Multiple Source of Microseismic Signal Classification by Adaptive Short-time Fourier Transform Method

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Abstract — Classification of multi-source microseismic signal has been the difficulty in the mine safety microseismic monitoring data processing. The paper proposes using adaptive short-time Fourier transform (ASTFT) method to analyze the time-frequency characteristics of the signal, construct the signal feature vector, and using the high-dimensional K-mean classification to realize the automatic classification of multiple source signals. ASTFT overcome the short-time Fourier transform (STFT) of the conventional time-frequency resolution is caused by fixed time or frequency of fuzzy phenomenon, its emphasis lies in the selection of time window length adaptive algorithm, according to the characteristics of all kinds of microseismic signal quickly and reasonably choose the best length of window function, compared with other time-frequency analysis method, research has shown that this method the signal high time-frequency resolution, provide the characteristic signals and more accurate quantitative values. In the LuGu mining stope safety monitoring applications of the classification results are consistent with artificial classification, and for the mine microseismic signal automatic processing of new ideas are put forward.

Keywords - adaptive short-time transform; microseismic signal classification; mine safety monitoring; high-dimensional k-mean classification

I. INTRODUCTION

Microseismic safety monitoring technology has been developed rapidly in the application of mine safety monitoring. However, the complex operating environment and the disturbance factor of mine make a lot of vibration jamming signal (such as mechanical vibration and explosion etc.) of the scene can be easily collected by micro seismic monitoring system. The diversity and the non-stationary randomness of those signal determine the signal recognition and analysis must be very important but also extremely difficult, it is necessary to accurately quantify the characteristics of all kinds of noise signals to get accurate signal classification.

The micro seismic signal is non-stationary signal, at present, the major analysis method are Short-Time Fourier transform [1], wavelet transform [2] and S-Transform[3], etc. The Short-time Fourier transform (STFT) use sliding window of a fixed length to intercept the signal and describe it’s local feature by assuming the non-stationary signal is piecewise stationary, but according to the restriction of measurement uncertainty principle to the time-frequency resolution of window function[4], STFT need to consider the coordination of two factors of time and frequency resolution, which resulted in the limitations in its practical application. Similarly, wavelet transform is limited in its promotion since it is hard to find the wavelet function which can reflect the actual signal features in practice. S-Transform[5,6] as a hybrid of short-time Fourier transform and wavelet transform has good effect on non-stationary signal analysis. It effectively overcomes the shortcoming that STFT cannot change the size of time window, and introduce multi-resolution analysis of wavelet transform, and also keep direct contact with the Fourier spectrum[7]. Ni [8] using the short-time Fourier frequency analysis method to the car to start flutter analysis and the time-frequency analysis of the distinction; Zhu [9] the short-time Fourier transform is used to deconvolution in oil and gas detection technology has obtained the good effect.

In paper, the adaptive short-time Fourier transform is introduced to microseismic signal classification of safety monitoring of underground engineering, and apply this technology in China in a mine microseismic monitoring subject, through the signal time-frequency analysis, construct the characteristic vector of the quantitative indicators of multiple source signals, and the high-dimensional K-mean classification method[10] for automatic classification of multi-source signal for microseismic source signal identification and analysis provides an effective technical means.

II. METHOD AND PRINCIPLE

A. Basic theory of short-time fourier transform

Gabor[1] introduced the Short-Time Fourier transform to measure the frequency of the sound. \( g(t) = g(-t) \) is a real symmetric window function, the Short-Time Fourier transform can be defined as follows \( g_{x\tau} = g(t-u)e^{-j\omega} \).
The time-frequency resolution of Short-Time Fourier transform depends on the time frequency span of window function $g$ is an even function, so $g(t-u) = g(t-u)e^{-i2\pi u}$, $u$ as the center, along $u$ the span of time and does not depend on $u$ and $\xi$, that is

$$\sigma^2 = \int_{-\infty}^{\infty} (t-u)^2 |g(t-u)| dt = \int_{-\infty}^{\infty} |g(t)| dt, \quad (2)$$

Selection of window function $g(n)$, it is a cycle for $N$ symmetric discrete signal, the signal of discrete for short time Fourier transform (STFT),

$$S(f, n) = \langle f, g_n \rangle = \sum_{k=-N}^{N} f(k) g(n-k), \quad (3)$$

We selects the Gaussian function as the window function of short time Fourier transform (STFT). Its definition is as follows,

$$\phi_k(n) = e^{-\beta n^2/k^2}, \quad |k| \leq T, \quad (4)$$

**B. Maintaining the Integrity of the Specifications**

The time-frequency resolution of the short-time Fourier transform is only related to the time frequency span of window function, which depends on the form and length of the window function. For the short-time Fourier transform with fixed window function, its time-frequency resolution is fixed, which results in a fuzzy phenomena in time or frequency when a short burst signals without any prior knowledge were analyzed. This window length adaptive algorithm, which can select optimal window function length quickly and reasonably according to the characteristics of signals, can solve the above problem. It is well known that a shorter window function can make the short-time Fourier transform fast tracking of the signal changes, but the frequency resolution is poor ; a longer window function can get better frequency resolution, but blurred the time variation. Time frequency resolution is time-frequency energy clustering in time-frequency map, so that the higher aggregation, the higher resolution. Adaptive algorithm is based on the normalized local time-frequency energy maximum value to select the best time window length. In this paper, the local energy of each sample point is calculated by short-time Fourier transform, which is a function that takes $T$ as the independent variable.

$$E_n = \sum_{k=-N/2}^{N/2} \sum_{m=-N/2}^{N/2} |f(k+m)|^2 \exp \left( -i2\pi \left( \frac{k+m}{N} \right) \right)$$

$$= \sum_{k=-N/2}^{N/2} g^2(k) \sum_{m=-N/2}^{N/2} |x(k+m)|^2, \quad (5)$$

So that the best length is given by:

$$T^* = \max \{A, g_n(k), e_k(k)\}, \quad (6)$$

Where

$$e_k(n) = \sum_{n=-N/2}^{N/2} |x(k+m)|^2, \quad (7)$$

$A_n$ as the reciprocal of the energy of window function and a penalty factor for the increase of window length, as inner product.

The optimal short-time Fourier transform of the signal can be obtained by:

$$S(f, n) = \langle f, g_n \rangle = \sum_{k=-N/2}^{N/2} \exp \left( -i2\pi \left( \frac{k+m}{N} \right) \right) \exp \left( -i2\pi \frac{n-k}{T} \right), \quad (7)$$

**III. MODEL ANALYSIS**

The first example is analyzed the type design of the time window. As shown in Figure 1(I), an original signal $x$ is designed, which composed of two sinusoidal signals $x_1$, $x_2$ and a pulse signal. Frequency of $x_1$ and $x_2$ are 50Hz and 100Hz, the length of pulse signal is the same as time $t$ and the amplitude is 10 at 2100 and 2132 point and 0 at other points. Based on this signal, time-frequency analysis of short time Fourier transform with different window function is carried out to verify the effect of the spectrum analysis. The length of window function (Hamming window, Gauss window) are 3.2ms, 6.4ms, 12.8ms.

The time-frequency analysis map of Hamming window and Gauss window are shown in Figure 1(I) and Figure 1(III). Under the condition of the design parameters, the resolution of pulse signal of Hamming window is higher than Gauss window. STFT transform must select the appropriate time window length, which is the key of the signal time-frequency analysis. On one hand, the short time window causes poor frequency resolution; on the other hand, the longtime window could result in the phenomenon of frequency mutual superposition of different time.

The signal of second example selection is composed by two different frequency sine FM signal, the frequency are 50Hz and 100Hz, the sampling points and sampling rates are 257 and 256.

Figure 2(I) shows waveform of original signal, Figure 2(II) is the spectrum diagram, Figure 2(III-VI) shows the time-frequency spectrum of STFT, Wavelet transform, S-Transform and ASTFT. By setting the time window parameters, it can be found that the adaptive short time transform not only conducive to real-time processing of signals by having less parameters, but also has high time-frequency aggregation and resolution, which is suitable for the characteristic analysis of the microseismic noise signal.

**IV. APPLICATION OF MICRO SEISMIC SIGNAL TIME-FREQUENCY ANALYSIS IN LUGU IRON MINE**

The monitoring points of Lugu Iron Mine top mountain mine goaf micro seismic monitoring are arranged on the
pedestrian slope roadway of the 2560 working face to the 2550 working face (the plane layout figure is shown in Figure 3), the location of the sensor is located at the green point.

The purpose of safety monitoring is to monitor the change of surrounding rock burst in order to analyze the change law of the stress area, so the vibration signal of rock burst is needed. However, there are many kinds of noise source (non broken rock vibration signal) are produced during the production process and the original waveform of these signal are morphologically similar, it cannot be distinguished only by artificial reading wave. Based on this practical problem, the ASFFT frequency analysis method of mine micro seismic signal pre classification is introduced. Three component sensors (signal sampling is 1ms, the length of time is 3s, and the sum of sample points is 30000) are used in the safety monitoring. signal from different direction can be time-frequency analyzed by ASFFT. Depending on the signal source can be divided into the following types (see Figure 4).
IV. Wavelet transform time-frequency spectrum (scale = 64)

V. ST time-frequency spectrum

VI. Adaptive Short-Time Fourier Transform

Figure 2. The contrast of the ST time-frequency spectrum with synthetic signal.

(1) Rock burst signal

Figure 4(I) clearly shows a band of energy concentration area at 50Hz caused by downhole equipment electromagnetic interference and a energy concentration zone in the vicinity of 25Hz produced by rock fracture and, the duration of the rock burst event is about 300ms, and the peak value corresponds to frequency in the range of 15-30Hz.

(2) Blasting signal

Figure 4(II) shows the medium hole blasting signal, it can be seen that its frequency dispersed in a wide range and the high frequency components significantly, energy concentration area corresponding to the frequency range of 25-150Hz, and frequency distribution in the range of 0-500Hz. The energy of blasting signal is directly related to the amount of explosive. And the energy attenuation rate of blasting signal is faster than rock burst signal, the corresponding frequency is in the range of 130-170Hz. The arrival time of P wave and S wave can be clearly identified.

(3) Mechanical Equipment Signal

Figure 4(III) shows the locomotive signal, its duration is determined by actual running time of locomotive, the frequency component is obvious and the peak frequency is 25Hz and 50Hz, the frequency of 50Hz is electromagnetic interference in the operation of the downhole equipment, namely, the main frequency range of the locomotive signal is 20-30Hz. This signal has obvious reproducibility in time domain, energy and frequency have no significant change with time, the energy of main frequency signal is about 5, and the energy of signal components on both sides of the main frequency decreases gradually. The high frequency part of the Time-frequency Spectrum is electromagnetic interference caused by a variety of power supply and electronic equipment in mine.

(4) Electric Signal

Figure 4(IV) shows an electrical pulse signal, whose energy is concentrated in the high frequency band (>120Hz), and the energy is concentrated on the 120-150Hz in time-frequency Spectrum.

Figure 3. The diagram of sensor placement.
V. MULTI-SOURCE MICROSEISMIC SIGNAL CLASSIFICATION

Many mines, noise signals in the human disturbance, the characteristics of the frequency of a single, strong regularity, its characteristic value and human activities, equipment related to category, the construction of the time, especially in the time domain. All kinds of signal characteristics of the specific value as shown in table I,

<table>
<thead>
<tr>
<th>Source feature vector (T)</th>
<th>Max amplitude (mm/s)</th>
<th>Frequency band (Hz)</th>
<th>Main frequency (Hz)</th>
<th>Brilliant Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock burst (T1)</td>
<td>106 (105)</td>
<td>20-40 (30)</td>
<td>20 (20)</td>
<td>23 (23)</td>
</tr>
<tr>
<td>Blast (T2)</td>
<td>28400 (28400)</td>
<td>0-400 (150)</td>
<td>100 (100)</td>
<td>9300 (9300)</td>
</tr>
<tr>
<td>Mechanical Equipment (T3)</td>
<td>30 (30)</td>
<td>20-30 (25)</td>
<td>20 (20)</td>
<td>5 (5)</td>
</tr>
<tr>
<td>Electric signal (T4)</td>
<td>30000 (3000)</td>
<td>50 (50)</td>
<td>50 (50)</td>
<td>11000 (11000)</td>
</tr>
</tbody>
</table>

Mine in different kinds of micro seismic signals in frequency, amplitude, energy and so on various aspects have obvious differences, values in the amplitude, frequency, frequency and remarkable energy parameters for the element characteristic vector $T_n$ for construction,

$$T_n = [t_1, t_2, t_3, t_4].$$

(7)

Type of $T_n$ represent different types of seismic signal feature vector, $t_1$ is the maximum amplitude of signal, $t_2$ is the signal frequency value, $t_3$ is the signal frequency, and $t_4$ is the brilliant for signal energy.

Based on the Euclidean distance as the standard of the high-dimensional K-mean classification analysis [11], $X_1, X_2$ sample for two n mode, $X_1 = [x_{11}, x_{12}, ..., x_{1n}]^T$, $X_2 = [x_{21}, x_{22}, ..., x_{2n}]^T$, so the Euclidean distance is

$$D(X_1, X_2) = \sqrt{(t_{11} - t_{12})^2 + ... + (t_{1n} - t_{2n})^2}.$$ (8)

Select 7 days in practical monitoring signals for clustering analysis, the analysis results show that the characteristic signals is extracted by adaptive short-time Fourier transform can realize a preliminary classification of microseismic signals, such as in table II,

<table>
<thead>
<tr>
<th>Type</th>
<th>Rock burst</th>
<th>Blast</th>
<th>Mechanical Equipment</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic processing</td>
<td>141</td>
<td>5</td>
<td>39</td>
<td>62</td>
</tr>
<tr>
<td>Artificial processing</td>
<td>152</td>
<td>5</td>
<td>50</td>
<td>71</td>
</tr>
</tbody>
</table>

In the table, the microseismic signal automatic classification results similar to artificial classification, meet the application requirements.
VI. CONCLUSIONS

(1) Adaptive short-time Fourier transform can dynamically adjust window width, and algorithm parameters less because human disturbance is little, at the same time can guarantee high time-frequency resolution, help to accurately and efficiently processing multi-source noise signals, can be used for real-time micro seismic signal recognition and processing.

(2) In the paper, a combined into signal ASTFT time-frequency analysis, by adjusting the gauss window width factor value, it is concluded that ASTFT middle frequency resolution factor to change the laws of the Gaussian window width, the time resolution of high frequency and frequency resolution is improved, the lower the frequency of the low-frequency component but time resolution is improved.

(3) Using ASTFT to LuGu iron mine microseismic signals, time-frequency analysis is relatively accurate mine goaf microseismic safety monitoring multi-source signals of all kinds of quantitative indicators, using the high-dimensional K-mean classification to realize the automatic classification of multiple source signals, improve the accuracy of event orientation, analysis the changes of the surrounding rock stress provides an effective technical means.

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