IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received August 22, 2020, accepted September 4, 2020, date of publication September 8, 2020, date of current version September 18, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3022787

Feature Extraction of Mine Water Inrush Precursor

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This work was supported by the National Key Research and Development Program of China under Grant 2017YFF0205500.

ABSTRACT Coal water inrush acoustic emission (AE) signal is characterized by time varying, nonstationary, unpredictable and transient properties. To extract effective features representing coal water inrush information, the AE signal is analyzed by the wavelet characteristic energy spectrum coefficient based on wavelet theory. The feasibility of the wavelet feature coding has confirmed from code scheme's availability and consistency, and it proves that the coding method can be used as a sign of waveform identification. The inclusion of energy distribution characteristics makes the waveform features more ordered and simplified. While the analysis of the obtained feature encoding in chronological order, it is possible to obtain the state of the time series signals, to lay an important basis for analyzing the evolution of water inrush acoustic emission coal from the time-series level, such that a change dynamic characteristic acoustic emission signal becomes possible. And this will lay an important foundation for the time sequence analysis of acoustic emission event's evolution in mine water inrush, reduces the trans-mission of invalid signals and improves the efficiency of downhole communication.

INDEX TERMS Coal water inrush, acoustic emission, wavelet feature coding, wavelet characteristic energy spectrum, wavelet theory.

I. INTRODUCTION

Mine water inrush is one of the main safety disasters in the process of mine construction and production. However, the threat of water inrush is extremely serious because of complex hydrogeological conditions. The frequent occurrence of water-inrush accidents has caused substantial economic losses and casualties. In the past ten years, the number of large water-inrush accidents was 517, and 2,753 people were injured or lost their lives. In the past 20 years, more than 300 coal mines have had water-inrush accidents, and economic losses have amounted to more than 50 billion yuan in RMB. Therefore, the development of an accurate method for predicting water inrush is essential [1], [2].

In recent years, with the development of acoustic emission technology, it has be-come an important tool for water inrush research in coal mines [15]–[18]. However, due to the characteristics of the acoustic emission system and the limitations of the prior art methods in rock acoustic emission testing, a large number of interference signals are mixed into the acoustic emission signal. In the process of downhole transmission signals, invalid interference signals will increase the load of communication, occupy the resources of downhole communication, affect the quality of communication and the difficulty of real-time monitoring of water-inrush precursor signals. This has greatly affected the application of acoustic emission technology in geotechnical and mining engineering [3]–[5].

Because the AE signal has the characteristics of suddenness, diversity of source signal and diversity of interference noise, etc., the wavelet transform has good localization properties in both time and frequency domain. Therefore, wavelet transform is the most effective method for analyzing this type of signal [6]–[9]. Based on wavelet transform and wavelet characteristic energy spectrum coefficient, the wavelet signature energy spectrum coefficient encoding of mine acoustic emission signal is studied in this article. The results show that the feature coding scheme has a high recognition rate and can effectively distinguish the various waveforms and types of interference in actual production, it also reduces the invalid interference signal, improves the efficiency of downhole communication and the reliability of signal recognition.

The associate editor coordinating the review of this manuscript and approving it for publication was Qilian Liang.

The proposed feature coding has the advantages of simple structure and short running time, which is beneficial to realize real-time pattern recognition and provides a new idea for real-time pattern recognition.

II. WAVELET PACKET CHARACTERISTIC POWER SPECTRUM COEFFICIENT

The wavelet characteristic energy spectrum coefficient is used to characterize the distribution of AE signal energy in each frequency band of wavelet packet decomposition. Different information components in the signal will cause the energy of AE signal to be distributed in different frequency bands. Therefore, the wavelet characteristic energy spectrum coefficient can be selected to characterize the characteristics of the response signal and the interference signal. Wavelet feature coding requires fewer parameters to describe signal characteristics. It can be used to identify different types of interference signals and response signals. It is also very beneficial to suppress the instability of response signals and suppress interference signals in the same frequency band.

Assume that the acoustic emission signal of the discrete sampling sequence is $f(n)$, Under J scale wavelet decomposition, $f(n)$ will have $J+1$ frequency range components in the form of the total energy constant, that is, the following formula holds to

$$f(n) = A_J f(n) + D_J f(n) + D_{J-1} f(n) + L + D_1 f(n) \quad (1)$$

If

$$E_J^A f(n) = \sum_{n=1}^{N} (A_J f(n))^2$$
$$E_j^D f(n) = \sum_{n=1}^{N} (D_j f(n))^2, \quad j = 1, 2, \cdots, J \quad (2)$$

$E_J^A f(n)$ and $E_j^D f(n)$ represent the low-frequency signal energy component and each high-frequency signal energy component on the decomposition scale J of the signal, respectively.

The total energy of the AE signal is

$$Ef(n) = E_J^A f(n) + \sum_{j=1}^{J} E_j^D f(n) \quad (3)$$

The wavelet characteristic energy spectral coefficient is defined as the ratio of the energy component of each wavelet decomposition to the total energy, which can represent the distribution of energy components in different frequency bands at each wavelet decomposition scale. rE_J^A and rE_j^D to represent the low-frequency and high-frequency wavelet characteristic energy spectral coefficients respectively, [19], [21], [22]

$$rE_J^A = \frac{E_J^A f(n)}{Ef(n)}, rE_j^D = \frac{E_j^D f(n)}{Ef(n)}, \quad j = 1, 2, \cdots, J \quad (4)$$

Figure 1 shows the waveform of the acoustic emission signal collected in the coal mine. The wavelet characteristic energy spectrum coefficient analysis method is used to process the wavelet decomposition of the sixth order of the AE signal to recon-struct the waveform and its characteristic energy spectrum coefficient.

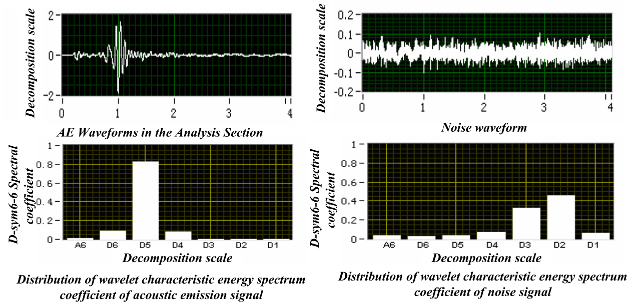

FIGURE 1. Wavelet characteristic power spectrum coefficient of AE and noise signals.

It can be seen from Figure 1, there is a clear difference between the energy spectrum distribution of acoustic emission signals and noise signals, which is of great value for identifying different types of signals and suppressing noise signals.

III. WAVELET CHARACTERISTIC POWER SPECTRUM FEATURE ENCODING

The feature code representation is to determine whether each spectral coefficient is in a valid state or an invalid state by analyzing whether it has impact characteristics and the distribution characteristics of each spectral coefficient. The method of forming the wavelet characteristic energy spectrum coefficient: 1. The wavelet characteristic energy spectrum coefficient is obtained by performing wavelet transformation on a waveform of a specified length; 2. Judge the impact of each decomposition layer according to the impact. If the impact is not satisfied, clear all the coefficients of the layer and set the layer as a non-impact sign; 3. According to the result of step 2, ad-just the wavelet characteristic energy spectrum coefficient to form a new wavelet characteristic energy spectrum coefficient, and reconstruct the waveform. The impact judgment method is the peak-to-average ratio method. Define several parameters:

Unitized mean

$$\mathrm{h_{avg}} = \frac{\mathrm{V_{rms}}}{\mathrm{V_{top}}} \quad (5)$$

Unitized peak

$$\mathrm{h_{max}} = \frac{\mathrm{V_{max}}}{\mathrm{V_{top}}} \quad (6)$$

Peak-to-average ratio

$$\mathrm{h} = \frac{\mathrm{h_{max}}}{\mathrm{h_{avg}}} \quad (7)$$

V_{top} is the maximum set peak of the acquisition device, V_{msx} is the maximum peak of the signal in the analyzed interval, V_{rms} is the root mean square of the signal in the analyzed interval.

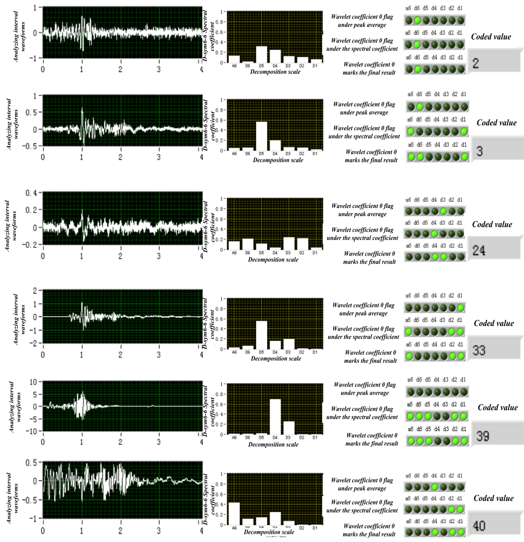

FIGURE 2. Wavelet characteristic power spectrum and encoding of AE signals.

Take $h = 4$ as the impact discrimination threshold as an example. If $h < 4$, it is considered that the signal at this decomposition level is mainly noise. The characteristic spectral coefficient of this layer is set to 1, and the corresponding wavelet coefficient is set to 0. Otherwise, It is considered that there is an impact signal, and the characteristic spectral coefficient of the layer is set to 0, and the corresponding wavelet coefficient is not processed. Thus the state of the waveform can be determined as follows

The digital representation is: 1000111, which is the characteristic code correspond-ing to the illustrated waveform. It is found that the signal on the d1 layer is generally weak. In order to reduce the amount of calculation, consider removing the d1 layer, that is, only the a6 d6 d5 d4 d3 d2 status code is considered. And the encoding meth-od is

$$CodeValue = a_6^* 2^0 + d_6^* 2^1 + d_5^* 2^2 + d_4^* 2^3 + d_3^* 2^4 + d_2^* 2^5 \quad (8)$$

The waveform can be represented by the code "49".

The principle of uniqueness is the basic principle of controlling heavy and garbled characters; one of the purposes of encoding is to improve the accuracy of information processing, information access, information transmission, information retrieval, information control, information utilization, and information statistics. One code can only represent one object, and one control object can only have one code. Therefore, the proposed coding scheme should be able to effectively analyze all signals, all waveforms can be encoded, and can effectively distinguish different wave-forms. Waveforms with a certain characteristic can be identified according to the coding, and there should be no bit errors. According to the analysis, the feasibility analysis of the coding scheme proposed in this article is performed [4], [13], [14].

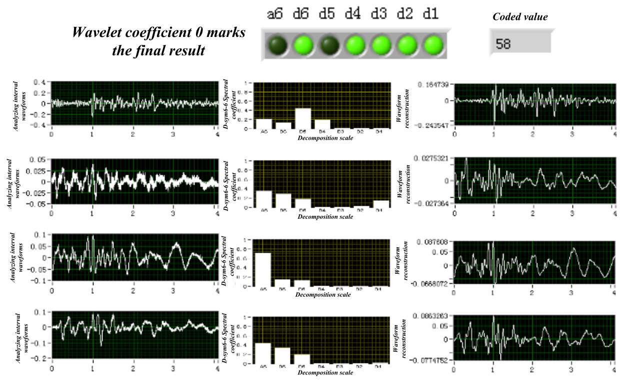

FIGURE 3. Characteristic energy spectrum and reconstitution waveform of encoding 58.

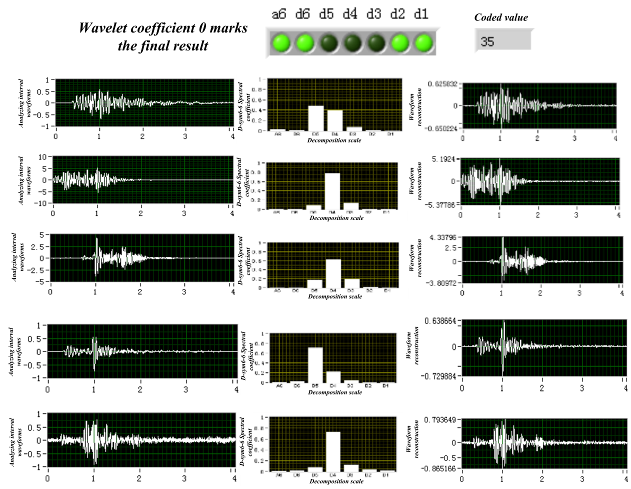

FIGURE 4. Characteristic energy spectrum and reconstitution waveform of encoding 35.

A. EFFECTIVENESS OF THE CODING SCHEME

Figure 2 shows the wavelet decomposition of different waveforms, the spectral coefficients, and the corresponding coding situation.

It can be seen that the extracted morphological quantization coding can distinguish different types of waveforms.

B. CONSISTENCY OF CODING SCHEME

Figure 3 shows the recognition of waveforms with the same code value "58".

Figure 4 shows the recognition of waveforms with the same code value "35".

It can be seen from the morphological comparison analysis of the original wave-forms, that the coding scheme proposed in this article has a higher recognition rate, It can encode common interferences and establish an identification library in actual production, which can effectively distinguish the waveforms and types of various interferences [12], [13].

IV. CONCLUSION

Based on wavelet analysis, this article studies some existing problems and key technologies in the field of acoustic emission signal processing and feature extraction.

1. According to the characteristics of coal-rock acoustic emission signals, the correlation principle of wavelet energy spectrum coefficients is introduced. The wavelet energy spectrum coefficients are used to characterize the response signals and interference signals of coal mines. The waveforms of the acoustic emission signals collected in the coal mine are processed to obtain the wavelet decomposition of each order of the acoustic emission signals and the reconstructed waveforms and their characteristic energy spectrum coefficients.

2. The wavelet characteristic energy spectrum feature vector is extracted by using the wavelet characteristic energy spectrum coefficient. Based on the wavelet characteristic coding, a wavelet characteristic coding method of acoustic emission signals is proposed. After the wavelet feature vector feature encoding processing, an independent code corresponding to the waveform is obtained. This code can be used as a sign of distinguishing each other, and it also contains the energy distribution characteristics, making the waveform features more orderly. The coding scheme can be used as a waveform index value, avoiding the tedious process of pattern recognition, and has the advantage of simplifying recognition.

3. The state time series of coal mine acoustic emission signals can be obtained by the coding method proposed in this article, and the evolution process of coal mine water inrush events can be analyzed, which provides new ideas and methods for solving the problems of monitoring technologies such as acoustic emission.

ACKNOWLEDGMENT

Thanks to the modern analysis and computing center of CUMT for providing computing services.

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