Correlation inversion detection algorithm and imaging simulation of wood defects focused by stress signal based on Symlets wavelet

BinZeng1, XuanLi1a* and Zhenwei Mao1
1Zhejiang A&F University, Hangzhou, Zhejiang Province, 311300, China
20010044@zafu.edu.cn  *Corresponding author’s e-mail:112306207@qq.com

Abstract. Aiming at the problems of traditional wood natural defect detection methods such as difficult to remove interference signals, weak signal enhancement, and low defect detection accuracy, a wood natural defect detection method based on Symlets wavelet and inversion reconstructed signals is proposed. First, the defect information is extracted by multi-scale slice based on Sym3 wavelet. Then, the high-frequency abnormal signal components of the defect stress after reconstruction are "focused" correlated inversion detection and analysis, and the defect information extraction process based on the inversion "focusing" is realized. Finally, the characteristic signals of natural defects in wood are effectively separated to achieve high-precision detection and three-dimensional image reconstruction of the position and shape of the defects. This method has achieved good experimental simulation results, and the recognition accuracy of wood knots and other defects is over 97%.

1. Introduction
In wood processing and grade inspection, the shape and number of wood defects (such as knots) will increase the difficulty of wood processing and are important indicators for determining wood grade. Therefore, the efficient identification of wood defects is one of the important research topics in the field of wood processing and inspection[1].

In 2016, Cetiner I.[2] proposed a method for quality control of wood material, knot features obtained from Wavelet Moment (WM) in the feature extraction step. In 2018, Perlin L.P.[3] proposed a new method to determine the pulp location of wood structural elements based on ultrasonic tomography. In 2019, Espinosa L.[4] examines the defects in the center and eccentric position of the two types of wood chips. In 2020, Habite T.[5] uses continuous wavelet method to detect the location and defects of spruce wood core. Mousavi M.[6] used the empirical mode decomposition of ultrasonic signal to extract the characteristics of wood hole defects. Tiitta M.[7] used the method of air coupled ultrasonic measurement to detect and evaluate the natural defects of wood boards. The classification accuracy varied between 72 and 77% in the tests.

The internal defects of wood (such as wood knots) are natural products, the position and shape of the defects are affected by factors such as density and moisture content. It is very difficult to accurately detect defects, the research methods in the above-mentioned documents all have interference signals and cannot accurately detect defects, further improvements are needed in the accuracy and efficiency of detecting defects. In this paper, wavelet analysis, dimensionality reduction, inversion reconstruction and other methods are used to more effectively remove the defect interference signal[8], and at the same time, two steps are carried out on the high-frequency defect signal: 1).
Multi-scale chip defect information extraction process, 2). Based on multiple scale "focuses" on the inversion of the associated defect information extraction process. This method is effective for effective analysis and high-precision detection of local abnormal defects and other signals.

2. The stress signal through the wood defect will produce local waveform mutation [8]
This paper uses stress wave to detect wood internal defects. When the stress wave signal encounters a class of defects (wood knots) during the internal propagation of the wood, the waveform will have a mutation signal, mutation signal is also called singular signal, the mutation point of the mutation signal often implies more important information, is one of the important characteristics of signal.

![Figure 1](image1.png)
Figure 1. Detection of defect A in sections from left to right
As shown in Figure 1, stress wave signal was detected from left to right at the horizontal position of A. When the detection signal arrives at a defect, the mutation of acceleration amplitude is obvious. The reason for the mutation is [8]: Defect A is a node, and with the increase of node density, the amplitude of acceleration of the waveform increases significantly.

3. Multi-scale slice defect information extraction based on Symlets wavelet

![Figure 2](image2.png)
Figure 2. Multi-scale slice defect information extraction based on Symlets wavelet
When the stress wave propagates inside the wood, the objective equation of its propagation mathematical model [9] is as follows:

$$(C_{13} + C_{55}) n_{1}^2 n_{2}^2 = (C_{11} n_{1}^2 + C_{55} n_{2}^2 - \rho \cdot V^2)((C_{55} n_{1}^2 + C_{33} n_{2}^2 - \rho \cdot V^2)$$  \hspace{1cm} (1)

$n_k$ is the direction cosine of the Angle between the incident direction of the plane under consideration and the x, y, and z axes, $\rho$ is the density, $V$ is the velocity.

The propagation model of stress wave in wood is used for reference in this paper, Symlets wavelet[10] is used to denoise, reconstruct and extract defect information from defect signals, to multiscale slicing detect signals in the specified frequency band and time period of the defect signal spectrum.

The formula of Symlets wavelet is as follows:

$$m_0(\omega) = \frac{1}{\sqrt{2}} \sum_{k=0}^{2^{N-1}} h_k e^{-jk\omega}, \hspace{0.5cm} s = e^{j\omega}, W(s) = U(s)W \left( \frac{l}{2} \right)$$  \hspace{1cm} (2)

The Symlets wavelet is usually represented as symN(N=2,3,…8)

In this paper, according to the actual situation of wood internal node defects found that sym3 wavelet compared with other wavelet methods for the signal high frequency contained fine defects extraction filter design simple and efficient, four filters of the Sym3 wavelet (H0, H1, G0 and G1) are selected to filter the high-frequency noise in acceleration signal, extract and calculate the fault amplitude of wood inside.

As shown in Figure 2, using the VCI imaging method and image reconstruction of the position, size and shape of the node defect, PYTHON and openCV library for virtual simulation of image presentation, to achieve multi-scale slice defect information extraction, through the reconstructed position and shape size The information better restores the defect characteristics.

4. Correlation inversion detection algorithm for focusing wood defects with stress signal based on Symlets wavelet

4.1. transform The inversion coefficient by wavelet domain, construct the inversion space

First, the equations obtained by Taylor expansion of objective function formula (1) are transformed into the wavelet domain, The generalized inverse operator matrix $H$ is transformed by two-dimensional wavelet transform:

$$H = LDL^T = H + E, \hspace{0.5cm} W_s \Delta V = -W_s G$$  \hspace{1cm} (3)

Among them, $E$ and $D$ are diagonal matrices; $L$ is the unit lower triangular matrix,$W_s$ is a wavelet operator, $s$ is the scale operator.

In inversion space wavelet domain transformation equation, the singularity of multiscale generalized inverse operator matrix is reduced, the stability increased.

4.2. Correlation "focusing" inversion is performed of defect spectrum reconstructed based on the appropriate scale basis and wavelet basis

Localized time and frequency inversion is performed, the stress signal with different resolution can be further identified by combination of the scale base and the wavelet base on the low resolution, combination of signals at high resolution, the initial space at any scale $L^2(u)$. The inversion series is developed as follows:

$$R(k) = \sum_{-\infty}^{\infty} c(t) \phi_t(k) + \sum_{j=0}^{\infty} \sum_{t=-\infty}^{\infty} d(j,t) \lambda_{j,t}(k)$$  \hspace{1cm} (4)

In the process of multi-dimensional inversion series approximation of stress signals related to internal defects of wood, $R(k)$ Achieve low resolution inversion approximation at different scales, as the index $j$ increases, By adding higher resolution, stress signal defects are identified in a more refined manner at a higher resolution.
4.3. VCI image reconstruction of node defects based on correlation "focusing" inversion
As shown in Figure 3, in the two intervals of [250,430] and [2550,2670], the relevant "focusing" inversion of junction defect B and defect A was performed based on the sym3 wavelet. Compared with Figure 2, the defect stress signal is high-pass filtered to defect stress signal to reserve inversion details, the defect stress signal is low-pass filtered to retain smooth shape calculation. Thus, the multi-scale enhanced extraction of more defect details in high frequency stress signals is further realized, good results have been achieved in noise removal and effective information extraction.

![Correlation "focusing" inversion is carried out for the knot defect A](image)

![Correlation "focusing" inversion is carried out for the knot defect B](image)

Figure 3."Focused" correlation inversion of reconstructed signal spectrum based on SYM3

5. Experiment and analysis

5.1. The experimental simulation
In this paper, the basic principle of stress-wave wood nondestructive testing[12] is adopted for experimental simulation. As shown in Figure 4, the experiment detects the mutation points of the stress wave signal from multiple angles, sends the stress signal from the transmitter to the receiver from multiple angles to ensure the integrity of mutual verification and defect signal detection.
5.2. Analysis of experimental results

(1) Analysis on the reconstruction effect of real defect image based on the three-dimensional data of defect detail sub-signal spectrum

Three-dimensional imaging method based on VCI[11] is used to reconstruct three-dimensional images of the position, size and shape of knot defects from multiple angles, and virtual simulation image rendering was carried out using PYTHON language and Opencv library function. As shown in Figure 5, the left part is the imaging result of using multi-scale slices to extract defect information. The ability to identify defects A and B is poor, and there is a problem of rough extraction and large noise. The right part of Figure 5 shows that the "focus" inversion method extracts the imaging result of the defect, which greatly improves the accuracy and efficiency of identifying defects A and B, and basically coincides with the true position and shape of the defect.

(2) Expand analysis of test results for 600 specimens

As shown in Table 1, this paper tested and analyzed 300 red pine samples and 300 elm samples:

a) Sym3 wavelet could effectively eliminate noise and extract defect information more effectively. Therefore, the detection accuracy of Method II (Sym3 wavelet) for red pine and elm nodes was about 94%, significantly higher than that of Method I (db3 wavelet), which was about 90%.

b) Method III Invert the reconstructed defect signal spectrum by correlation "focusing", realized multi-scale enhanced extraction of defect details, the accuracy of detecting defects such as wood internal defects and lacunae is above 97%, obtained good experimental simulation results.
Table 1. Comparison of experimental results of wood defect detection algorithm.

| Detection accuracy | Red pine knots | Elm knots |
|--------------------|----------------|-----------|
| I. Db3 wavelet defect information extraction | 90.76% | 89.93% |
| II. The defect information extraction method based on Sym3 wavelet multi-scale slice method | 94.49% | 94.07% |
| III. Inversion extraction method based on multi-scale "focused" correlation | 97.99% | 97.15% |

6. Conclusion

The application of wavelet transform in the field of wood inspection is a hot research topic. This paper uses Symlets wavelet and stress wave to detect natural defects in wood (such as knots, etc.) and draws the following conclusions:

1. This paper found that the application of sym3 wavelet to detect natural knot defects in wood is more effective, and the design of the sym3 wavelet filter is simple and efficient, which can remove more noise and extract more effective information.

2. This paper studied the correlation "focusing" inversion based on multi-scale elastic waves of Symlets wavelet, it can effectively improve the resolution of radial chord direction of stress wave signal of wood internal defect, realize multi-scale enhanced extraction of defect details. Through experimental simulation, the accuracy of multi-scale "focused" correlation inversion extraction algorithm is above 97%, which proves the efficiency of this algorithm. At the same time, the algorithm fully considers the wave field characteristics of the stress wave signals of different target bodies, so that the inversion results are more in line with the actual internal defects of the wood, which has a higher reliability and clear application significance.

3. In the process of actual detection of wood defects by stress waves, signals such as reflection, refraction, and transmission are mixed, which brings errors to the positioning of defects, these are problems that need to be further solved in subsequent research.

Acknowledgments

This work was funded by Zhejiang Provincial Natural Science Fund under grand No.LY16F010020; Zhejiang Science and Technology Department Project under grand No.2015C32083.

References

[1] Norlander R., Grahn J., MAki A. (2015) Wooden knot detection using convNet transfer Iserning. Lecture Notes in Computer Science.,9127:263-274.
[2] Cetiner I., Var A.A.,Cetiner H. (2016) Classification of Knot Defect Types Using Wavelets and KNN. Elektronika ir Elektrotechnika.,22 (6): 67-72.
[3] Perlin L.P., Valle A.D., Pinto R.C.D.A. (2018) New method to locate the pith position in a wood cross-section based on ultrasonic measurements. Construction and Building Materials., vol. 169:733-739.
[4] Espinosa L.,Prieto F., Brancheriau L., Lasaygues P. (2019) Effect of wood anisotropy in ultrasonic wave propagation: A ray-tracing approach. Ultrasonics.,91:242-251.
[5] Habite T., OlssonA., OscarssonJ. (2020) Automatic detection of pith location along norway spruce timber boards on the basis of optical scanning. European Journal of Wood and Wood Products.
[6] Mousavi M., Taskhiri M.S., Holloway D., Olivier J.C., Turner P. (2020) Feature extraction of wood-hole defects using empirical mode decomposition of ultrasonic signals. NDT & E International., 114.
[7] Tiitta M., Tiitta V., Gaal M., Heikkinen J., Lappalainen R. Tomppo L. (2020) Air-coupled ultrasound detection of natural defects in wood using ferroelectret and piezoelectric sensors. Wood Science and Technology., 54:1051–1064
[8] Zeng B., Dai D., Xiong W., Wang Y.X. (2013) Real-time Fault Diagnosis Approach Based on Lifting Wavelet and Distance Seeking Clustering, International Journal of Applied Mathematics and Statistics., 5(24):249-257.

[9] Feng H.L., Li G.H., Fang Y.M., Li J. (2010) Stress Wave Propagation Modeling and Application in Wood Testing. Journal of System Simulation., 22(6):1490-1493.

[10] Hu G.S., Ren Z., Huang W.Y. (2002) A construction method of symmetric wavelets and its application in fault signal processing of electric machines. Power System Technology., 26(11):7-10.

[11] Zeng Z.Y., Feng H.L., Du X.C., Fang Y.M. (2019) A stress wave tomography algorithm for internal defects in radial and longitudinal (RL) planes of wood. Journal of Zhejiang A&F University, 36(2):211-218.

[12] Yan Z.X., A Pilot Study on 2D Image Construction of Inner-defects in Log Cross-section Based on Stresswave. Northeast Forestry University.