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0.345 Attenuation Law of Vibration Signals during Caving

LI Xu[1]*, GU Tao[2]
[1]Department of Mechanics and Electronics Engineering, North China Institute of Science and Technology, East of Beijing Yanjiao, 101601, China, Tel: +8601061597476
[2]Department of Computer Engineering, North China Institute of Science and Technology, East of Beijing Yanjiao, 101601, China, Tel: +86188 0119 3011
*Corresponding author, e-mail:gucnm@163.com

Abstract

To study on the characteristics of the vibration signals of coal and stone hitting the armor plate during caving, a hybrid algorithm based on first order forward difference and wavelet transform modulus-maxima method is presented which can be used in the longwall top coal face. First, in order to reduce the noise interference, the pre-processing of the vibration signals is done by the first order forward difference method. Second, the wavelet transform modulus-maxima method is used to analyze the resluts of the difference for the post-processing of the data. Finally, attenuation formula is defined in the first-level details (D1). We can learn by the experimental results that the hybrid algorithm provides real-time, high confidence identification of coal and stone by analysis of the first-level details that has approximate 0.345 attenuation law between the wavelet transform modulus-maxima (the maximum coefficient) and the wavelet transform modulus-minima (the minimum coefficient). Because the wavelet transform modulus-maxima's abscissa and the wavelet transform modulus-minima's abscissa are adjacent to each other, the concept of Singularity-point Couple (SPC) is defined. Based upon the attenuation law and the defined concept, interference signals can be eliminated, vibration signals can be restored, and some prediction work can be done.

Keywords: *0.345 attenuation law, SPC, first order forward difference, wavelet transform modulus-maxima*

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1. Introduction

The mechanized caving coal face has been explained by Figure 1 in [1]. The key technique during caving is how to decide what time the tail support should be up or down. When the tail support is up, the caving is stopped. On the contrary, it is caving. The caving opportunity is controlled by the coal worker's observing and his experiences at present. This leads to the low level of mining efficiency and automation during caving. So it is of significance to study on the technique for the tail support controlling. In [1, 2], we have discussed the audio processing technology. In this paper, we will aim at the vibration signal processing technology. Two kinds of technology have been adopted respectively in our instruments.

The algorithm of static coal-rock interface recognition [3-6] can not be applied appropriately during caving. It is essential to solve the controlling of tail support with the technique adopted based upon the dynamical identification of coal and rock in the process of caving. For accurate controlling, the environmental requirements during caving should be taken into account specially. Experiences of previous studies [1, 2] show that it can avoid strong noise interference using digital signal processing technique to process the vibration signals of coal and stone bumping the transporting coal armor plate. Based on previous research results [1, 2], the identification rule is investigated using the first order forward difference method and the wavelet transform modulus-maxima method, and the 0.345 attenuation law of vibration signals is proposed. The attenuation law provides an important application in coal mine safety production.

2. Caving Signal and the Signal Processing

During the whole process of caving, the vibration signal which is caused by the coal and stone bumping the armor plate is sampled by vibration sensor with the speed 200k

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samples/sec. The sound noise has been eliminated totally to the sampled vibration signals. The caving signal model can be given by:

$$f(t) = Vib\_coal(t)+Vib\_rock(t)+Vib\_noise(t) \quad (1)$$

Where Vib_coal(t) is the vibration signal of coal falling, Vib_rock(t) is the vibration signal of stone falling, and Vib_noise(t) is the noise signal.

In real-time signal acquisition system, f(t) is composed of several signals listed in (1) or maybe f(t) is a single signal merely. In order to reduce the interference of Vib_noise (t), pre-processing of data for f(t) is done by (2):

$$\triangle f(k)=f(k+1)-f(k) \quad (2)$$

Where △is the first order forward difference operator.

Interference signals are effectively suppressed by the calculation of △f(k), all the vibration signals have discrete values by analysis of the first order forward difference. Figure 1 is the original vibration signal stone3 sampled during caving. Figure 2 is the first order forward difference results of signal stone3.

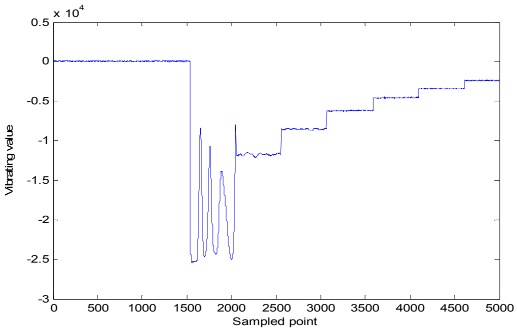

Figure 1. Vibration Signal stone3

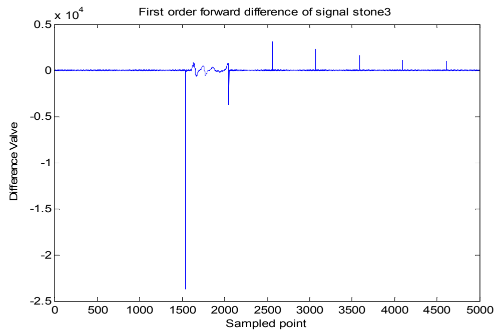

Figure 2. First Order Forward Difference Result

Wavelet analysis is a powerful tool for numerical analysis and can be very computational efficient. We adopt the most commonly used orthogonal wavelets to do the post-processing of the data. The orthogonal wavelet series approximation to a signal f(t) is given by:

$$f_J(t)=\sum_k S_{J,k}\Phi_{J,k}(t)+\sum_k d_{J,k}\Psi_{J,k}(t)+...+\sum_k d_{1,k}\Psi_{1,k}(t) \quad (3)$$

Where $\Phi(t)$ is the scaling function, $\Psi(t)$ is the wavelet function. J is the number of multiresolution scales and k ranges from one to the number of coefficients in the corresponding component.

The Sj,k are called as the approximation coefficients, and the dj,k are the detail coefficients. Accordingly, the wavelets series approximation of the original signal f(t) is written as:

$$f(t) \approx S_J(t)+D_J(t)+\ldots+D_1(t) \quad (4)$$

Where

$$S_j = \sum_k S_{j,k}\Phi_{j,k}(t),\ D_j = \sum_k d_{j,k}\Psi_{j,k}(t);\ j=1,\ldots,J.$$

Two-scale relations is given by:

$$\frac{1}{2}\Phi\left(\frac{t}{2}\right) = \sum_{n \in z} \Psi(n)\Phi(t-n) \tag{5}$$

Post-processing of the data for $\Delta f(k)$ is done by (6). Here, the orthogonal wavelet db5 is used to analyze the pre-processing results. Db5 wavelet is the compactly supported orthonormal wavelet which belongs to the Daubechies familie. Higher order Daubechies functions are not easy to describe with an analytical expression. The order of the Daubechies functions denotes the number of vanishing moments, or the number of zero moments of the wavelet function.

$$d_j[k] = \sum_{m=-\infty}^{\infty} \Delta f_{j+1}[m] h_1[m-2k] \tag{6}$$

Where h1[k] is the high-pass filter for decomposition.

We use (7) to do inverse wavelet transform [7], the first-level details of $\Delta f(k)$ is reconstructed, shown in Figure 3.

$$\Delta f'_{j+1}[k] = \sum_{m=-\infty}^{\infty} d_j[m] r\_h_1[k-2m] \tag{7}$$

Where r_h1[k] is the high-pass filter for reconstruction.The relationship between h1[k] and r_h1[k] is given by:

$$r\_h_1[k] = (-1)^k h_1[N-1-K] \tag{8}$$

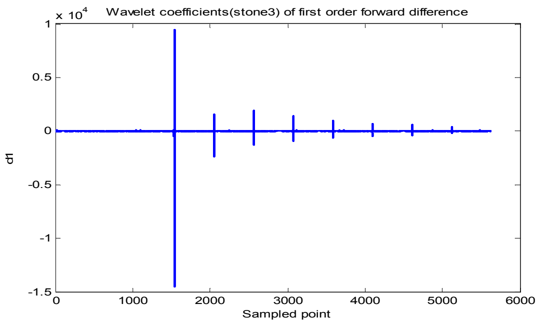

Figure 3. Coefficients in d1 by the △-W Transform

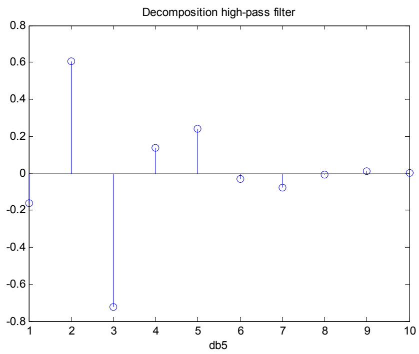

Figure 4. High-pass Filter for Decomposition

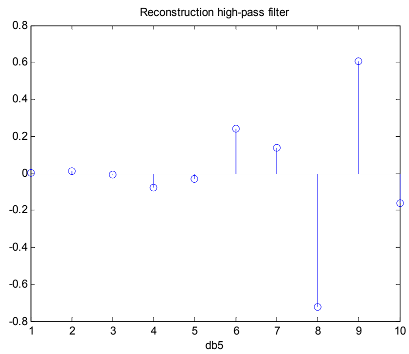

Figure 5. High-pass Filter for Reconstruction

The high_pass filters for decomposition and reconstruction are determined by the characteristics of the vibration signals, the used db5 wavelet's high_pass filters are shown in Figure 4 and Figure 5.

We can find from Figure 2 and Figure 3 that the unilateral characteristics of the data in Figure 2 has become bilateral data in Figure 3 after post-processing of the data for $\Delta f(k)$. We can search out the Singularity-point [8, 9] Couple of the vibration signals in D1 using the wavelet transform modulus-maxima method after the signal has been reconstructed. We define (2), (6), and (7) as the Δ-W transform. The difference of the original signal is constructed by the SPC's data rule. The rule can be used to eliminate the interference signals, and to identify the falling rock from coal.

3. The Rule of Coefficients in D1

3.1. The SPC and it's Characteristic

In order to analyze the problem of distinguishing rock from coal easily, we define the concept of Singularity-point Couple (SPC) as follows.

The maximum coefficient and the minimum coefficient is obtained from coefficients in d1 after the sampled signal has been done by the Δ-W transform. If the maximum coefficient's abscissa and the minimum coefficient's abscissa are adjacent to each other, the Singularity-point Couple (SPC) is defined. If the maximum coefficient's abscissa and the minimum coefficient's abscissa are not adjacent to each other, it is not the SPC. The local maximum coefficient's abscissa and the local minimum coefficient's abscissa are not adjacent to each other, the SPC is not constructed either. The concept of SPC is illustrated in Figure 6.

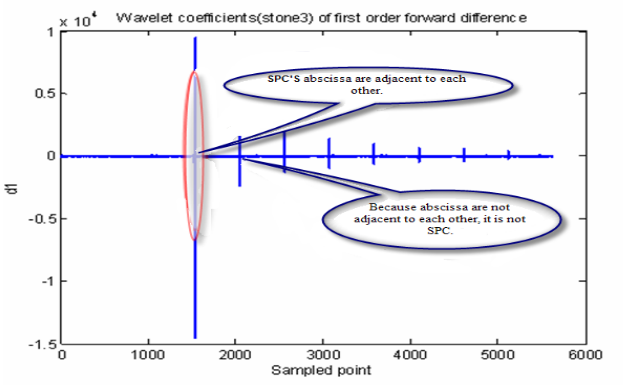

Figure 6. The Concept of SPC

3.2 The Application of SPC

To get the wavelet transform modulus-maxima and the wavelet transform modulus-minima, five groups of vibration signals sampled during caving are analyzed by the Δ-W transform. Table 1 gives the maximum coefficient and the minimum coefficient in D1 of every group signals.

Table 1. The Maximum Coefficient and the Minimum Coefficient in D1

D1	**Coal1**	**Coal-stone**		**Stone1**	**Stone2**	**Stone3**
Vmax	3435.7	9579.4	11158	875.84	2941.5	9458.9
Vmin	-2235.1	-6243.1	-17036	-1330.9	-4508.2	-14529

The SPC is found out in every group's D1 owing to the adjacent abscissa. In fact, the SPC is composed of the maximum coefficient and the minimum coefficient by the calculation and analysis of every group's signal. The recognition rule for distinguishing rock from coal during caving can be given as follows by investigating the characteristic of SPC corresponding to the falling material:

IF SPC'S |Vmax |>| Vmin |
COAL IS FALLING
ELSE SPC'S |Vmax|<| Vmin |
ROCK IS FALLING
ENDIF

3.3. The Attenuation Law of SPC

The attenuation percentage formula is defined as follows:

$$\Delta\% = \frac{|V_{\max} - |V_{\min}||}{|\max[V_{\max}, |V_{\min}|]|} \tag{9}$$

The data in Table 1 is investigated by (9). Table 2 presents there is an approximate 0.345 attenuation law between the maximum coefficient and the minimum coefficient in D1.

Table 2. The Attenuation Law of SPC in D1

The first-level detail coefficients	**Coal1**	**Coal-stone**		**Stone1**	**Stone2**	**Stone3**	**average**
△%	0.3494	0.3483	0.3450	0.3419	0.3475	0.34896	0.34684

Experimental results show the average value of the attenuation law is independency of the falling altitude of coal and rock. The average value is approximate constant 0.345. There are no SPC and 0.345 attenuation law to interference signals and to the aftermath of vibration signals according to the investigated results.

There are no SPC and 0.345 attenuation law in the second-level details (D2) to the fifth-level details (D5) by analysis of the wavelet transform modulus-maxima and the wavelet transform modulus-minima, shown in Table 3 to Table 6. However, the trend of data between the maximum and the minimum in d3 and in d5 are similar as the trend in d1. There are no obvious rules between the maximum and the minimum in d2 and in d4.

Table 3. The Maximum Coefficient and the Minimum Coefficient in D2 (no SPC and 0.345 attenuation law)

D2	**Coal1**	**Coal-stone**		**Stone1**	**Stone2**	**Stone3**
Vmax	1138.5	2127.2	3605.8	348.35	1037.3	3326.3
Vmin	-1453.7	-2036.1	-3172.1	-455.12	-1021.7	-3342.7

Table 4. The Maximum Coefficient and the Minimum Coefficient in D3 (no SPC and 0.345 attenuation law)

D3	**Coal1**	**Coal-stone**		**Stone1**	**Stone2**	**Stone3**
Vmax	1184.6	2840.1	4878.8	301.14	1118.9	3551.7
Vmin	-1098.6	-2576.7	-5310.8	-362.83	-1261.3	-4020

Table 5. The Maximum Coefficient and the Minimum Coefficient in D4 (no SPC and 0.345 attenuation law)

D4	Coal1	Coal-stone		Stone1	Stone2	Stone3
Vmax	374.91	1078.7	2327.3	281.44	466.89	1532
Vmin	-396.36	-918.44	-2246.5	-285.41	-537.42	-1731.4

Table 6. The Maximum Coefficient and the Minimum Coefficient in D5 (no SPC and 0.345 attenuation law)

D5	Coal1	Coal-stone		Stone1	Stone2	Stone3
Vmax	380.24	979.85	1460.2	328.46	736.81	1005.4
Vmin	-370.54	-915	-1654.7	-359.56	-674.28	-1048.6

Assuming that the Wf(u,s) is the vibration signal f(t)'s wavelet transform, if the Wf(u,s) obtains the local maximum value and the local minimum value, (10) should be met as follows:

$$\frac{\partial wf(u,s)}{\partial u} = 0 \tag{10}$$

Each element of the set {u} can be calculated to meet the condition of (10). If the Wf(u,s) obtains the global maximum value(Vmax) at the abscissa u0, the global minimum value(Vmin) will be obtained at the abscissa v. The relationship between u0 and v is given by:

$$v = u_0 \pm 1 \tag{11}$$

Simultaneously, (12) is established approximately:

$$\frac{|V_{\max} - |V_{\min}||}{|\max[V_{\max}, |V_{\min}|]|} \approx 0.345 \tag{12}$$

Signal filtering and prediction can be done by (11) and (12).

4. Applications of the Attenuation Law
4.1. Filtering and Identification Model

Other types of vibration signals can interfere with the normal recognition of the vibration signals of coal and stone during caving. Accordingly, the interference signals should be filtered before coal or stone distinguished. There are several types of the interference signals during caving: (1) The first type: The sampled signals are caused only by the system noise vibration, there is no coal or stone falling during caving. (2) The second type: The vibration signals are caused by the coal or stone bumping the armor plate. The first sampled data corresponds to the coal or stone falling. The second sampled data is the repercussion of the first sampled signals. Because it does not correspond to the actual material falling, it belongs to the interference signals. These types of interference signals are analyzed by the △-W transform, the investigated results show there are no SPC and 0.345 attenuation law in these interference signals. Thus, the 0.345 attenuation law can be used to filter these interference signals.

The identification model for coal and stone can be described as follows:

```
If 0.33 =< △% <=0.35
If Vmax>abs(Vmin)
Out 'Coal'
Else
Out 'Stone'
EndIF
Else
Out 'Noise'
EndIF
```

The algorithm provides recognition rates in industrial tests as follows.

Table 7. Recognition Rates

	Signal1	Signal2	Signal2	Signal2
recognition rate	95.6%	96.3%	95.1%	97.1%

4.2. Restoring the Original Signal

If the relationship of the SPC's data has been known to the vibration signals of coal and stone during caving, the original signals can be restored by the data of the SPC and the coefficients in D1.

The coefficients in the first-level details are shown in Figure 3. To restore the original signal, the data of the SPC is reserved; other data in D1 is cleared. Then the signal stone3 which is shown in Figure 7 is reconstructed by the data of the SPC and the other layer wavelet coefficients. Comparing Figure 1 and Figure 7, we know the absolute error is between 0.0065724~1438.9. The restored signal fulfills the requirements.

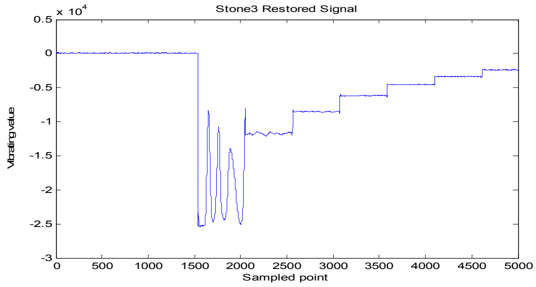

Figure 7. The Restored Signal stone3

5. Conclusion

In this paper the concept of the SPC is defined and the attenuation law of SPC is investigated. The vibration signals of coal and stone can be distinguished correctly by the attenuation law. If the maximum coefficient or the minimum coefficient is known in D1, the prediction work can be done by formula (10), and the original signals also can be reconstructed. Experimental results show that the 0.345 attenuation law is the characteristic of the sampled vibration signals. It is of significance to eliminate the noise occurred during caving and to improve the automatic caving technology.

References

[1] LI Xu, GU Tao. *New Technique of Distinguishing Rock from Coal Based on Statistical Analysis of Wavelet Transform*. Proc. SPIE 2009; 7343: P73430A.
[2] GU Tao, LI Xu. *New Equipment of Distinguishing Rock from Coal Based on Statistical Analysis of Fast Fourier Transform.* Global Congress on Intelligent Systems. 2009; P269-273.
[3] AVTOMATGORMASH (SU). *Coal-rock interface moning method.* Patent Number: SU891914-b.
[4] Asfahani J, Borsaru M. Low-activity spectrometric gamma-ray logging technique for delineation of coal/rock interfaces in dry blast holes. *Applied Radiation and Isotopes.* 2007; 65(6): 748-755.
[5] YU Feng-ying, TIAN Mu-qin, HU Jin-fa. Coal-rock Interface Recognition Based on Neural Network. *Mechanical Engineering & Automation.* 2007; 8: 4-6. (in Chinese)
[6] YU Shi-jian. Wavelet Multi-Resolution Analysis of Weak Reflected Wave From The Interfaces Of Coal Seam And Strata. *Chinese Journal of Rock Mechanics and Engineering.* 2005; 24(18): 3224-3228. (in Chinese)
[7] S Mallat. A theory for multiresolution signal decomposition: the wavelet representation. *IEEE Trans. Patt. Anal. and Mach. Intell.,* 1989; 11(7): 674-693.
[8] S Mallat, WL Hwang. Singularity detection and processing with wavelets. *IEEE Trans. Info.* Theory, 1992; 38(2): 617-643.
[9] Vivek Kumar, Mani Mehra. Wavelet optimized finite difference method using interpolating wavelets for solving singularly perturbed problems. *Journal of Wavelet Theory and Applications*. 2007; 1(1): 83-96.
[10] CJ Kicey, CJ Lennard. Unique reconstruction of band-limited signals by a Mallat-Zhong wavelet transform algorithm. *Fourier Analysis and Appl.*, 1997; 3(1): 63-82.