Defects Description in Blockboard by Hough Transform and Minimum-Perimeter Polygons

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Abstract

The blockboard defects were detected by Hough transform and Minimum-Perimeter Polygons. X-ray nondestructive testing system was used to obtain X-ray blockboard images. The rough binary images of blockboard were got from X-ray images. An initial area of the blockboard defect was simplified by Mathematical morphology, and then the edges of the area image were detected by Minimum-Perimeter Polygons (MPP). Large numbers of lines around the boundary were detected by Hough transform. The lines data were processed by the mathematics and computer graphics methods. The results show that the blockboard defects can be described by several certain lines on the screen. And then, the parameters of lines can be obtained by computers easily. Hence, to defects description, the method in this paper is much more convenient and faster than the traditional methods.

Keywords: *Blockboard defects, X-ray Nondestructive Testing, Digital Image Processing, Hough Transforms, Minimum-Perimeter Polygons*

1. Introduction

Blockboard is widely used material in many fields recently, such as in the furniture and carpentry. It plays an important role in our lives. It is advanced man-made sheet by comprehensively using of timber resources, thought as an ideal substitute for natural high quality timber [1]. However, its physical-mechanical properties are largely unknown, and it is difficult to precisely determine the bonding quality in the combination of wood components with different thickness (strips and veneers) [2]. Because its major components are cemented with agglutinant, the bond quality, uniformity degree and situation of filler are necessary for the blockboard. Once the testing methods of blockboard are destructive, it will lead to large waste of timber resources. Now, a new blockboard nondestructive testing method was proposed based on X-ray technology. This method can detect the specimen without damaging both the appearance and internal structure. Furthermore, the internal defects of objects can be detected accurately.

Through the X-ray images of blockboard, the positions of defects can be identified easily, and the scales of the defects can also be roughly estimated. We can apply computer technology to extract the information of blockboard defects from the images automatically, and then identify the defect characteristics for the optimal sawing solution such as areas, types, severity et al. However, the accuracy of extracting defect information depends on edge detection methods. There are various edge detection algorithms. First-order derivative operators are used in most of them such as Sobel edge operator [3, 4], Roberts edge operator, and Prewitt edge operator [5]. If a pixel point is on the boundary, its neighborhood will be in the transition zone. Laplacian operator [6] is a second-order derivative operator and is used to detect the boundary at locations of the zeros crossing. Canny operator [7, 8], another gradient operator, is used to determine a class of optimal filters for different types of boundaries. All these operators detect boundary points by gray gradient change of the image pixels in the neighborhood. The disadvantage of these methods is sensitive to noise. And they are not very suitable for extracting the defect boundary of the blockboard images, because the characteristics of defects in blockboard are basically straight lines, not curves.

Compared with these traditional edge detection methods, polygonal approximations using Minimum-Perimeter Polygons (MPP) are more adaptive in the image processing of blockboard boundary detection.

After using the MPPs method, Hough transform is applied to find straight lines on the polygon boundaries. And parameters of these lines can be acquired accurately by the Hough method. The Hough transform is an approach that can be used to find and link line segments in an image.

In this paper, a new mathematical model of the major defects of blockboard is created. Therefore this model combines with Hough transform can describe the boundary of blockboard defects more directly and precisely. The tools of Matlab were applied to implement the experiment in this paper. The results showed that our method can obtain more distinct and more accurate boundary points than the traditional methods of boundary detection. Moreover, the boundary information can be stored in a computer easily and described again quickly.

2. X-ray blockboard nondestructive detection theory

In recent years, X-ray detection method has been widely applied in the field of nondestructive detection. Wood defects image was acquired first by an X-ray image system as the major application way using X-ray. Then, blockboard defects and other internal structure features were detected by subsequent evaluation methods.

2.1 Basic Imaging Principle of X-Ray.

X-ray is a kind of electromagnetic wave which has shorter wavelength than visible lights. It can penetrate a certain thick opaque body of blockboard. After penetrating the body, X-ray will be absorbed partly when it passes through the blockboard. The abilities of absorption are different between different types of areas in the blockboard. Therefore, after the X-ray has intensity as I_0, penetrating the substance has a thickness as T, the intensity of the X-ray is:

$$I = I_0 e^{-\mu T} \tag{1}$$

where, I_0 is the intensity of incident ray, I is the intensity of transmitted ray, T is the thickness of the substance, and μ is the attenuation coefficient. It is the basic attenuation principle of monochromatic narrow X-ray [9]. An attenuation diagram of X-ray imaging law is shown in Figure 1.

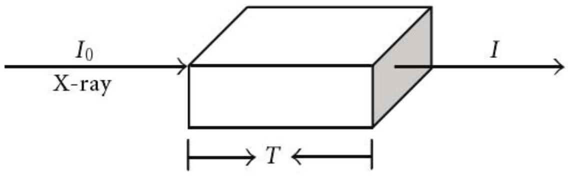

Figure 1. Attenuation diagram of X-ray imaging law.

2.2 X-Ray Blockboard Nondestructive Detection Imaging System.

The diagram of X-ray blockboard nondestructive detection imaging system is shown in Figure 2. The system used in our experiment is capable of producing blockboard defects images. The sample will be placed between the X-ray source and the image intensifier. The X-ray source gives off the X-ray which will be absorbed partly by the material when it penetrates the objects. Absorption quantity is related to the types and the density of blockboard defects. The attenuation of X-ray in the material reduces the energy, reflected in different degrees of activating the same image intensifier screen. The visual information of image intensifier is transmitted to a computer by a CCD camera. The digital signals transmitted by the A/D converter circuit from the simulation signals are deposited in the image storage system for the defects image detection.

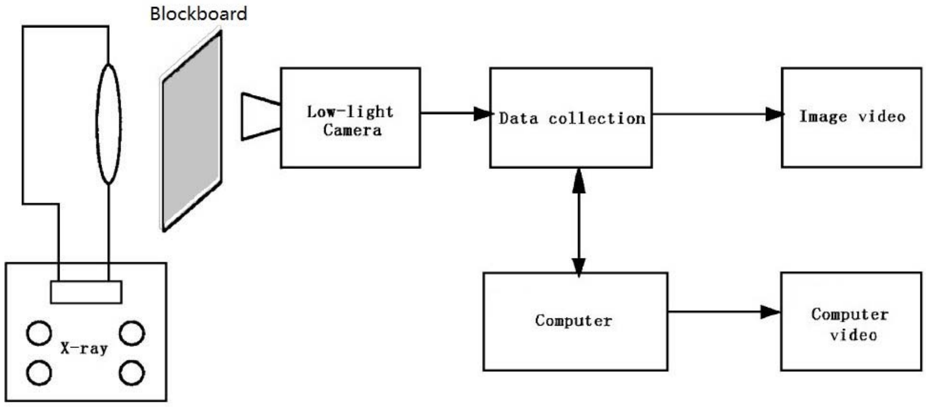

Figure 2. Blockboard x-ray nondestructive system.

3. Hough transform and minimum-perimeter polygons method

Hough transform is one approach that can be used to find and link line segments in an image. Given n points in an image, suppose that we want to find subsets of these points that lie on straight lines.

In principle, the parameter-space lines corresponding to all image points (x_i, y_i) could be plotted, and then image lines could be identified by where large numbers of parameter-space lines intersect. A practical difficulty with this approach, however, is that a (the slope of the line) approaches infinity as the line approaches the vertical direction. One way around this difficulty is to use the normal representation of a line: $x\cos\theta + y\sin\theta = \rho$.

Figure .3 (a) illustrates the geometric interpretation of the parameters ρ and θ . [10]

A horizontal line has $\theta = 0^\circ$, with ρ being equal to the positive x-intercept. Similarly, a vertical line has $\theta = 90^\circ$, with ρ being equal to the positive y intercept, or $\theta = -90^\circ$, with ρ being equal to the negative y intercept. Each sinusoidal curve in Figure .3 (b) represents the family of lines that pass through a particular point (x_i, y_i) . The intersection point (ρ', θ') corresponds to the line that passes through both (x_i, y_i) and (x_j, y_j) .

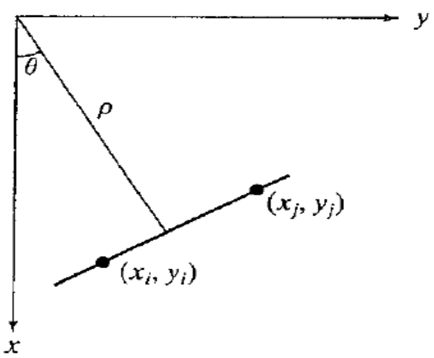

Figure 3 (a). lines in the xy-plane.

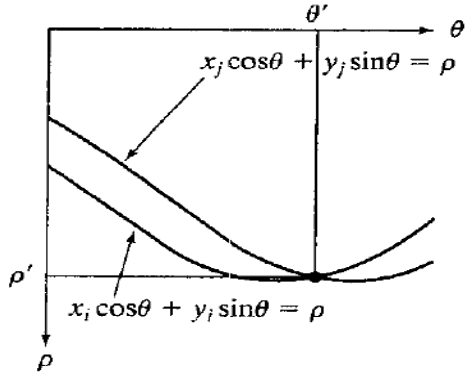

Figure 3 (b) . Sinusoidal curves in the $\rho\theta$-plane

A boundary of blockboard defect can be approximated with arbitrary accuracy by a polygon. Because the major defects in blockboard are usually similar to polygons, especially rectangles. For a closed curve, the approximation is exact when the number of segments in the polygon is equal to the number of points in the boundary so that each pair of adjacent points defines a segment in the polygon.

The goal of polygonal approximation is to capture the main boundary shape with the fewest possible polygonal segments. Several polygonal approximation techniques of modest complexity and processing requirements are well suited for image processing applications.

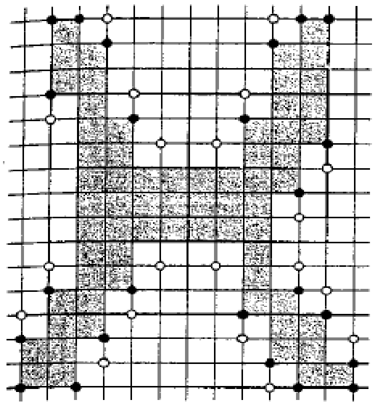

Figure 4 (a)

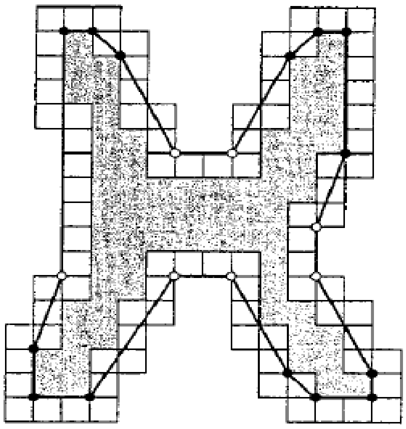

Figure 4 (b)

We form a MPP by using the convex vertices (black dots) and concave vertices (white dots) that we have got. They are shown again in Figure.4 (a), the shaded region and background grids are include for easy reference.

Through omitting some details of the algorithm for finding MPPs, The preceding discussion is summarized in some steps for finding the MPP of a region [5].

Figure.4 (b) shows the final result of MPP after these processing steps.

4. A mathematical model of blockboard defects

Following the Hough transform processing, the straight lines surrounding the blockboard defect boundary are obtained. These lines can be described by the parameters ρ and θ directly; however, we still need another method to use these lines for the description of blockboard defect area. That is why we create this new mathematical model. This model is used to describe the defect areas based on the equation of the straight line. In this paper, we use the normal representation equation of a line. By applying this model, we can describe or record the defect area more easily and more clearly.

As we know, a line: $x\cos\theta + y\sin\theta = \rho$ in the xy-plane (in Figure.5 (a)), we use the inequation: $x\cos\theta + y\sin\theta > \rho$ to illustrate the region under the line (shadow region). In other words, the shadow region can be described by that inequation.

For the sake of brevity, we describe a line by the equation: $f_0 = x\cos\theta + y\sin\theta - \rho$. So the shadow region can be described by another inequation: $f_0 > 0$. If ρ and θ are given, we can also write the $f_0 = f(\rho,\theta) > 0$.

Then, we give a concise definition of $f_0 > 0$ as (f_0+). In a similar way, the symbol: (f_0-) means the region upon that line.

Next, to use Set theory for reference, we define 3 kinds of operator for combining regions. They are:

1. intersection of regions: "•"(can be omitted)
2. union of regions: "+"
3. complement of regions: "–"(not common use)

For instance, in Figure.5 (b), the shadow region S is surrounded by 4 lines: f_1, f_2, f_3, f_4 and the region A is not included in S. Finally, through applying the mathematical model, the region S can be described as:

$$S = (f_1-)(f_4-)(f_3+) + (f_2-)(f_4+)(f_3-) - A$$

Actually, the region A is also surrounded by other 4 lines, as an instance, they are overleaped.

Based on the mathematical model of blockboard defects, we apply the Hough transform to detect the lines in the blockboard defect image. And then, we obtain the data of these lines, there are the parameters ρ and θ.

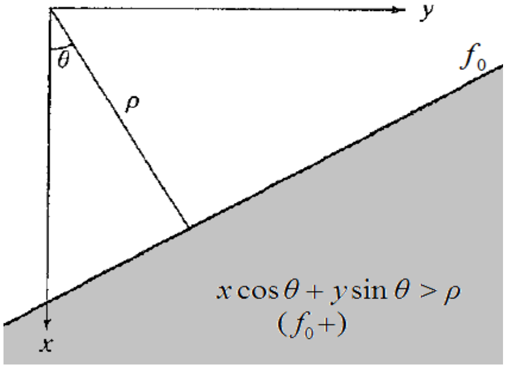

Figure 5 (a). line and shadow region in xy-plane.

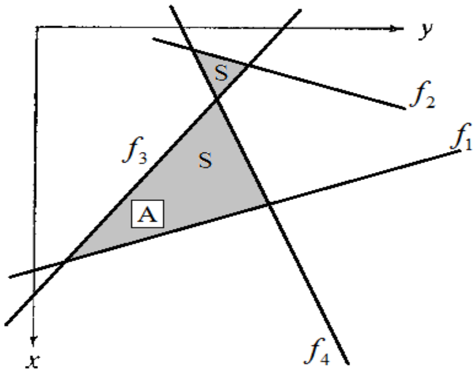

Figure 5 (b). shadow region S in xy-plane.

Though observing some practical applications, we found that these data are usually too many for describing the defect. In other words, most of them are redundancy. For the reason of easier processing and describing, we should decrease the number of data by approximate consolidation method.

To suppose, we have detected n lines, they are $\{f_1, f_2, \cdots, f_n\}$ .For any $f_k = f(\rho_k, \theta_k)$ .The method is summarized in the following steps:

1. Ascending sort $\{\theta_1, \theta_2, \cdots, \theta_n\}$ to $\{\theta_{i_1}, \theta_{i_2}, \cdots, \theta_{i_n}\}$.

2. Define $d_k\theta = \left|\theta_{i_k} - \theta_{i_{k-1}}\right| \quad k = 2,3,\cdots,n$. If $d_k\theta > T_\theta$ (T_θ is threshold set by experimenter) then put it in one certain set. So we get: $\{d_{i_1}\theta, d_{i_2}\theta, \cdots d_{i_s}\theta\}$.

3. Define $H_\theta = \min\{d_{i_1}\theta, d_{i_2}\theta, \cdots d_{i_s}\theta\}$. Similarly, we can get H_ρ .

4. Firstly, put θ_{i_1} into set $A_1\theta$ .Then traverse k form 1 to n. If $d_k\theta < H_\theta$, then put θ_{i_k} into set $A_1\theta$. When $d_k\theta \ge H_\theta$, put θ_{i_k} into a NEW set $A_2\theta$, and then put the next $\theta_{i_{k+1}}$ into the NEW set $A_2\theta$. (Certainly, $d_{k+1}\theta < H_\theta$). Do the same thing until the end, when k=n, we get a series of sets: $\{A_1\theta,\ A_2\theta, \cdots,\ A_p\theta\}$

Similarly, we can get $\{A_1\rho,\ A_2\rho, \cdots,\ A_q\rho\}$.

They are the approximate consolidation groups of the parameters ρ and θ .

For every group of ρ or θ , we can calculate the mean value of the group to instead of the values in the group.

Define $\overline{A_k\theta} = \frac{1}{t}\sum_{\theta_i \in A_k\theta}^{t} \theta_i$.

Accordingly we get values: $\{\overline{A_1\theta}, \overline{A_2\theta}, \cdots, \overline{A_p\theta}\}$ and $\{\overline{A_1\rho}, \overline{A_2\rho}, \cdots, \overline{A_q\rho}\}$.

For instance, a line $f_k = f(\rho_k, \theta_k)$, we find the $\theta_k \in A_s\theta, \rho_k \in A_t\rho$ .So we let $f_k = f(\overline{A_t\rho}, \overline{A_s\theta})$. For another line $f_{k'} = f(\rho_{k'}, \theta_{k'})$, we also find the $\theta_{k'} \in A_s\theta, \rho_{k'} \in A_t\rho$, so $f_k = f_{k'} = f(\overline{A_t \rho}, \overline{A_s \theta})$. By this method, we can achieve the approximate consolidation of defect data.

The last process of blockboard defect description is using the mathematical model of defects that we obtained to draw the defects on the screen again. It can make the defects in blackboard more direct viewing for experimenters.

In this paper, we show a simple example to illuminate the process. Consider we got a model contain 3 straight lines: $S = (f_a -)(f_b +)(f_c +)$,

which: $\begin{cases} f_a = f(\rho_a, \theta_a) = x\cos\theta_a + y\sin\theta_a - \rho_a \\ f_b = f(\rho_b, \theta_b) = \cdots, \quad f_c = f(\rho_c, \theta_c) = \cdots. \end{cases}$

First, we establish an image that has the same size as the original image. The new image is pure black; it means all the pixels gray value in the image is 0. And then, we substitute the coordinate Figures of each pixel point of the image into equations f_a , f_b , and f_c . If the outcome value of these equations satisfy the inequations:

$f_a < 0$, $f_b > 0$, and $f_c > 0$

Then turn the pixel gray value into 255(white). After all of the pixel points of the image are operated, the defect regions are redrawn completely. Then we can show it on the screen.

5. Experimental results

The determination of our boundary detection approach is to describe boundaries of blackboard defects in an image and separate it from normal blackboard structure. X-ray nondestructive system was used to detect the blockboard and then the blockboard X-ray image was obtained. Obviously, the image is fuzzy, low contrast and the gray scale distribution is uneven. Therefore, some image pre-processing methods are necessary, they are gray-scale transformation, histogram equalization, wavelet de-noising, and select an appropriate threshold to segment the image to binary image. It is more conducive to the subsequent image boundary detection.

Figure 6. The area after applying the morphological opening and morphological closing.

Figure.6 is outcome of the defect image processed by MPP approximation method. Figure.7 shows the result that the image after Hough transform process with the peak locations superimposed.

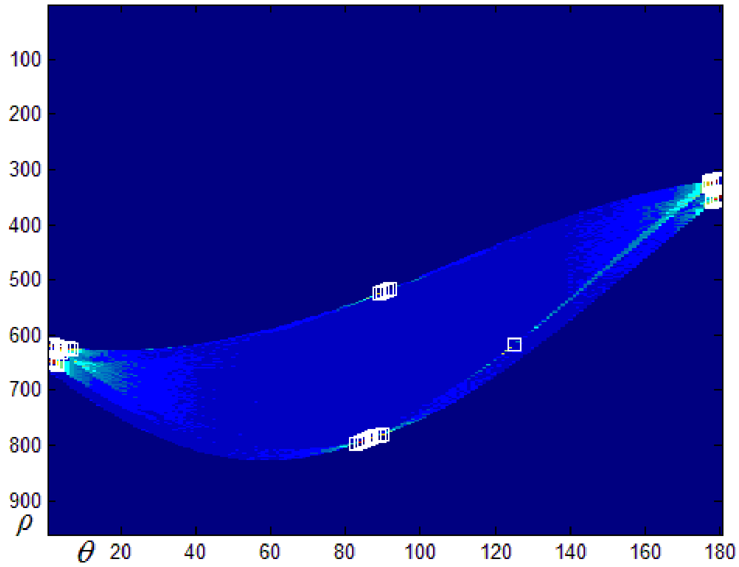

Figure 7. Hough transform with 94 peak locations selected.

We set an appropriate threshold for the Hough transform peaks detection, so we get 94 peaks in all. It means we have found 94 different lines to constitute the boundary. Evidently, the number of the lines is too much, it is neither convenient to describe nor to store in the computer. Table.1 shows the 94 group parameters of lines.

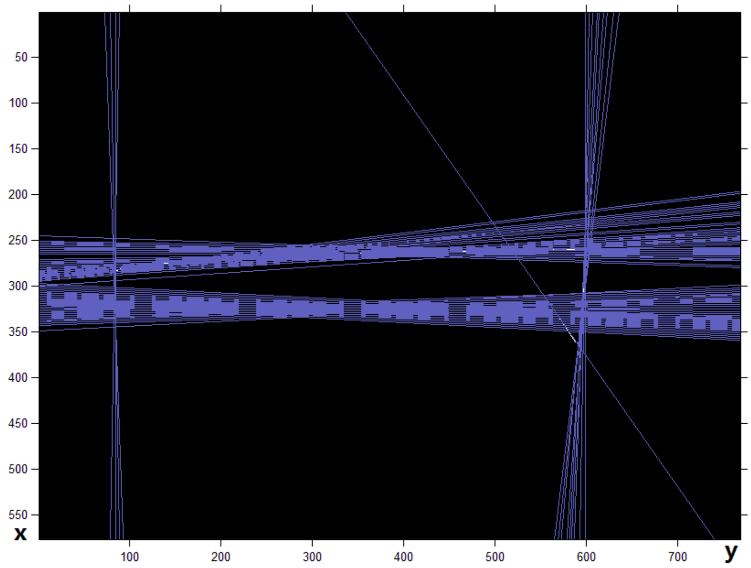

Figure 8. Defect area surrounded by lines.

Figure. 8 shows the resulting image with the detected boundary superimposed as blue lines.

Table 1. 94 group parameters of lines.

No.	1	2	3	…	92	93	94
ρ	318	319	320	…	791	794	796
θ	180°	179°	178°	…	85°	84°	83°

Then, we decrease the number of data by using approximate consolidation method. After analyzing these data, we decide to set the threshold $T_\rho = T_\theta$=10. Based on the thresholds, we finally obtain 6 group parameters of lines in Table 2.

Table 2. 6 group parameters of lines.

No.	**1**	**2**	**3**	**4**	**5**	**6**
$\overline{A\rho}$	623.0	521.3	787.7	618.0	318.5	352.5
$\overline{A\theta}$	3.8°	90.5°	86.6°	125.0°	180.0°	179.3°

The ultimate 6 group parameters of lines are illustrated in Figure.9.

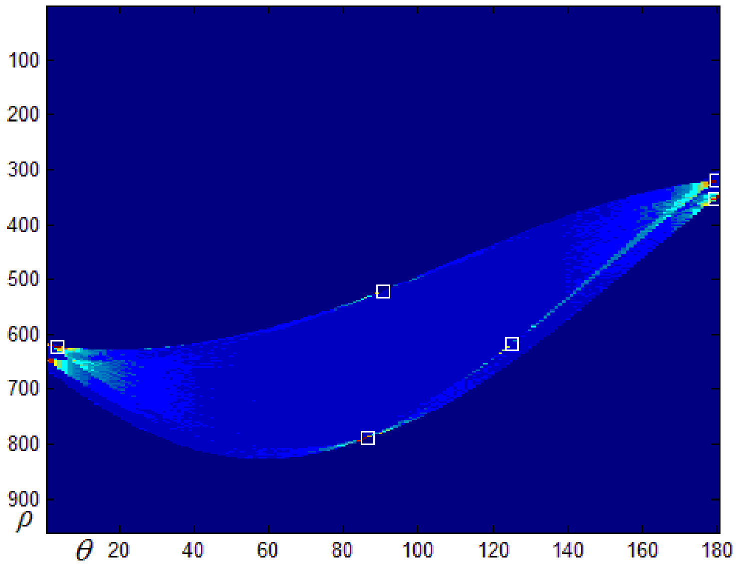

Figure 9. Hough transform with 6 peak locations selected.

To refer to the mathematical model we created, we can write down 6 equations of these lines based on their parameters. They are:

$$\begin{cases} f_1 = f(623.0, 3.8°) = x\cos(3.8°) + y\sin(3.8°) - 623.0 \\ f_2 = f(521.3, 90.5°) = x\cos(90.5°) + y\sin(90.5°) - 521.3 \\ \vdots \\ f_6 = f(352.5, 179.3°) = x\cos(179.3°) + y\sin(179.3°) - 352.5 \end{cases}$$

Then, we can describe the defect area S by a series of symbols that we defined as inequations.

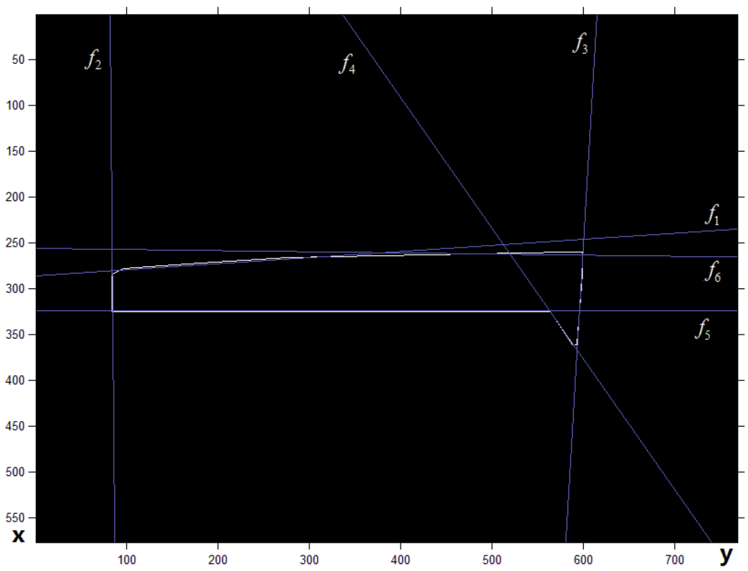

Figure 10. Defect area surrounded by least 6 lines.

$$S = (f_1+)(f_2+)(f_4-)(f_5+)(f_6-) + (f_3-)(f_4+)(f_6-)$$

And the lines are shown in Figure.10.

Thus, the goal of description is accomplished. We obtain a mathematical model of the blockboard defect image. The model is so simple and clear, it is not only easy to store in the computer but also convenience to observe.

As the last step, we redraw the region S by computer graphics algorithm. We can see defect on the screen again by using the defect mathematic model. It makes the defect in blackboard more direct viewing for experimenters. Figure.11 shows the result. The redrawing defect region may have little difference to the original area, because the inevitable error during calculating and processing system.

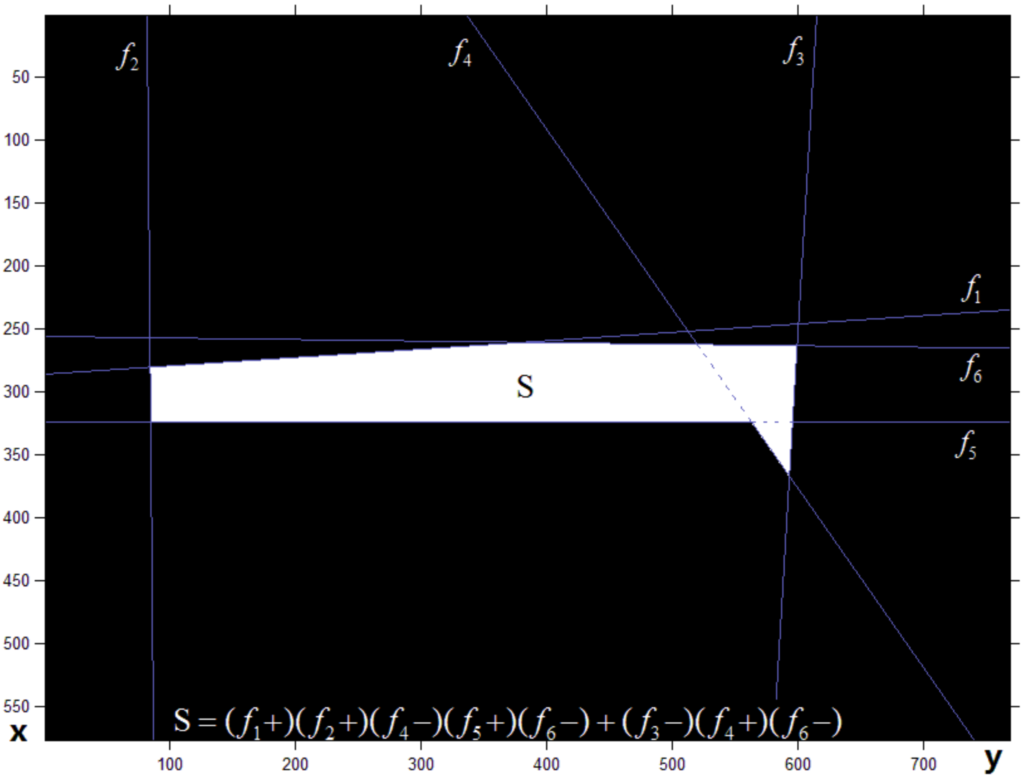

Figure 11. The redrawing defect region.

6. Conclusions

An X-ray imaging technique was implemented in blackboard nondestructive detection. Through blockboard images acquired by this technique, the blockboard defects information was visual. The detected defects can be further processed for description of defects locations and other defects characteristics. Then a new method for the blockboard image processing and analysis was proposed in this paper. It is mainly based on mathematical morphology, MPPs method, Hough transform, a new mathematical model and other computer graphics technique.

Hough transform was applied in the boundary detection of blockboard defect images. We designed a novel mathematical model for the result of Hough transform to detect the defect boundary. The experiment received a good result. As shown in the Figure.10–11, the method based on MPPs and Hough transform in detecting boundary of blackboard defects was effective. We can get a more accuracy and vivid description of blackboard defect boundary[13-14]. Thus, a promising method of blackboard boundary detection and description is provided. All the courses of image processing and data calculating in this paper were implemented using the Matlab software. The tools of Matlab are well done in the study of images.

After all the processing steps, the blockboard internal defects have been well identified. Simultaneously, the exterior and inner structure of the blockboard is unimpaired.

7. Acknowledgments

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