Defect Edge Detection in Blockboard X-ray Images by Shannon Entropy

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Abstract

A Shannon entropy-based image processing approach is introduced and applied to the blockboard X-ray images obtained from nondestructive scanning. X-ray nondestructive testing technology has been applied to the detection of internal defects in blockboard. In this paper, we select a probability distribution function to calculate the Shannon entropy in images processing. And we define a novel Defect Edge Index (DEI) for analyzing the defect edges in images. Through studying and processing the DEIs, the defect edges extracting is achieved. Furthermore, a new index E for quality evaluation was also studied out by the DEIs. The number of E can demonstrate the quality of examined blockboard. Experimental results display that the image processing method based on Shannon entropy theory is effective and the quality evaluation index E is accurate. Thus, a promising method for detecting and analyzing defect edges in blockboard X-ray images is provided.

Keywords: *Shannon Entropy, Image Processing, Edge Detection, Blockboard Defect Detection, X-ray Nondestructive Testing.*

1. Introduction

Recently, blockboard is a kind of material widely used in many fields such as the furniture-making and carpentry generally. It plays a significant role in the production of our life. 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 the combination of wood components having very different thickness (strips and veneers) makes it difficult to precisely determine the bonding quality [2]. Because its major components are cemented with agglutinant, detecting bond quality, uniformity degree and situations of filler is necessary. Once the testing methods of blockboard were destructive, it led to large numbers of timber resources waste. But nowadays, a new nondestructive blockboard was proposed based on X-ray technology. This kind of testing method can detect specimen without damaging both the appearance and structure. Additionally, the internal defects of objects can be detected accurately. Firstly, an X-ray machine is operated to pass through the sample blockboard. Then the image signal of the blockboard is transformed from X-ray camera into computer. And then the detected images are collected by applying image collection hardware and software of computer. Finally, the digital blockboard image is displayed on the screen.

After obtaining the blockboard image, the important step in the detection of defects in blockboard images is image edge detection. While there are many edge detection algorithms, each algorithm can be categorized based on whether it uses discontinuities or similarities in the image data or whether it is a local or global operator [3].In the classical method of edge testing, boundary operators are constructed by gray gradient change of the image pixels in the neighborhood, such as gradient operator, Laplacian operator, Sobel operator, Marr operator, or Canny operator. But the disadvantage common to all operators listed above is that they are sensitive to fluctuation [4].

These methods are already widely used in the field of image analysis and processing. Besides, in this paper, we propose an entropy-based detection of blockboard X-ray images. Defect edge is an important task in blockboard X-ray image processing. It is the significant stage in nondestructive testing of blockboard. Therefore, we endeavor to apply another novel method to achieve the task.

Entropy is a concept originating from thermodynamics, and then led into information theory firstly by Shannon [5]. Hence, in information field, we call it Shannon Entropy. It calculates the amount of information in the message. After calculating the total probabilities of all the elements in the message, we obtain the Shannon entropy of the message.

By the knowledge from information theory, the term of Shannon entropy has been also introduced into the image processing field. In this field, it can not only use to estimate the quantitative information of an image, but to detect the image edge as well. Thus, the Shannon entropy of image turns out to be the analysis of pixel value probabilities.

Shannon entropy is applied to compare the variation of information in two sides of the defect edge. We acquire the Shannon entropy of the image so as to get the information of the defect in blockboard X-ray images, which actually exist in the detected blockboard.

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.

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:

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

Attenuation diagram of X-ray imaging law is shown in Figure 1.

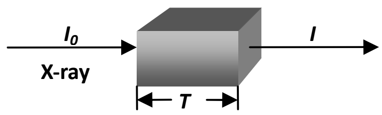

Figure 1 Attenuation diagram of X-ray imaging law.

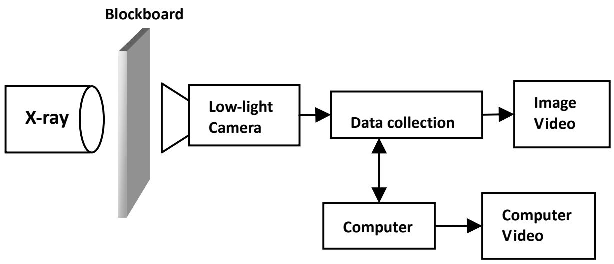

Figure 2 Blockboard x-ray nondestructive system.

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.

3. Shannon entropy Theory

Shannon entropy, named after Claude Shannon, was first proposed in 1948[6]. Since then, Shannon entropy has been widely used in the information sciences. Shannon entropy is a measure of the uncertainty associated with a random variable. Specifically, Shannon entropy quantifies the expected value of the information contained in a message.[7]

Usually, the Shannon entropy has another name, which is information entropy. In information theory, the concept of entropy is used to quantify the amount of information necessary to describe the microstate of a system [8]. The entropy is related to the concept of Kolmogorov complexity, which reflects the information content of a sequence of symbols independent of any particular probability model [9,10]. More specifically, the Kolmogorov complexity of an object is a measure of the computational resources needed to specify the object. Then, if a system presents a high value of entropy, it means that much information is necessary to describe its states. Depending on the specific application, the entropy can be defined in different ways [11].

Firstly, we review the definition of Shannon entropy. Shannon entropy is regarded as a description of a generic scattering, including but not always the probabilistic distribution.

Consider a discrete set $X\{x_1, x_2, x_3, \cdots, x_n\}$, and x_i indicates the i-th possible value of X out of n symbols. Define the function $p(x_i)$ denoting the possibility of $x = x_i$ when $\forall x \in X$, that is:

$$p(x_i) = P(x = x_i) \tag{2}$$

Then the Shannon entropy of a discrete random distribution $p(x_i)$ is defined as:

$$H(p, X) = -\sum_{i=1}^{n} p(x_i)\log p(x_i) \tag{3}$$

where the logarithm is taken on base 2.

Consider a $m \times n$ gray-level image (the X-ray images are always gray-level images) X. It is a 2-Dimensional image, so it can be described through a matrix below:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix} \tag{4}$$

In digital gray image analysis, the value x_{ij} can refer to the gray levels of each pixel in the image, which can vary from 0 to 255. They are all integers, that is: $\forall x_{ij} \in \{0,1,2,3,\cdots,255\}$.

In order to calculate the Shannon entropy score of image X, firstly, we will define function $p(x_i)$, which can refer to the distribution of gray levels.

$$p(x_{ij}) = x_{ij} / \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \tag{5}$$

Therefore, the Shannon entropy value of image X can be calculated as shown in Eq. 6.

$$H(p, X) = -\sum_{i,j=1}^{m,n} p(x_{ij})\log p(x_{ij}) \tag{6}$$

The theoretical maximum of the Shannon entropy is $\log(m \times n)$, when the gray value of every pixel is equal to the average gray value of this image X, i.e.

$$\forall x_{ij} = \bar{x} = \left(\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \right) / (m \times n) \tag{7}$$

It means each gray value of pixel is equally likely distributed. Additionally, the theoretical minimum of the Shannon entropy is zero; it can be calculated from an extreme example, which $X = (0, 255)$. It means the difference between each pixel in the image is quite large.

That is reasonable, because it accords with the definition of Shannon entropy well. However, this kind of Shannon entropy value is not convenient to understand for defect edge detection. Because the gray value of pixel will changes dramatically near the defect edge, but the Shannon entropy value near the defect area is close to zero. We want to describe the defect edge through a higher value. And, for the sake of convenience of data processing later, we also need the Shannon entropy value to be normalized. Hence, we crate the Defect Edge Index (DEI), it can be calculated by Eq.8. below:

$$Dei(p, X) = 1 - H(p, X) / \log(mn) \tag{8}$$

This equation changes $H(p, X) \in [\log(mn), 0]$
to $Dei(p, X) \in [0,1]$. In general circumstances, when X contains the more defect edge, the DEI will more close to 1, and if there is no obvious defect in it, the DEI of X will come near to 0.

We take Eq.6 into Eq.8, and then simplify it. Finally, we can get the Eq.9 that is the formula for computing the DEI.

$$Dei(X) = \sum_{i,j=1}^{m,n} \left(\frac{x_{ij}}{mn\bar{x}} \cdot \frac{\log x_{ij}}{\log(mn)} \right) - \frac{\log \bar{x}}{\log(mn)} \tag{9}$$

$\bar{x}$ is the average gray value of the image X , from the Eq.7.

4. Defect Edge Detection in Blockboard X-ray Images

Next, we start to analyze blockboard X-ray image based on Shannon entropy theory.Firstly, we select a square $n \times n$ neighborhood X_i as the i-th part in the image (we divide the image into N parts, $i = 1,2,3,\cdots,N$). And then calculate the DEI of this square X_i , the result is $Dei(X_i)$. After calculating every part of the image from X_1 to X_N , we obtained a group data of DEI. Just as we demonstrated before, the defect edge regions of the image have higher DEI (near 1), to the opposite, other normal areas have lower DEI relatively.

Actually, there is still an issue in the computing process, which is how to choose the value of n. Obviously, in real digital images, the minimum n=2 (n=1 represents only one pixel, it is meaningless to edge detection), and n will not larger than the size of the detected image. Hence, in theory, we can choose any integer number for n among this interval. However, the value of n will affect the calculating consequence of DEI and the quality of defect edge detection. If we use a small value, the detection will be too sensitive and find out too many fake defect edges. And if the value of n is large, the detection will be rough and omit many real defect edges.

So, we need to do experiment to figure out a proper n value for the defect edge detection in blockboard x-ray images by Shannon entropy.

In order to estimate the effect of defect edge detection of selected n, we designed an algorithm that made the result more clear and direct viewing. Because of the X_i contains the more defect edge, the DEI will more close to 1, we set the color of DEIs which are most near 1 bright, and the other DEIs dark. And then, draw the all DEIs on the screen. Certainly, different n value will correspond to different picture. We can contrast the picture of DEI with the original X-ray image, and work out a proper n value for the defect edge detection.

Figure 3 is the original X-ray image, and the Figure 4-7 are the processed results of different n value.

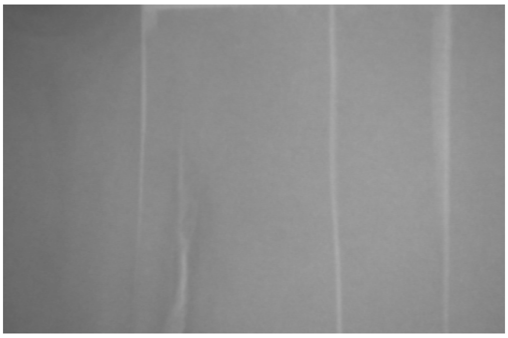

Figure 3 Original image.

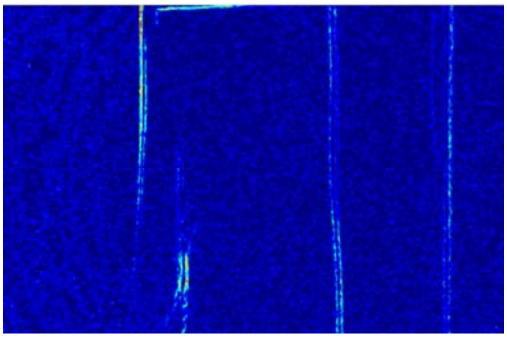

Figure 4 n=3

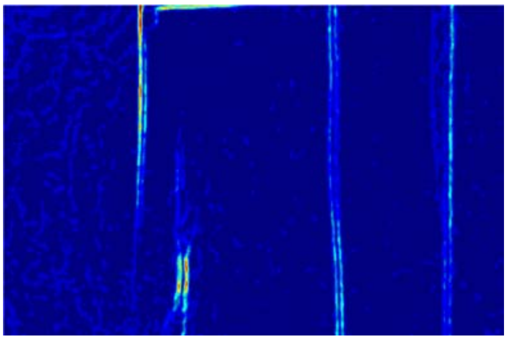

Figure 5 n=6

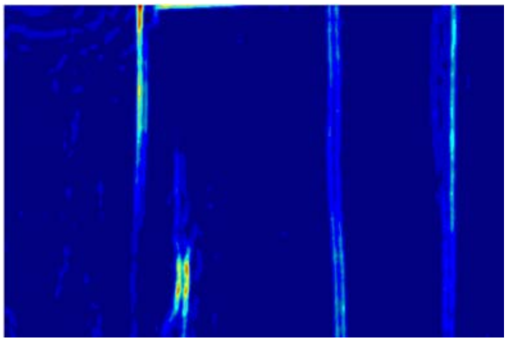

Figure 6 n=10

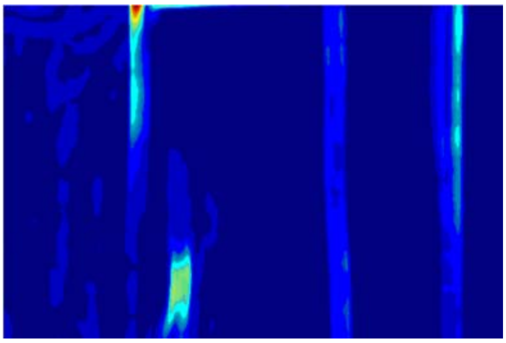

Figure 7 n=20

After the experiment, we consider n=6 is the best value for this kind of defect edge detection.

5. Edge Extracting and Quality Evaluation via DEIs

From the chapter 4, we can get the images of DEI distribution, and the range of DEIs is from 0 to 1. Apparently, by observing these images, we find out it contains two kinds of information mainly, one is defect regions and the other is background (non-defect areas). Naturally, we only concern the defect areas, so we need to extract the defect edge from the images by means of setting the threshold of DEI. Actually, the algorithm of edge extracting is simple.

Firstly, we analyze the distribution of DEIs and select a value ε that $\min(Dei) \le \varepsilon \le \max(Dei)$. Then check all the DEIs, let:

$$\delta(Dei)=\begin{cases}0 & Dei<\varepsilon \\ 1 & Dei\geq\varepsilon\end{cases} \tag{10}$$

So we obtain the δ and draw them on the screen, set 1 in white and 0 in black. ε is the threshold, but not quite clear. Hence, we define another variable χ instead:

$$\chi=\frac{\max(Dei)-\varepsilon}{\max(Dei)-\min(Dei)}\times 100\% \tag{11}$$

From the Eq.11, we know $0\%\leq\chi\leq 100\%$.

In this experiment, we also analyze the image showed in Figure 3, and set n=6. Figure 8 illustrates the distribution of the DEIs.

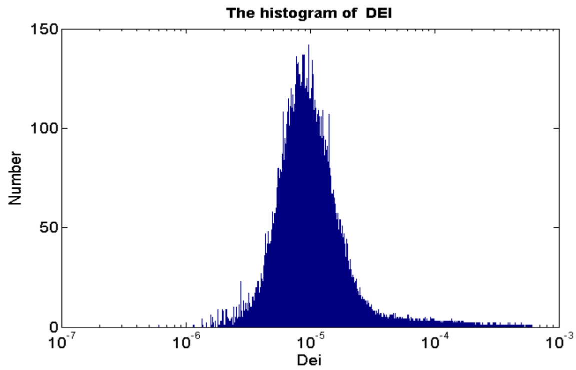

Figure 8 DEIs' distribution

Figure 9 $\chi=70.84\%$

Figure 10 $\chi=90.67\%$

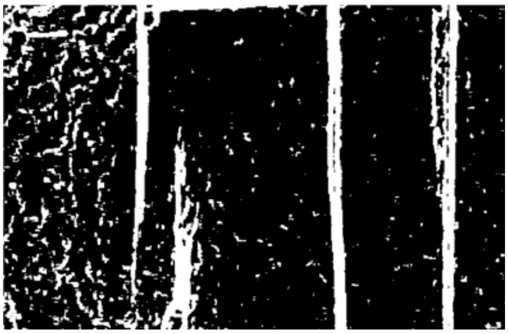

Figure 11 $\chi=96.57\%$

The result of experiment shows in Figure 9-11. So we need to choose a suitable value χ to extract edges from the DEIs, because it influences the effect strongly. And we think $\chi = 90.67\%$ is fitness for this kind of detection.

Next, we made a method to evaluate the quality of blockboard. Quality evaluation is an important goal of the blockboard non-destructive examination. To achieve this purpose, a new index of quality evaluation was studied out by the DEI.

We define the quality evaluation index:

$$\mathrm{E}(Dei,\varepsilon) = \sum_{\substack{x \in Dei \\ x > \varepsilon}} x \cdot \exp\left(\frac{x - \min(Dei)}{\max(Dei) - \min(Dei)} \cdot 10 \right) \tag{12}$$

ε is the threshold that appeared before, and it can be computed from the Eq.11:

$$\varepsilon = (1 - \chi) \cdot \max(Dei) + \chi \cdot \min(Dei) \tag{13}$$

And as the consequence of experiment showed previously, it is best that we let the $\chi = 90\%$.

In Eq.12, the constraint condition:

$x > \varepsilon \ (x \in Dei)$ is indispensable. The areas of these values are just at the edge. And multiply these values by a kind of weight before adding them. We use the exponential weight because the values will increase very fast. Then sum E is the quality evaluation index, it can well represent the defect edges in images. The higher number of E demonstrates the more defect edges contained in the X-ray image of blockboard. Namely, the quality of this blockboard is poorer. That is why we call E the quality evaluation index. We design the algorithm of E based on statistical theory and a series of experiments meticulously, hence, the result of it can be in accord with the real situation very well.

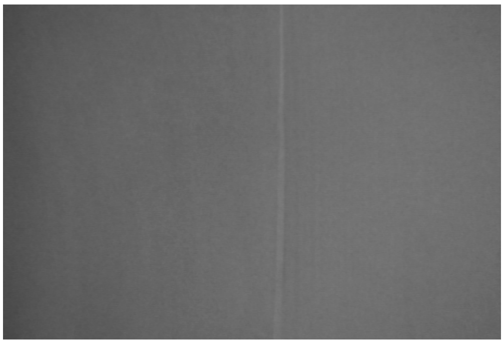

Figure 12 E=164.255374

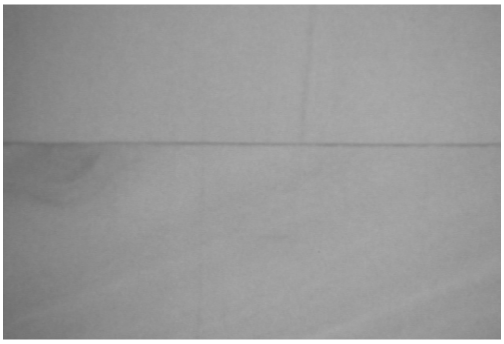

Figure 13 E=296.002058

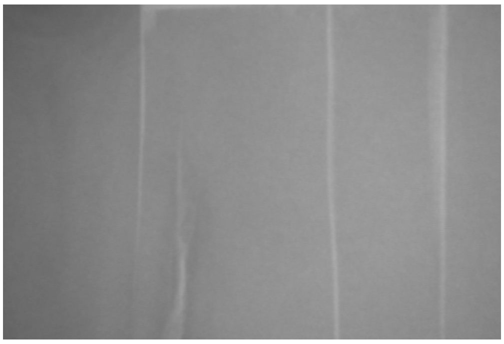

Figure 14 E=362.658552

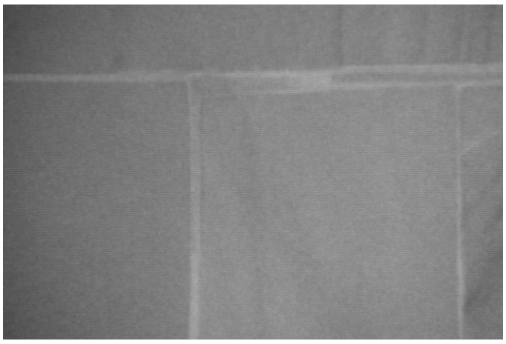

Figure 15 E=624.857546

Figure 16 E=773.983423

The result of experiment shows in Figure 12-16, which the first image there is little defect inside gets a small number of E. To contrast, the last image undoubtedly gets a large number of E. They conform to our anticipation well, which the larger number of E demonstrates the poorer quality of tested blockboard as well as the more defect edges contained in it.

6. Conclusion

To be compared with other nondestructive testing, X-ray has many advantages, for instance, higher resolution, fast testing speed, higher penetrability and visible testing result and so forth. X-ray nondestructive technology was applied to the detection of internal defects in the blockboard for the purpose of production quality controlling. Shannon entropy theory was applied in the defect edges detection of blockboard X-ray images.

In this paper, we select a probability distribution function to calculate the Shannon entropy in real digital images processing. And then, for normalizing the value of Shannon entropy, Defect Edge Index (DEI) was defined. After calculating the DEI of each $6 \times 6\ (pixel)$ square in the image, the image of DEIs' distribution can be showed. From analysis of the DEIs' distribution, we can get the information of the defect edges in the blockboard X-ray image. The effect of edge extracting depends on the parameter χ , which is linked to the threshold ε . (By experiments, we choose the $\chi = 90\%$) Finally, a new index E for quality evaluation was studied out by the DEI. The higher number of E demonstrates the quality of this blockboard is poorer. The experimental result displayed that the image processing method based on Shannon entropy theory was effective. Thus, a promising method for detecting and analyzing defect edges in blockboard X-ray images is provided.

7. Acknowledgment

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