Omnidirectional Structure Element of Mathematical Morphology Applied to Wood Computed Tomography Testing

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***Abstract*—With the increase of wood demand, wood nondestructive testing technology becomes more and more important. Many nondestructive technologies are established on the basis of multi-subject and high technology. Wood nondestructive testing technology is a comprehensive subject. Recently it has achieved fast development. X-ray computed tomography (CT) scanning technology has been applied to the detection of internal defects in the logs for the purpose of obtaining prior information, which can be used to arrive at better log sawing decision. In addition to the recognition of wood internal defects, computed tomography (CT) technology can be applied to wood nondestructive testing. Math morphologic is a new science based on strict math theory basis, taking set theory as basis, analysing and understanding the digital image, which is also a good tool of geometry morphologic analysis and description; having be a new theory and method under digital image management area, producing great influence on digital image management theory and technology. An approach of image edge detection based on morphology of omnidirectional and multi-scale structuring element is constructed by weighting method of morphological operation.**

***Keywords*—Computed tomography; Wood nondestructive testing; mathematical morphology; Omnidirectional structure Element; image processing**

I. INTRODUCTION

With the increase of wood demand, wood nondestructive testing technology becomes more and more important. Many nondestructive technologies are established on the basis of multi-subject and high technology. These years many testing methods have been applied and tested in the lab, they are radiographic testing, microwave testing, optical testing, ultrasonic testing, mechanic testing, acoustic emission, nuclear magnetic resonance (NMR) testing. In all testing methods, radiographic testing is one of the most frequently used testing methods. X-ray as radioactive source is applied frequently in the radiography testing methods.

Conventional medical CT scanners are designed for human-sized objects and densities and therefore use non-lethal X-ray energies, and thus cannot resolve slices less than 1–2 mm thick [1]. Compared with conventional radiographic testing CT has many advantages: first in conventional radiography the wood is placed between an X-ray source and X-ray sensitive film, the image of wood with defects formed represents the distribution and degree of integral attenuation of the X-ray in their passage through the wood [2]. 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 wood. In a conventional two dimensional shadow radiograph the depth information is lost, but when X-ray transmission information is obtained from a multitude of radiographic images scanned at different angles, a complete three-dimensional image can be obtained [3]. Second conventional radiographs have relatively low contrast resolution (ability to resolve small density differences). It can only resolve 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 [4]. 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 [5]. 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 [6].

X-ray computed tomography (CT), which uses x-ray as radioactive source, is a branch of radiographic testing method. Computed tomography is being increasingly employed for automated detection and localization of internal defects in logs prior to their scanning [5, 7]. In all methods, CT has received the greatest profits in industrial log inspection because of its internal imaging capacity, high penetrating power, efficiency and resolution [2, 5, 7]. The research described in this paper refers to CT-based image and data.

The edge of image embodies a great deal of information, is the important attribute to obtain image features during image identification. Edge detection could draw the outline of target object to reach object identification. Essentially, image edge is the discontinuous reflection of part of image; it indicates one ending of one field and starting of another field. Effect of edge detection influenced directly accomplishment of after work.

Mathematical morphology is based on set theory algorithm, characteristics of non-linearity, and it not only presents image set features to well detect image edge, but also satisfies real-time request. Moreover, based on edge detection, by changing

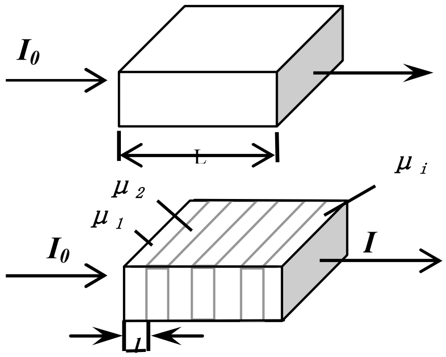


Figure 1. Attenuation diagram of Beer law

the shape and size of structure element image edge can be extracted, as well as overcoming the influence of noise.

II. Basic Imaging Principle of Computed Tomography

A. Basic Imaging Principle of Computed Tomography

Different energy source used by computed tomography as radiation source has different imaging principle. Take X-ray for example，after irradiating the object, a beam of single X-ray attenuation complies with Beer law. Attenuation diagram of Beer law is shown in Fig. 1.

When ray imposes the object, ray intensity is:

$$I = I_0 \exp(-\mu l) \tag{1}$$

When the object is heterogeneous:

$$I = I_0 \exp[-l(\mu_1 + \mu_2 + \cdots + \mu_i)] \tag{2}$$

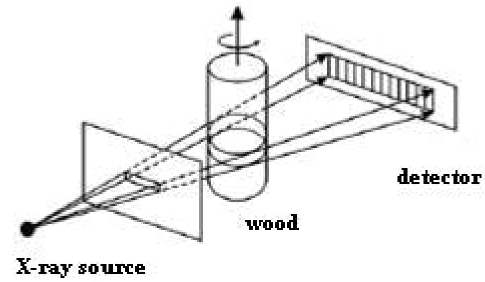
where I_0 is the initial intensity of X-ray;

I is the ray intensity after attenuation;

μ_i is ray attenuation parameter of different object;

l is the length of each detected object.

B. Structure of CT Scanning System



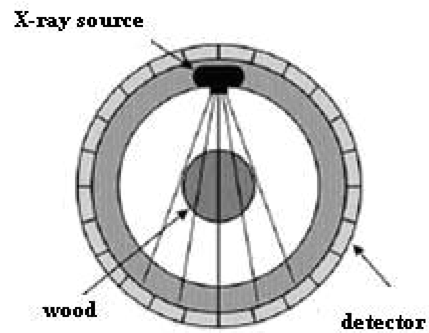


Figure 3. Diagram of mechanic system

X-ray CT system is composed of five parts as shown in Figure 2: radiation source, mechanic scanning system, data acquisition system, display and storing system.

CT mainly uses three radiation sources: low-energy X-ray source, γ-ray source and high-energy X-ray source. The function of mechanic scanning system is to rotate and translate the detected object while scanning and to adjust the distance and relative position between radiation source, object and detector. Diagram of mechanic system is shown in Figure 3.

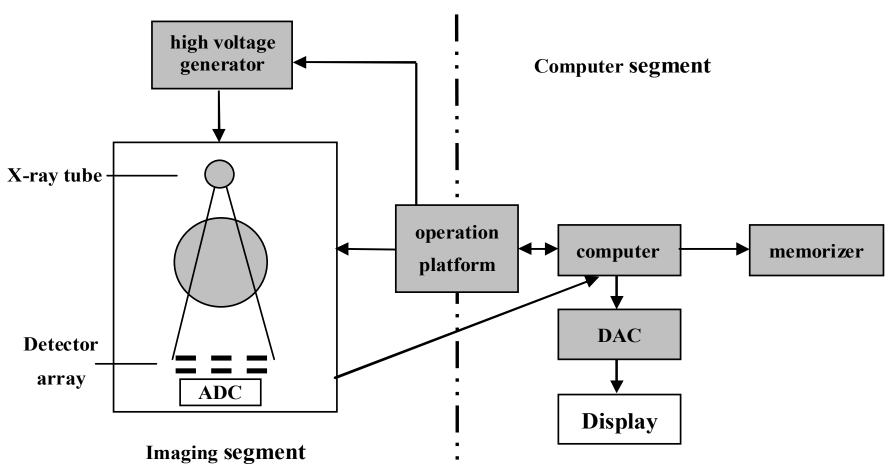


Figure 2. Structure of CT scanning system.

Main performance indexes of mechanic scanning and accuracy.

The central exponent of data acquisition system is the detector. It receives ray signal, and forms original data of CT system, its performance affects the CT image quality directly.

By specific software computer system can complete processing, image reconstructing, image displaying and storing. Its main function is processing and controlling.

III. BASIC THEORY OF MATHEMATICAL MORPHOLOGY

Math morphologic is a new science based on strict math theory basis, taking set theory as basis, analysing and understanding the digital image, which is also a good tool of geometry morphologic analysis and description; having be a new theory and method under digital image management area, producing great influence on digital image management theory and technology. In digital image, edge contains a great deal of valuable information, and it can reflect character of object, so it has an important intention about image analysis and image filtering.

Math morphology is the tool for analysing the image based on structuring element. Basic ideas are to measure and extract corresponding shape using structuring element which have specific figuration to reach the image of analysing and identification.

There are four basic algorithms in math morphology: dilation, erosion, opening and closing algorithm, they are of own characteristic in binary image and grey-scale image. These basic algorithms also induce and combine various math morphological algorithms.

An edge is a boundary between two region of relatively uniform intensity indicated by a strong gradient or a discontinuity function.

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 $\boldsymbol{Z}^2$, the dilation of A by B, denoted $A \oplus B$, is defined as

$$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \phi\}. \quad (3)$$

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

$$A \oplus B = \{z \mid [(\hat{B})_z \cap A] \subseteq A\}. \quad (4)$$

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

$$A \otimes B = \{z \mid (B)_z \subseteq A\}. \quad (5)$$

In a word, the equation (5) 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,

$$(A \otimes B)^c = A^c \oplus \hat{B}. \quad (6)$$

B. Opening and Closing

As can be seen from the equation (3) and (5), 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

$$A \circ B = (A \otimes B) \oplus B. \quad (7)$$

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

$$A \cdot B = (A \oplus B) \otimes B. \quad (8)$$

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.

IV. 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

$$\begin{aligned}&(f \oplus b)(s,t) = \\ &\max\{f(s-x, t-y) + b(x, y) \mid (s-x), \\ &(t-y) \in D_f; (x, y) \in D_b\}\end{aligned}. \quad (9)$$

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

$$\begin{aligned}&(f \otimes b)(s,t) = \\ &\min\{f(s+x,t+y)-b(x,y)|(s+x), \\ &(t+y)\in D_f;(x,y)\in D_b\}\end{aligned} \quad (10)$$

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

$$f \circ b = (f \otimes b) \oplus b . \quad (11)$$

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

$$f \cdot b = (f \oplus b) \otimes b . \quad (112)$$

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

$$(f \cdot b)^c = f^c \circ \hat{b} . \quad (13)$$

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

$$-(f \cdot b)^c = (-f \circ \hat{b}) . \quad (14)$$

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.

V. EDGE DETECTION BASED ON OMNIDIRECTIONAL OF MORPHOLOGY

A. Selection of Omni Directional Element

Omnidirectional and multi-scale element is one way to plot out square filter windows; it almost covers all line trends within square windows. In $(2N+1)\times(2N+1)$ window, its omnidirectional structure element is:

$$W_f = \{f(n_1 + f_{1,} n_2 + f_2)/\theta_f = f\alpha \,|\, -N \le f_{1,} f_2 \le N\}$$

$$\forall f = 0,1,\cdots 4N-1 \qquad and\ \alpha = 180^\circ / 4N$$

In which α is the angel of rotation. For example: when N=2, omnidirectional structure elements in 5×5 window shown as Fig. 4 represents composition structure element.

$$\alpha = 0^\circ, 22.5^\circ, 45^\circ, \cdots 135^\circ, 157.5^\circ$$

B. Selection of Multi-Scale Structure Element

Assume that one structuring element sequence $\{g_i|i=1,2,\cdots,n\}$ have same shape in common and size increased followed by the accretion of i, then defining sequence $\{g_i\}$ is multi-scale sequence. If the size of structure element scale could be adjusted reasonably, take different image feature in various scales. It can overcome noise and get

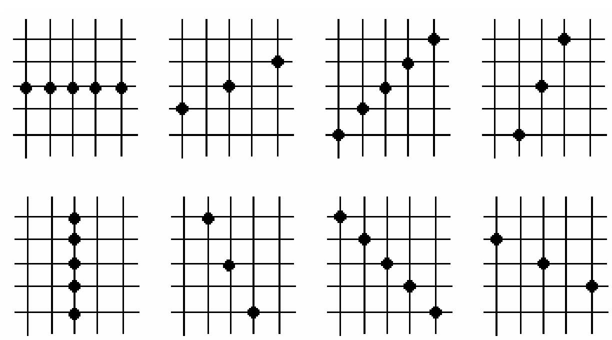


Figure 4. Omni directional structure element

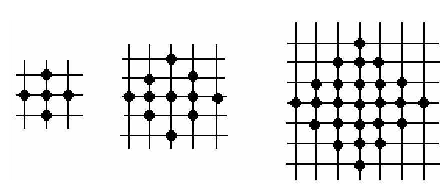


Figure 5. Multi-scale structure element

satisfied edge information, effectively. In general, select basic structure element g_i (3×3 cross type), the size of g_i increased by the accretion of i . The images in Fig. 5 are $(2i+1)\times(2i+1)$ pixels.

C. Edge Detection Algorithm of Omnidirectional Multi-scale Structuring Element

According to the introduction above, the procedure of algorithm of omnidirectional multi-scale structuring element is as follows:

(1) Select the suitable omnidirectional and multi-scale morphological structure elements according to the shape of image edge.

(2) By using omnidirectional and multi-scale structuring element, as well as equation (15) below, edge detection operators separately detect edge information of original image from different direction, different scale.

Based on dilation and erosion, an edge detection gradient operator is:

$$E_d = f(x,y)\oplus g(x,y) - f(x,y)\otimes g(x,y) \qquad (15)$$

(3) Use weighted algorithm of edge detection in image:

$$H(x,y)=\sum_{n=M}^{M}\omega_\tau B_n(x,y). \qquad (16)$$

Where $H(x,y)$ is the new and complex edge image, ω_τ is weight under various directional and scale, [m，M] is scope of n .

(4) Specifically select a method of weight ω_τ

Select a method of the same size and different direction for structure element ω_τ

Select structuring element set B_n which is with fixed size and different direction, n denotes direction sequence. Then use the eroding algorithm for grey- scale image.

Next calculate the times filled in grey-scale $f(x,y)$ at different direction, shown by $\beta_i (i=1,2,3...n)$

Calculate structuring element weight in various directions and the same structure element, shown by $\omega_\tau (i=1,2,3...n)$.

$$\omega_\tau = \frac{\beta_i}{\beta_1+\beta_2+...+\beta_n} \qquad (17)$$

Select method of the same direction and different size for structure element ω_τ . Calculate image variance at different size $\sigma_n^2 = |f - f_n|^2$, and weighted value $\omega_\tau = \sigma_{M-n}^2 / \sum_{n=M}^{M}\sigma_n^2$ depends on proportion of image variance in different size, which can reflect principle of selecting large, small structuring element weighted value.

VI. EXPERIMENT RESULT AND ANALYSIS

The image used in experiment is a decayed log CT image. 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.

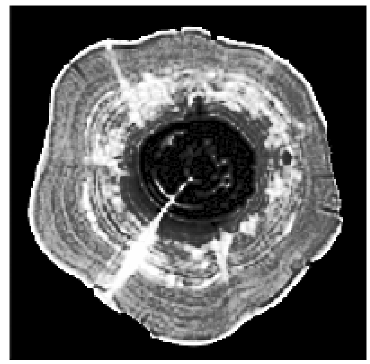


Figure 6. Original wood CT image

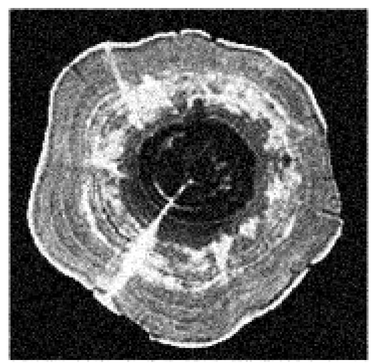


Figure 7. Wood CT image with noise

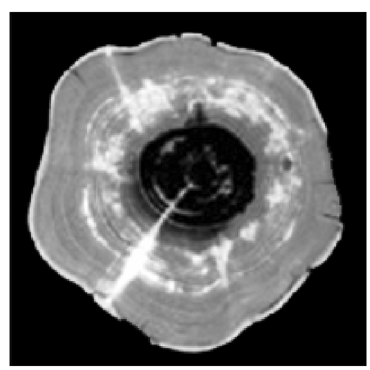


Figure 8. Anti-noise image by dilation and erosion

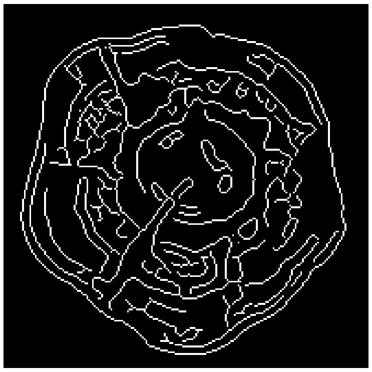


Figure 9. Image after single-structure element processing

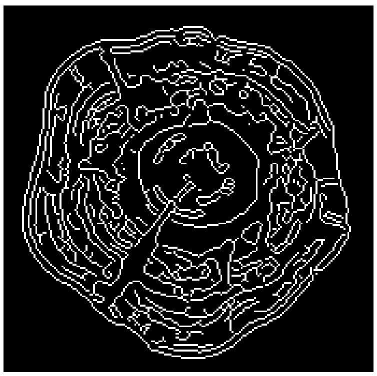


Figure 10. Image after Omnidirectional and multi-scale morphological processing

As can be seen in the figures above, the morphological method of dilation and erosion has better effect on reducing the noise. And omnidirectional and multi-scale morphological method has better effect on probing the edge which demonstrates the decay section in the wood.

VII. 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 nondestructive testing computed tomography has advantages such as higher penetrability, higher resolution, fast testing speed and visible testing result etc. Image edge detection is the main and important study direction of image management and computer vision. The article adopted one edge detection method - omnidirectional and multi-scale structure element of mathematical morphology to settle the conflict between noise and extraction of detecting edge. The method possesses better real time feature, anti-interruption, and precise orientation feature. Practicability can be seen from the results of experiment.

REFERENCES

[1] W. H. Stuppy, J. A. Maisano, M. W. Colbert, P. J. Rudall, "Three-dimensional analysis of plant structure using high-resolution X-ray computed tomography." Trends in Plant Science. Vol.8 (1), pp. 2-6, 2003.

[2] 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.

[3] J.W. opmans, C.M.P Vazd, M.L. Rivers, "Using X-ray computed tomography in hydrology: systems, resolutions, and limitations." Journal of Hydrology, vol. 267, pp. 285–297,2002

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

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

[6] 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.

[7] Thawornwong, S. Occeña, L.G., Schmoldt, D.L., Lumber value differences from reduced CT spatial resolution and simulated log sawing. Comput. Electron. Agric. vol. 41, pp. 23- 43, 2003.

[8] X. Song and Y. Neuvo, Robust edge detector based on morphological filters, Pattern Recognition Letter. Vol. 14, pp. 889-894 , 1993.