APPLICATION OF WAVELET PACKET TRANSFORM TO ACOUSTIC EMISSION SOURCE LOCATION IN THIN PLATES

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Abstract: To improve the accuracy of acoustic emission (AE) source location, the wavelet packet transform is proposed to process the AE signals in this paper. The AE waves change shape due to the dispersion characteristics when they propagate in thin plates. Therefore, with the conventional method for AE source location by calculating arrival time differences based on the threshold crossing, the result is greatly affected by the level of threshold voltage and the measured value of wave velocity. To solve this problem, the wavelet packet transform was employed to isolate a single frequency from the output waveform of each sensor. Then the time differences due to propagation of this frequency component and the velocity of this frequency component were used for the location analysis. With this method the location error caused by the dispersion characteristics was decreased. Experiments using a pencil lead break as the AE source were carried out on a composite plate. The results proved this method is efficient.
Key words: acoustic emission (AE), source location, wavelet packet transform

Introduction: The most conventional method for the acoustic emission (AE) source location is location with the time differences of arrival at different sensors in the same array. The accuracy of time difference and wave velocity decides the accuracy of AE source location.

The classical plate theory predicts that AE waves propagate as two modes in plate-like structures: the flexural mode and the extensional mode. These modes travel at different velocities and exhibit dispersion characteristics [1-4]. In commercially available AE analyzers, the arrival time is determined by threshold crossing techniques. When the AE waves propagate in thin plates, they change shape due to the dispersion. The result will be that the timing clock will not be triggered on the same phase point of the waves. This is the main problem of threshold crossing techniques to locate sources in dispersive media. Considering the lack of the threshold crossing techniques, Ziola and Gorman used a cross-correlation technique to determine the arrival time differences of the flexural wave in plates [5].

Recently, the wavelet transform (WT) has been introduced to the time-frequency representation of transient waves propagating in a dispersive medium. Gaul and Hurlebaus [6], Oh-Yang Kwon and Young-Chan Joo [7], and Jeong and Jang [8] applied the WT to an AE source location using dispersive plate waves. For wave propagation in dispersive media, the accuracy of source location can be improved by using the time differences due to propagation of a single frequency. WT has the capability of time-frequency analysis and it can draw different frequency bands of the signal. But along with the increase of the scale, the higher the space resolution ratio of the wavelet function is, the lower its frequency resolution ratio is. This is a drawback of the wavelet function. The good character of wavelet packet transform that the wide window of frequency spectrum becomes narrow with the scale enlarging overcomes the lack of wavelet transform.

This paper introduces wavelet packet transform to process AE signals. A very narrow frequency band is extracted from the AE wave with wavelet packet transform. Then the time differences can be determined by cross correlating the decomposed signals. By using this method, the AE source location error is reduced effectively and the accuracy is enhanced.

Wavelet transform and wavelet packet transform: The continuous wavelet transform (CWT) is defined as follows

$$WT_x(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt = \langle x(t), \psi_{a,b}(t) \rangle \tag{1}$$

where

$$\psi_{a,b} = \frac{1}{\sqrt{|a|}}\psi(\frac{t-b}{a}) \qquad a,b \in R, a \neq 0$$

(2)

The result of CWT is a number of wavelet coefficients WT_x, which are the function of scale a and position b. For the actual computation of the WT, a and b should be discretized. This is called the discrete wavelet transform (DWT). If scales and positions are chosen based on the powers of two, analysis will be much efficient.

$$C_{j,k} = \int_{-\infty}^{\infty} x(t)\psi_{j,k}^{*}(t)dt = 2^{-j/2}\int_{-\infty}^{\infty} x(t)\psi^{*}(2^{-j}t-k)dt \qquad j,k \in Z$$

(3)

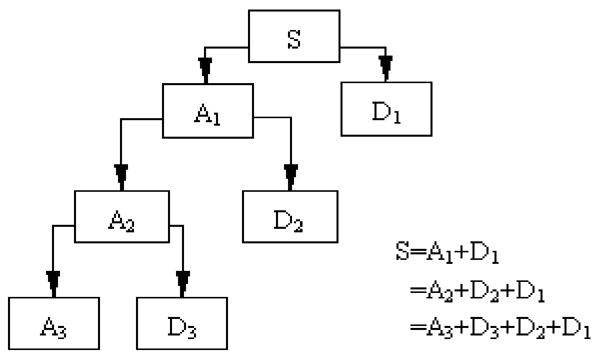

Figure 1. Wavelet Decomposition Tree

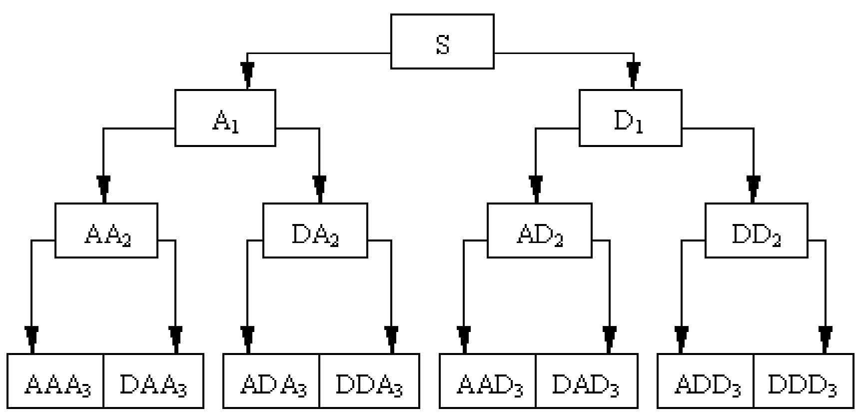

Figure 2. Wavelet Packet Decomposition Tree

In the DWT, a signal may be represented by its approximations and details. The approximation is the low frequency component of the signal. The detail is the high frequency component. In Figure 1, 'S' represents the raw signal, 'A' represents the approximations and 'D' represents the details. A signal can be broken into lower-resolution components by using different scales. This is the wavelet decomposition tree.

The function family $\{u_n(t)|n \in Z_+\}$ satisfying the formula (4) is defined as the orthogonal wavelet packet depending on the base function $u_0(t)$.

$$u_{2n}(t) = \sqrt{2}\sum_{k \in Z} h(k)u_n(2t-k)$$
$$u_{2n+1}(t) = \sqrt{2}\sum_{k \in Z} g(k)u_n(2t-k)$$

(4)

where $g(k) = (-1)^k h(1-k)$. The wavelet packet decomposition tree is shown in Figure 2. The wavelet decomposition tree is a part of this complete binary tree.

Experiments: The measurement for source location was carried out on a 330 X 165 X 2mm composite plate made of carbon fiber (alveolate paper structure in the middle). Two broadband AE sensors whose coordinates were (0,0) cm and (0,15) cm were positioned on the surface of the plate through coupling matter. The elastic waves were generated by the simulated source of pencil lead breaks at six representative locations whose coordinates are given in Table 1. The detected signals were amplified through the preamplifier (1801A) with frequency-band ranging from 100khz to 1000khz, then the signal was sent to the AE instrument. The experimental instrument is a digital acoustic emission instrument, which can record signals and analyses their waveforms and frequency characteristics. Its synchronous trigger is supplied with the software. Whenever any channel receives the signal crossing threshold voltage first, the control switch of the channel will be opened automatically and the signal will be received. Then the synchronous trigger function will be accomplished among different channels.

Firstly, the threshold crossing method was performed. The threshold voltage was set at 0.01V, 0.02V, 0.03V, respectively. Secondly, the cross-correlation method with wavelet-transformed signals was performed. The arrival time differences were calculated by using cross correlating the decomposed signals at level 5 by wavelet (db6) transform. Finally, the new method of the cross-correlation with wavelet packet transformed signals was performed. The arrival time differences were calculated by using cross correlating the decomposed signals at level 6 by wavelet packet (db6) transform. The velocities used in the location analysis were determined by using a pulse-receiver method.

Results: Results of source location based on the threshold crossing method and the cross-correlation method with wavelet-transformed signals are show in Table 2, 3, 4. With the threshold crossing method, the mean absolute errors are 0.4471(0.01V), 0.6865(0.02V) and 0.3782(0.03V), respectively. And using the cross-correlation method with wavelet-transformed signals, the mean absolute errors are 1.5366 (A_5) and 0.2343 (D_5).

With wavelet packet transform, the AE signal was decomposed into narrow frequency bands. The frequency bands containing the main energy of signal are show in Figure 3. Experimental results based on the cross-correlation method with wavelet packet transformed signals are show in Table 5, 6. The mean absolute errors are 0.0113 ($ADAAAA_6$) and 1.0027 ($DDAAAA_6$).

Experimental results indicate that the mean absolute error using the cross-correlation method with wavelet packet transformed signals is the least.

Table 1. Coordinates of AE Source Positions

SOURCE NO.	LOCATION (*cm*)
1	(7.50,0)
2	(5.00,4.00)
3	(10.00,4.00)
4	(7.50, -4.00)

5	(5.00, -4.00)
6	(10.00, -4.00)

Table 2. Results of Source Location Based on the Threshold Crossing Method

NO.	0.01V		0.02V		0.03V	
	TIME (μs)	LOCATION (cm)	TIME (μs)	LOCATION (cm)	TIME (μs)	LOCATION (cm)
1	-1.2500	(7.4075,0)	-1.2500	(7.4075,0)	5.2500	(7.8885,0)
2	-31.7500	(5.1505,0)	-34.2500	(4.9655,0)	-34.0000	(4.9840,0)
3	38.2500	(10.3305,0)	31.7500	(9.8495,0)	31.7500	(9.8495,0)
4	0.5000	(7.5370,0)	11.7500	(8.3695,0)	4.0000	(7.7960,0)
5	-26.7500	(5.5205,0)	-53.7500	(3.5225,0)	-35.0000	(4.9100,0)
6	8.7500	(8.1475,0)	40.7500	(10.5155,0)	38.5000	(10.3490,0)

Table 3. Results of Source Location Based on the Cross-correlation Method with Wavelet-transformed Signals (A_5)

SOURCE NO.	TIME (*us*)	LOCATION (*cm*)
1	0.5000	(7.5370,0)
2	-29.0000	(5.3540,0)
3	7.7500	(8.0735,0)
4	1.2500	(7.5925,0)
5	13.0000	(8.4620,0)
6	-28.7500	(5.3725,0)

Table 4. Results of Source Location Based on the Cross-correlation Method with Wavelet-transformed Signals (D_5)

SOURCE NO.	TIME (*us*)	LOCATION (*cm*)
1	-0.5000	(7.4630,0)
2	-23.5000	(5.7610,0)
3	32.0000	(9.8680,0)
4	8.5000	(8.1290,0)
5	-29.2500	(5.3355,0)
6	30.7500	(9.7755,0)

Table 5. Results of Source Location Based on the Cross-correlation Method with Wavelet Packet Transformed Signals ($ADAAAA_6$)

SOURCE NO.	TIME (*us*)	LOCATION (*cm*)
1	-0.2500	(7.4830,0)
2	-32.2500	(5.3070,0)
3	32.0000	(9.6760,0)
4	0.2500	(7.5170,0)
5	-32.0000	(5.3240,0)
6	32.2500	(9.6930,0)

Table 6. Results of Source Location Based on the Cross-correlation Method with Wavelet Packet Transformed Signals ($DDAAAA_6$)

SOURCE NO.	TIME (*us*)	LOCATION (*cm*)
1	-0.5000	(7.4660,0)
2	-11.2500	(6.7350,0)
3	32.0000	(9.6760,0)
4	-37.0000	(4.9840,0)
5	-16.0000	(6.4120,0)
6	16.2500	(8.6050,0)

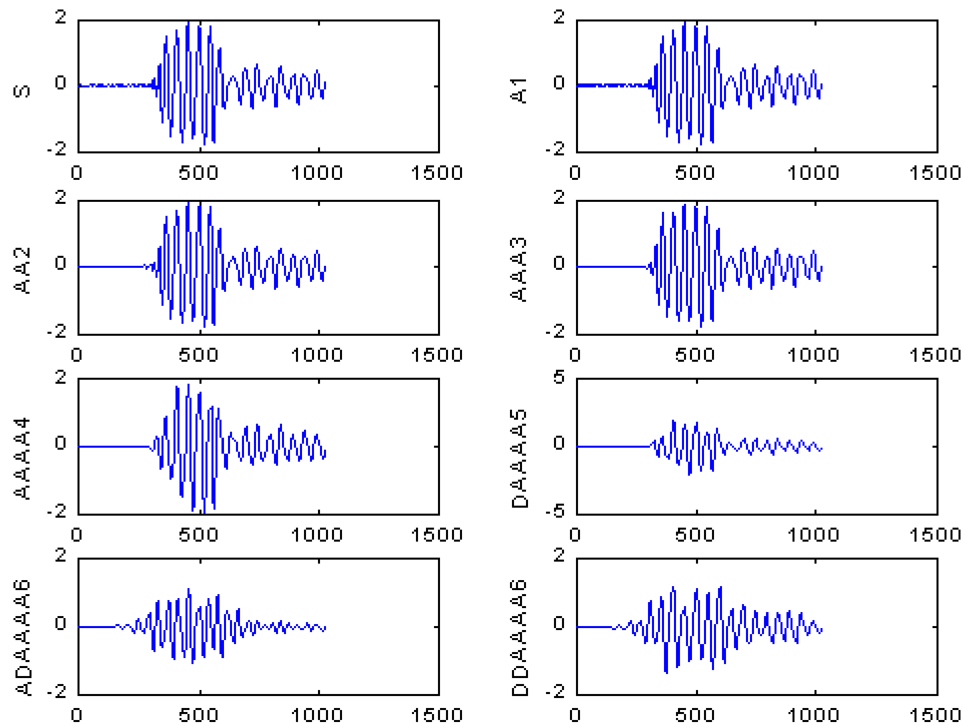

Figure 3. Original Signal and Decomposed Signals by the Wavelet Packet Transform

Discussion: With the threshold crossing method, the level of threshold voltage must be set artificially. Experimental results indicate that the level of threshold voltage is the main factor to influence the precision of AE source location. So the artificial influence is great on results of source location.

Using the cross-correlation method with wavelet-transformed signals, the AE source location can be independent of the level of threshold voltage. Experimental results indicate that the mean absolute error is decreased when the narrow frequency band (D_5) containing the main energy of signal is used.

With wavelet packet transform, AE signals can be decomposed into narrower frequency bands. The frequency band $ADAAAA_6$ is narrower than the frequency band D_5 and can be regarded as a single frequency approximately. So the frequency-disperse effect is greatly lessened. The mean absolute error using the frequency band $ADAAAA_6$ is the least, only 0.0113. The accuracy of source location is improved.

Conclusions: This paper presents an AE source location method based on wavelet packet transform. By using this method, the AE source location can be independent of the level of threshold voltage and the location error caused by the dispersion characteristics is decreased. The accuracy of AE source location in thin plates is improved.

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