the “middle ridge line” in the watershed algorithm is accurately and quickly obtained.
4.3.3. Image segmentation implementation process and test based on improved watershed algorithm

In order to solve the problem of “over segmentation” in image segmentation, the image quality is improved. In this paper, the main idea of image transform segmentation based on improved watershed algorithm is as follows: first, the image is preprocessed to reduce the interference of the factors such as uneven illumination and noise. In the experiment, the preprocessing methods such as median filtering and linear convolution filtering are used to denoise and filter the image, and the edge information of the target is protected. Then image transformation is carried out to increase the contrast of the image, and the target and the background area are better differentiated. Then the Euclidean distance transformation is carried out to the image (base area and copper overburden region), and the threshold segmentation of the obtained Euclidean distance transform image is processed. The threshold of the image is fixed by experimental test, and the best threshold is found, and the effective region is obtained. Finally, a complete ridge line is obtained by improving watershed algorithm. The specific implementation process is shown in Figure 8 as follows:

![Figure 8. Improved watershed algorithm image segmentation implementation process](image)

MATLAB software programming is used to implement the new improved watershed algorithm image segmentation test results as shown in Figure 9 (Black: substrate area, white: Copper overlying area, blue: skeleton of copper clad area) [12]. The new algorithm has no redundant branch points, although it has a small number of scattered breakpoints, it does not affect the recognition and detection of the defects in the later period of the image, and the algorithm has high detection efficiency and reliable stability.

![Figure 9. Improving the test results of the algorithm](image)

5. Conclusion

On the basis of the PCB automatic optical detection device of the experimental prototype surface array camera array built in the laboratory, this paper uses the MATLAB image processing tool, combined with the morphological processing of the related digital image, and compares the image segmentation effect by comparing the image skeleton and the thinning algorithm, and aims at the traditional watershed image segmentation algorithm. In this paper, a new watershed algorithm is developed for image segmentation of PCB board. The experimental results show that the improved watershed algorithm is accurate and efficient in searching and marking the “ridge line” in the watershed, and the segmentation effect of the image is remarkable and reliable. It lays a good foundation for the subsequent identification and processing of PCB plate defects.
6. Acknowledgment

Author: Tao Gao, the first grade of graduate students at Shenzhen University
Title: Research on Image Segmentation Algorithm Based On Area Array Camera PCB Automatic Optic Inspection

Acknowledgments my work was supported by Shenzhen Science and Technology Innovation Commission Project JCYJ2014041809143575 I am very grateful to Professor Feng Ping for his guidance and support.

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