Improved Multi-scale and Structuring Element Morphological Detection in the Log CT Image

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***Abstract*—Mathematical morphology is a new subject established based on rigorous mathematical theories. In the basis of set theory, mathematical morphology is used for image processing, analysing and comprehending. It is a powerful tool in the geometric morphological analysis and description. It has become a new theory in the digital image processing field. Moreover, it has deep influence on the image processing theory and technology. Edge is the basic feature in the medical image. It involves a lot of valuable target information of boundary, which is used for image processing, target identifying and image filtering. The mathematical morphology is an effective theory used to locate the image edge. In the paper multi-scale and structuring element in mathematical morphology is used to detect log CT image with defect, and provides a new method in log defect recognition.**

***Keywords*—Mathematical morphology; Multi-scale and structuring element; Edge detection; Computed tomography; Image processing.**

I. INTRODUCTION

There have been a number of log nondestructive testing methods studied and tested in laboratory experiments in the recent years. During practice and application five common nondestructive testing methods were formed, they were ultrasonic testing, radiographic testing, X-ray computed tomography (CT) testing, nuclear magnetic resonance (NMR). Meanwhile acoustic emission testing, laser testing, infrared testing and eddy current testing etc. were used in practice in specific conditions.

In all testing methods radiographic testing is one of the most common methods and X-ray is applied frequently. In the paper X-ray computed tomography (CT) was applied for log nondestructive testing. CT is a branch of X-ray nondestructive testing. Compared with conventional radiographic testing CT has many advantages: first in conventional radiography the log is placed between an X-ray source and X-ray sensitive film, the image of log with defects formed represents the distribution and degree of integral attenuation of the X-ray in their passage through the log [1]. Thus all structures in the path of the X-ray beam are superimposed in the image and cannot be distinguished. Therefore conventional radiographs provide only limited information about the detected log. Second conventional radiographs have relatively low contrast resolution (ability to discern small density differences). It can only discern the defects with large density distinction such as knot and serious decay. But using images produced by CT overcomes the problems caused by the superimposition of structures in conventional radiographs, and provides detailed defect information. It has a better contrast resolution [2]. CT is able to discriminate physical density differences as small as 0.5 percent while a 10 percent difference in physical density is needed for visual detection with conventional radiographs [3]. Moreover the CT image is shown on a computer monitor, the fact that the defects can be visualized directly, cannot be realized by using conventional radiographs [4].

After acquiring the log image, image edge detection is a key stage in the detection of defects in log images [5]. In the paper mathematical morphology is used to detect the edge of log image.

The word “morphology” commonly denotes a branch of biology that deals with the form and structure of animals and plants. The same word used here in the context of “mathematical morphology” is a tool for extracting image components that are useful in the representation and description of region shape, such as boundaries, skeletons, and the convex hull [6]. The language of mathematical morphology is set theory. As such, morphology offers a unified and powerful approach to numerous image processing problems. Mathematical morphology is a mathematic tool to analyze the image based on the structuring element. Its basic concept is to use specific morphological structuring element to measure and extract corresponding shape in the purpose of image analysis and identification.

II. BASIC THEORY OF MATHEMATICAL MORPHOLOGY

A. Dilation and Erosion

Dilation and erosion operations are fundamental to morphological processing. In fact, many of the morphological algorithms are based on these two primitive operations.

1) Dilation

With A and B as sets in $\mathbf{Z}^2$, the dilation of A by B, denoted $A \oplus B$, is defined as

$$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \phi\}. \qquad (1)$$

Equation (1) is based on obtaining the reflection of B about its origin and shifting this reflection by z. The dilation of A by B then is the set of all displacements, z, such that $\hat{B}$ and A overlap by at least one element. Based on this interpretation, equation (1) may be rewritten as

$$A \oplus B = \{z \mid [(\hat{B})_z \cap A] \subseteq A\}. \quad (2)$$

Set B is commonly referred to as the structuring element in dilation, as well as below morphological operations.

2) Erosion

For sets A and B in the $\boldsymbol{Z}^2$ the erosion of A by B, denoted $A \otimes B$, is defined as

$$A \otimes B = \{z \mid (B)_z \subseteq A\}. \quad (3)$$

In a word, the equation (3) indicates that the erosion of A by B is the set of all points z such that B, translated by z, is contained in A.

Dilation and erosion are duals of each other with respect to set complementation and reflection. That is,

$$(A \otimes B)^c = A^c \oplus \hat{B}. \quad (4)$$

B. Opening and Closing

As can be seen from the equation (1) and (3), dilation expands an image and erosion shrinks it. Two other important morphological operations are introduced below: opening and closing. Opening generally smoothes the contour of an object, breaks narrow isthmuses, and eliminates thin protrusion. Closing also tends to smooth sections of contours but, as opposed to opening, it generally fuses narrow breaks and long thin gulfs, eliminates small holes, and fills gaps in the contour.

The opening of set A by structuring element B, denoted $A \circ B$, is defined as

$$A \circ B = (A \otimes B) \oplus B. \quad (5)$$

Thus, the opening by B is the erosion of A by B, followed by dilation of the result by B.

Similarly, the closing of set A by structuring element B, denoted $A \cdot B$, is defined as

$$A \cdot B = (A \oplus B) \otimes B. \quad (6)$$

Which, in words, says that the closing of by B is simply the dilation of A by B, followed by the erosion of the result by B.

III. Morphology Theory in Gray-Scale Image

Use the basic operations of dilation, erosion, opening and closing to develop several basic gray-scale morphological algorithms, especially, for edge extraction via the morphological operations. Throughout the discussions that follow, digital image functions of the form $f(x, y)$ and $b(x, y)$ are dealt with, where $f(x, y)$ is the input image and $b(x, y)$ is a structuring element, itself a sub-image function. The assumption is that these functions are discrete. That is (x, y) are integers, f and b are functions that assign a gray-level value which is a real number from the set of real numbers.

A. Gray-Scale Dilation

Gray-scale dilation of f by b, denoted $f \oplus b$, is defined as

$$(f \oplus b)(s,t) = \max\{f(s-x, t-y) + b(x, y) \mid (s-x), (t-y) \in D_f; (x, y) \in D_b\}. \quad (7)$$

Where D_f and D_b are the domains of f and b, respectively. f and b are functions rather than sets.

The condition that $(s-x)$ and $(t-y)$ have to be in the domain of f, and x and y have to be in the domain of b, is analogous to the condition in the binary definition of dilation, where the two sets have to overlap by at least one element.

B. Gray-scale Erosion

Gary-scale erosion, denoted $f \otimes b$, is defined as

$$(f \otimes b)(s,t) = \min\{f(s+x, t+y) - b(x, y) \mid (s+x), (t+y) \in D_f; (x, y) \in D_b\}. \quad (8)$$

Where D_f and D_b are the domains of f and b, respectively. The condition that $(s+x)$ and $(t+y)$ have to be in the domain of f, and x and y have to be in the domain of b, is analogous to the condition in the binary definition of erosion, where the structuring element has to be completely contained by the set being eroded.

C. Gray-scale Opening and Closing

The expressions for opening closing of gray-scale images have the same form as their binary counterparts. The opening of image f by sub-image (structuring element) b, denoted $f \circ b$, is

$$f \circ b = (f \otimes b) \oplus b. \quad (9)$$

Opening is the erosion of f by b, followed by a dilation of the result by b.

Similarly, the closing of f by b, denoted $f \cdot b$, is

$$f \cdot b = (f \oplus b) \otimes b. \quad (10)$$

The opening and closing for gray-scale images are duals with respect to complementation and reflection. That is,

$$(f \cdot b)^c = f^c \circ \hat{b}. \quad (11)$$

Because $f^c = -f(x, y)$, equation (11) can be written also as

$$-(f\cdot b)^c = (-f \circ \hat{b}). \quad (12)$$

Opening and closing of images have a simple geometric interpretation. Suppose that we view an image function $f(x,y)$ in 3-D perspective, with x and y axes being the usual spatial coordinates and the third axis being gray-level values. In this representation, the image appears as a discrete surface whose value at any point (x,y) is the value of f at those coordinates. Suppose that we open f by a spherical structuring element, b, viewing this element as a "rolling ball". Then the mechanics of opening f by b may be interpreted geometrically as the process of pushing the ball against the underside of the surface, while at the same time rolling it so that the entire underside of the surface is traversed. The opening, $f\circ b$, then is the surface of the highest points reached by any part of the sphere as it slides over the entire undersurface of f.

D. Morphological Gradient

In addition to the operations discussed above in connection with the removal of small dark and bright artifacts, dilation and erosion often are used to compute the morphological gradient of an image, denoted g:

$$g = (f \oplus b) - (f \otimes b). \quad (13)$$

As opposed to gradients obtained using the conventional method in image processing, morphological gradients obtained using symmetrical structuring elements tend to depend less on edge directionality.

E. Top-hat Transformation

The so-called morphological top-hat transformation of an image, denoted h, is defined as

$$h = f - (f \circ b). \quad (14)$$

Where as before, f is the input image and b is the structuring element function.

IV. Multi-Scale and Structuring Mathematical Morphology

In the study of edge detection, there is a conclusion that if the morphological edge operators have powerful ability to eliminate noise, the structuring element scale of morphological operator is larger than or equal to the scale of noise point, however, in the real image, large scale structuring element has better effect in reducing noise, and it is benefit for detecting entire contour. But at the same time some small detailed information is eliminated as noise. In the contrast, if small structuring element is used, the noise point can not be reduced effectively. However, it can not omit small detailed information as noise. That is, small scale element can well keep detailed information in the image.

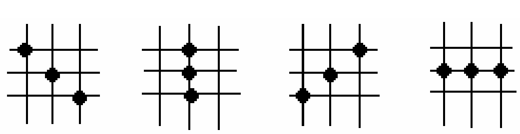

Figure 1. 3×3 structuring elements

In order to solve the problems above, multi-scale and structuring element morphological theory was established. More ideal edge can be acquired by combining different edge results deriving from the method of multi-scale and structuring element.

It is paradox between edge positioning and noise smoothing in conventional morphological edge detections, edge can not be well acquired. Therefore it is necessary to take shape and scale into account to select multi-structuring element, then fix the shape sequence and scale sequence of structuring element separately.

Let B_m be a structuring element, $B_m = \{B_1, B_2, B_3, \cdots, B_n\}$, where ***m*** a scale sequence, ***n*** is a shape sequence. That is, make ***m*** kinds of scale structuring elements, each scale element involves ***n*** kinds of shape structuring element:

$$B_1 = \{B_{11}, B_{12}, B_{13}, \cdots, B_{1n}\},$$
$$B_2 = \{B_{21}, B_{22}, B_{23}, \cdots, B_{2n}\},$$
$$B_3 = \{B_{31}, B_{32}, B_{33}, \cdots, B_{3n}\},$$
$$\vdots$$
$$B_m = \{B_{m1}, B_{m2}, B_{m3}, \cdots, B_{mn}\}.$$

Follows are four kinds of 3×3 structuring elements, the shape sequences is shown in Fig. 1. Different scale structuring element can be established based on Fig. 1, such as Fig. 2.

B_1= [(-1, 1), (0, 0), (1,-1)];
B_2= [(0, 1), (0, 0), (0,-1)];
B_3= [(-1,-1), (0, 0), (1, 1)];
B_4= [(0, 0), (1, 0), (2, 0)].

Select different shape structuring elements in a fixed scale B_{mn} (m is a fixed value), use it to process a gray-scale image $f(x,y)$ with erosion algorithm. Then, calculate the times of different shape structuring elements filled into a gray-scale image $f(x, y)$, denoted $\beta_i (i = 1,2,3,\cdots,n)$. Next calculate the weight of different structuring elements,

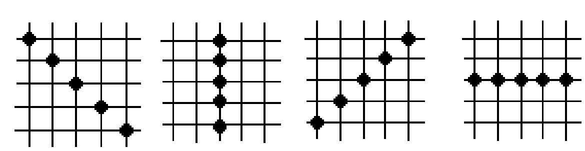

Figure 2. Extended structuring elements

denoted $\alpha_i\,(i=1,2,3,\cdots,n)$.

$$\alpha_i = \frac{\beta_i}{\beta_1+\beta_2+\cdots+\beta_n}. \tag{15}$$

Detect the edge of with above structuring elements, then sum all the edge information F_i, F is the entire edge of image $f(x,y)$, that is,

$$F = \sum_{i=1}^{n}\alpha_i F_i . \tag{16}$$

V. EXPERIMENT AND ANALYSIS OF DECAYED LOG CT IMAGE

The image used in experiment is a log CT image with decay. Compared with other nondestructive testing, computed tomography (CT) has advantages such as higher penetrability, higher resolution, faster testing speed and visible testing result and so on. Therefore it provides a new method for log nondestructive testing.

Fig.3 and Fig.4 are original decayed log CT image and image after equalization. Fig.5, Fig.6, Fig.7 and Fig.8 are processed image by using conventional Robert operator, Sobel operator, Prewitt operator and Log operator edge detection with automatic threshold.

Fig.9 and Fig.10 are the edge detection images by using opening and closing operation. Fig.11 is the edge detection image by using morphological gradient operation. Fig.12 is the edge detection image by using morphological multi-scale and structuring element operation. As can be seen in Fig 5 to Fig.8, the images after conventional edge detection operators can not well display detailed edge information in decayed log CT image. Robert, Sobel and Prewitt operator can not detect intact edge information, and Log operator can not gain continuous edge. Fig.9 to Fig.11 have better continuous edge than Fig.5 to Fig.8. However, they are not indicative of intact edge information. But as can be seen in the Fig.12, it detects more detailed edge, and it can reflect accurate defect position.

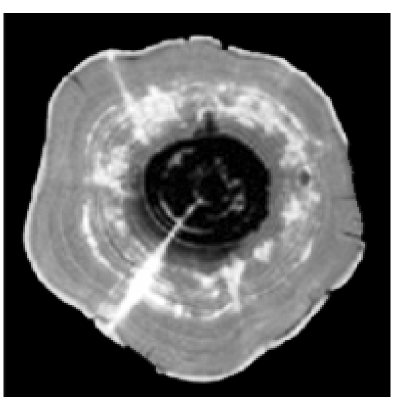

Figure 3. Decayed log CT image.

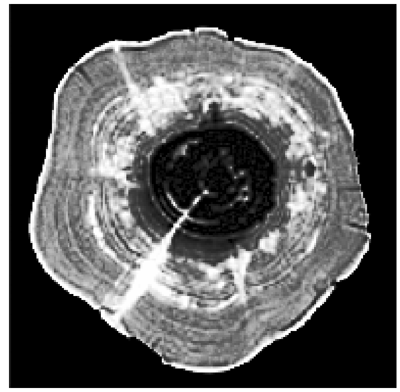

Figure 4. Image after equalization

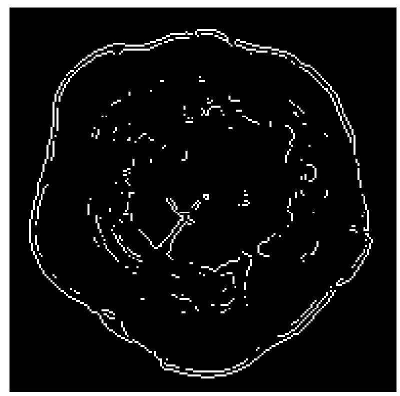

Figure 5. Image after Robert operator processing

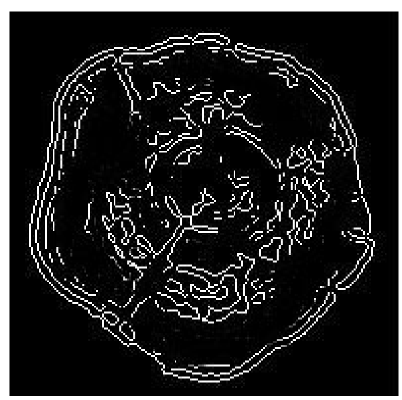

Figure6. Image after Sobel operator processing.

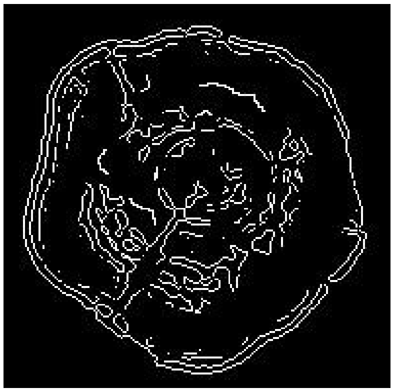

Figure 7. Image after Prewitt operator processing

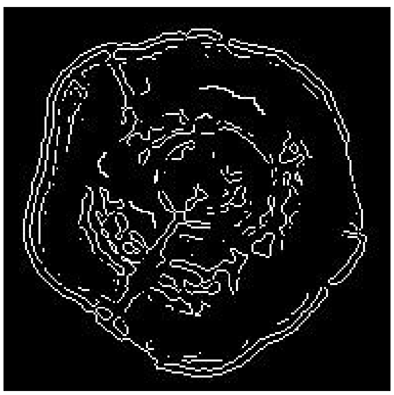

Figure 8. Image after Prewitt operator processing.

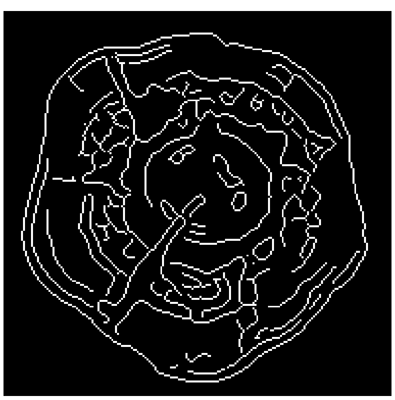

Figure 9. Image after opening operation

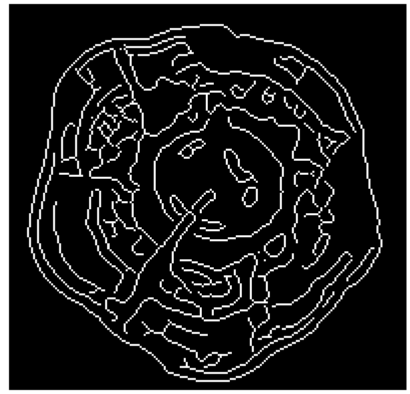

Figure 10. Image after closing operation

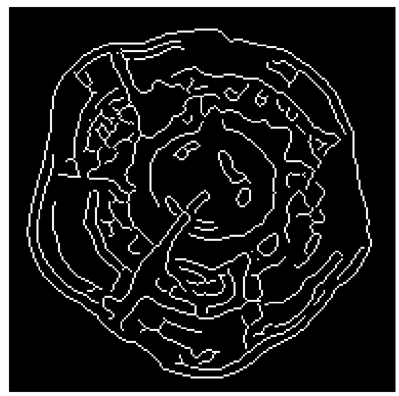

Figure 11. Image after morphological gradient operation

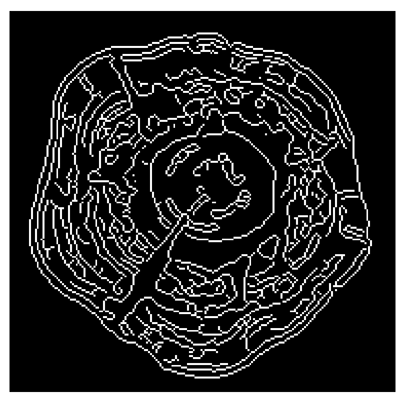

Figure 12. Image after multi-scale and structuring element operation

VI. Conclusion

X-ray computed tomography (CT) was applied to the detection of internal defects in the logs for the purpose of obtaining prior information that can be used to arrive at better log sawing decision. Compared with other non-destructive testings computed tomography has advantages such as higher penetrability, higher resolution, fast testing speed and visible testing result etc. Mathematical morphology theory was applied in the edge detection of decayed log CT image. It is a powerful tool in the geometric morphological analysis and description. And multi-scale and structuring element morphological method was developed in the paper. As shown in the experimental result, the method based on multi-scale and structuring element morphological theory in detecting decayed log CT image was effective. Moreover, edge detecting is fast to realize and easy to operate by multi-scale and structuring element morphological method. Therefore, a new method based on mathematical morphology in detecting log CT image is provided.

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References

[1] E. Sarigul, A. L. Abbott, D. L. Schmoldt, "Rule-driven defect detection in CT images of hardwood logs." Computers and Electronics in Agriculture. vol. 41, pp. 101-119, 2003.

[2] A. Rinnhofer, A. Petutschnigg, J. P. "Andreu, Internal log scanning for optimizing breakdown." Computers and Electronics in Agriculture. vol. 41, pp. 7-21. 2003.

[3] S. M. Bhandarkar, X. Lou, R. Daniels, E. W. Tollner, "Detection of cracks in computer tomography images of logs." Pattern Recognition Letters. vol. 26, 2282-2294, 2005.

[4] J. W. Funck, Y. Zhong, D. A. Butler, C. C. Brunner, J. B. Forrer, Image segmentation algorithms applied to wood defection. Computers and Electronics in Agriculture. vol. 43, pp. 157-179, 2003.

[5] S. Thawornwong, L. G. Occena, D. L. Schmoldt, "Lumber value differences from reduced CT spatial resolution and simulated log sawing." Computers and electronics in agriculture. vol. 41, pp. 23-43, 2003.

[6] Rafael C. Gonzalez, Digital Image Processing Second Edition. Prentice Hall Inc. 2003.