A Study on Enhancing the Accuracy of P Wave Detection based on Double-Filtering Algorithm for Microseismic Signals from Underground Mines

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Abstract. Nowadays, intelligent mining is the global mining technology hotspot and the inevitable trend of mine development, especially in the environment where the safety, high efficiency and sustainable development of mines are directly restricted by the underground pressure disaster, which caused by high stress and mining disturbance. Microseismic monitoring technology is one of key technologies in underground pressure monitoring, which provides safety assessment on mine by analyzing microseismic signals to obtain their source location. The accuracy of P-phase onset time plays a key role in source location, where short term average/long term average (STA/LTA) method is the most wildly used method in P wave detection. However, the microseismic signal is too weak that can easily be affected by noise from underground mining, and STA/LTA ratio is also highly influenced. In this paper, a double-filtering algorithm based on band-pass filter and synchrosqueezing wavelet transform is proposed to remove the noise from field microseismic data. The results show that the double-filtering algorithm can greatly enhance the effect of STA/LTA, where more accurate P-phase onset time is obtained at the same time.

1. Introduction

With the increasing difficulty of mineral resources exploitation and the higher and higher requirements in mine safety in recent years, all countries attach great importance to the integration of mining and technology. Intelligent mine becomes one of development directions of the global mining industry [1]. As one of key technologies in intelligent mine construction, the microseismic monitoring system can monitor ground pressure activities 24 hours a day and find abnormal ground pressure areas in time through data analysis based on various parameters of microseismic data, which is the ultimate guarantee for safe, efficient and sustainable development of mines [2].
Most of data analysis in microseismic monitoring technology is based on the P-phase onset time of microseismic signals, where short term average/long term average (STA/LTA) method can detect P wave automatically by setting a proper threshold [3,4]. However, STA/LTA, whose ratio is very sensitive to the changes in signals, has strict requirements on data quality. When a microseismic signal is interfered by noise including human disturbance, power frequency interference and etc. from underground mines, the trend of STA/LTA ratio becomes quite complicated, and the P wave detection becomes a challenge. The study on improving the quality of microseismic signals to obtain a more accurate P-phase onset time by STA/LTA is very necessary.

In this paper, we propose a double-filtering method to enhance the accuracy of P wave detection for microseismic signals from underground mines. The double-filtering method is based on the band-pass filter and synchrosqueezing wavelet transform. Then the comparison of STA/LTA ratio between original data and filtered data is shown to evaluate the result of the double-filtering method. A field microseismic data from a mine in XinJiang is used here to illustrate the proposed method.

2. Brief mathematical theories

2.1. Short Term Average/Long Term Average (STA/LTA) Method

The STA/LTA ratio $R$ can be written as:

$$ R = \frac{STA}{LTA} = \frac{\frac{1}{ns} \sum_{j=i-ns}^{i} CF(j)}{\frac{1}{nl} \sum_{j=i-nl}^{i} CF(j)} $$

Where, $CF(j)$ is the characteristic function of the signal, $STA(i)$ is the short-time average of $CF(j)$ and $LTA(i)$ is the long-time average. $ns, nl$ are the length of short time and long time window, respectively.

$LTA(i)$ represents the noise level in a long term while $STA(i)$ can reflect the waveform change in short time. Not only microseisms, noise can also cause the waveform change in original data. The threshold $\lambda$ is preset to give a lower limit of $R$ to shield noise signals. When $R$ exceeds $\lambda$, we believe there exists a microseismic signal.

2.2. The double-filtering algorithm

By analyzing a large number of field microseismic data, the frequency range of the micro-seismic signal is found to be within the range of 20–1000Hz, where it is still difficult to separate the microseismic signal from noise signals in frequency domain for the original data containing noise with similar frequency and amplitude. The double-filtering algorithm based on band-pass filter and synchrosqueezing wavelet transform can remove the noise signals step by step.

Band-pass filter is one of the most wildly used filters, which allows signals in a specific band to pass through while shielding other bands [5,6]. The Kaiser window is used in band-pass filter, and the noise signals beyond 20–1000hz can be perfectly removed.

The synchrosqueezing wavelet transform is one of time-frequency analysis methods, which can characterize the energy spectrum of signals in time-frequency domain, allowing signal analysis in time and frequency domain simultaneously [7,8]. The function of synchrosqueezing wavelet transform is

$$ T_s(\omega, b) = \frac{1}{\Delta \omega} \sum_{a_1 \in \psi(\omega, b) - a_0} W_s(a_k, b) \alpha_k^2 \Delta a_k $$

(2)
Where $w_s$ is the wavelet coefficient of the signal $f(t)$, $a_k$ is the scale variable of $k^{th}$ component of $f(t)$, $b$ is time shift, $\Delta \omega = \omega_j - \omega_{j-1}$, and $\omega_j$ is the center frequency.

And the inverse transform is:

$$f(t) = \text{Re}\left[C_\psi^{-1} \sum_i T_i(a_i, b_i)(\Delta \omega)\right]$$ (3)

Where $C_\psi^{-1} = \int_0^{+\infty} \psi^*(\xi) \frac{d\xi}{\xi}$ is the Fourier transform of the conjugate of wavelet function, $\text{Re}$ is the real part of the component.

Microseismic signals and noise signals have different characteristics, which can be shown clearly in time-frequency spectrum based on the synchrosqueezing wavelet transform. Most of noise signals have lower energy with a wide distribution, while microseismic signals have higher energy and occur in a certain range of time scale. By removing the noise part of data in time-frequency spectrum, we can obtain higher quality signals with function (3).

3. Field data experiment

The microseismic data from a mine in XinJiang is used here to testify the effectiveness of the proposed method.

The original data is shown in Figure 1(a), and its sampling frequency is 6000Hz. The microseismic signal is quite weak under strong mixed noise. We set the short time as 0.005s, long time as 0.03s. The STA/LTA ratio $R$ is shown in Figure 2(a). With the effect of mixed noise, the trend of $R$ is quite complicated, where it is difficult to pre-set the $\lambda$ to pick up P-phase onset time.

By using band-pass filter, we can obtain the signal with its frequency range in 20~1000Hz, and its time-frequency spectrum is shown in Figure 3.

In the time-frequency spectrum, the energy is concentrated around 400Hz at 0.15~0.25s, and the energy in frequency range 150~450Hz is much higher than others. In this way, we remove the noise that frequency beyond 150~450Hz and the noise whose amplitude is lower than $10^{-5}$.

The time-frequency spectrum of filtered data is shown in Figure 4. Using function (3), the filtered data is shown in Figure 1(b) and its STA/LTA ratio is shown in Figure 2(b), where $R$ of noise part is much smaller than before while $R$ of microseismic signal is much larger. Choose $\lambda = 2.5$, P-phase onset time is shown as pink line in Figure 1, where the P-phase onset time of filtered data is more accurate than original data.

Figure 1. (a) Original data (b) Filtered data.

(a) Original data (b) Filtered data.

Figure 2. STA/LTA ratio
Figure 3. Spectrum of the band-pass filtered data.  

Figure 4. Spectrum of the filtered data.

4. Conclusion
In this paper, we studies the double-filtering algorithm based on the band-pass filter and synchrosqueezing wavelet transform to pick up the P-phase onset time of microseismic signals from underground mines more accurately. The band-pass filter based on Kaiser window can limit the frequency range of microseismic signals, while the synchrosqueezing wavelet transform provides a way to analysis data in time-frequency domain, and it is easier to separate the noise part from microseismic signal in time-frequency spectrum. The removal of noise part of data is achieved by the double-filtering algorithm. In this way, STA/LTA method is enhanced to pick up P-phase onset time accurately. The field data experiment has proved that the STA/LTA ratio of noise part of filtered data is smaller while the ratio of microseismic signal part is larger than before, and P-phase onset time is more accurate than before.

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