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*Article*

# Automatic P-Phase Onset Time Picking Method of Microseismic Monitoring Signal Underground Mine Based on Noise Reduction and Multiple Detection Indexes

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**Abstract:** The development of mineral resources in China has gradually entered the stage of deep mining. Rock burst, collapse and other ground pressure disasters caused by deep high stress have become major hidden dangers restricting mine safety production. Microseismic monitoring technology is an important means of ground pressure risk prediction. In this paper, the wavelet coefficient threshold denoising method in time-frequency domain, STA/LTA method, AIC method, Skew and Kurtosis method are studied, and the automatic P-phase onset time picking model based on noise reduction and multiple detection indexes is established. Through the effect analysis of microseismic signals collected by microseismic monitoring system of coral Tungsten Mine in Guangxi, automatic P-phase onset time picking is realized. the reliability of the P-phase onset time picking method proposed in this paper based on noise reduction and multiple detection indexes is verified. The picking accuracy can still be guaranteed under the severe signal interference of background noise, power frequency interference and manual activity underground mine, Which is of great significance to the data processing and analysis of microseismic monitoring.

**Keywords:** microseisms; P-phase onset time picking; STA/LTA method; AIC method; skew and kurtosis method; wavelet coefficient threshold denoising in time-frequency domain.

## 1. Introduction

The development of mineral resources in China has gradually entered the stage of deep mining. Rock burst, collapse and other ground pressure disasters caused by deep high stress have become a major hidden danger restricting mine safety production. Microseismic monitoring technology is an important means of ground pressure risk prediction (Gibowicz et al., 1998; Tian Yue et al., 2001; Li Shulin et al., 2005; Jiang Fuxing et al., 2006; Tang Lizhong et al., 2006; Feng Xiating et al., 2013; Wang Luchen et al. 2016; Feng Xiating, 2019; Palgunadi et al., 2020; Zhang Da et al., 2021; Zeng Zhiyi et al., 2023). For the microseismic monitoring system, the automatic identification and accurate picking of P-phase onset time of microseismic signals underground mine directly affect the timeliness and accuracy of microseismic source location, source mechanism inversion, and rock stability analysis (Liu Jinsong, Wang Yun, Yao Zhenxing, 2013; Bai Tian Yang, 2016; Yao Yanji et al., 2022). Therefore, the automatic identification and accurate picking of P-phase onset time of microseismic signals underground mine is the core premise of microseismic monitoring technology. Only by accurately identifying P-phase onset time can the accuracy of microseismic source location and source

mechanism inversion information be guaranteed, and then the ground pressure risk underground mine can be assessed (Feng Xiating et al., 2019; Li Tie et al., 2014; Li Xiang and Xu Nuwen, 2020).

The background noise, power frequency interference, artificial activity and other signals underground mine will seriously interfere with the effective microseismic signal, greatly reducing the signal-to-noise ratio of the microseismic information, resulting in increased difficulty in P-phase onset time picking (Wang Liguan, Wang Hui, Zhao Junjie, 2016). The microseismic monitoring system collect a large number of microseismic events every day. Although the P-phase onset time can be intuitively picked up by the manual operation of the data processor, the quality is greatly affected by the experience and subjectivity of the data processor (Li X, et al., 2017).

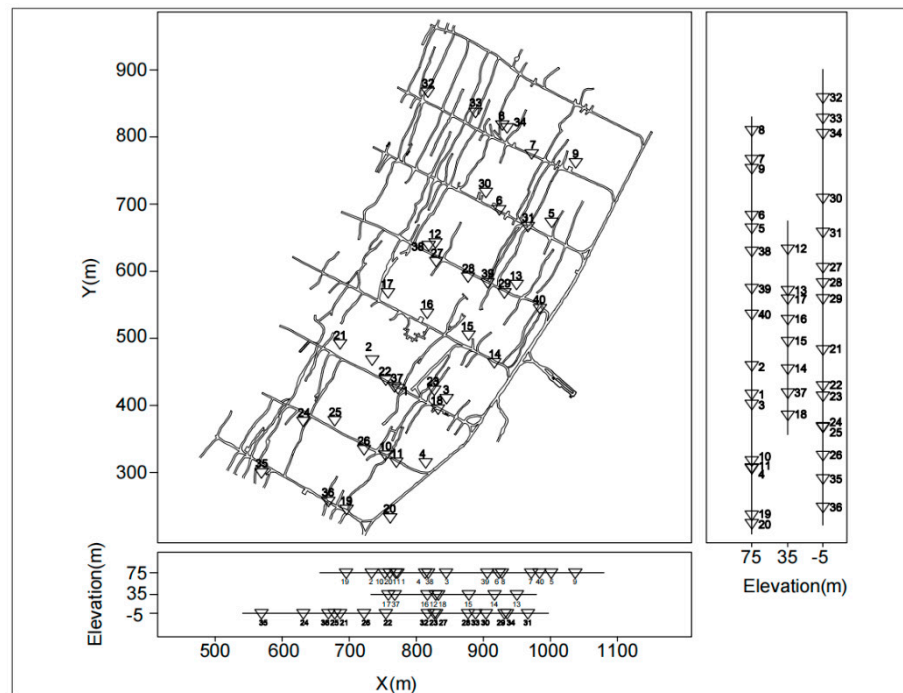
How to ensure the accuracy of automatic P-phase onset time picking of low SNR microseismic signal underground mine under severe interference environment? The traditional automatic P-phase onset time picking is mainly divided into the following categories: The first is the short-long-window ratio method (STA/LTA) (Allen, 1978; Liu Han et al., 2014), using the ratio of waveform amplitude, energy, waveform envelope function and other characteristic functions in the long time window and the short time window as the judgment criterion for P-phase onset time picking; The second is to assume that noise signals and microseismic signals have different statistical properties, and to use characteristic functions such as higher-order statistics (kurtosis and skewness) and entropy to realize automatic identification of microseismic signals (Saragiotis et al., 2002; Guo Tielong et al., 2017; Zhang Huanlan et al., 2013); The third type is to use cross-correlation theory to match the target waveform with the template waveform to get the relative P-phase onset time (Senkaya et al., 2014), and then add the absolute arrival time with the template waveform to get the P-phase onset time of the target waveform. Although the above method has effectively realized the automatic P-phase onset time picking, the picking accuracy still cannot meet the needs of microseismic location. Therefore, some scholars improve the recognition and picking effect of microseismic signals by analyzing the various characteristic differences between microseismic signals and environmental noise. For example, Song Weiqi et al. (2011) combined wavelet decomposition with Akaike information criteria to improve the P-phase onset time picking accuracy of microseismic signals. Tan Yuyang et al. (2016) made comprehensive use of the differences between microseismic signals and noise in energy, polarization and statistics, and effectively improved the anti-noise ability and picking accuracy of the P-phase onset time picking method to a certain extent. Some researchers also use the Time Frequency Transform (TFT) to transform the seismic wave signal in the one-dimensional time domain into the two-dimensional time-frequency domain, so that the location of the microseismic signal can be clearly identified on the time-frequency spectrum, and then signal processing and denoising can be carried out. Wavelet coefficient threshold denoising method in time-frequency domain has been widely concerned due to its simple principle (Donoho et al., 1994, 1995) and remarkable denoising effect (Chang et al., 2000; Mousavi et al., 2016, 2017; Cheng Hao et al., 2018; Zeng Zhiyi et al., 2023).

In this paper, the real-time processing of microseismic data are combined with the time-frequency domain wavelet coefficient threshold denoising method, STA/LTA method and AIC method (Liu Han et al., 2014; Zhang Huanlan et al., 2013), and the skew and kurtosis method based on higher-order statistics, established a P-phase onset time automatic picking model based on noise reduction and multiple detection indexes. Through the effect analysis of microseismic signals collected by microseismic monitoring system of coral Tungsten Mine in Guangxi, automatic P-phase onset time picking is realized. the reliability of the P-phase onset time picking method proposed in this paper based on noise reduction and multiple detection indexes is verified. The picking accuracy can still be guaranteed under the severe signal interference of background noise, power frequency interference and manual activity underground mine, Which is of great significance to the data processing and analysis of microseismic monitoring.

## 2. Data collection

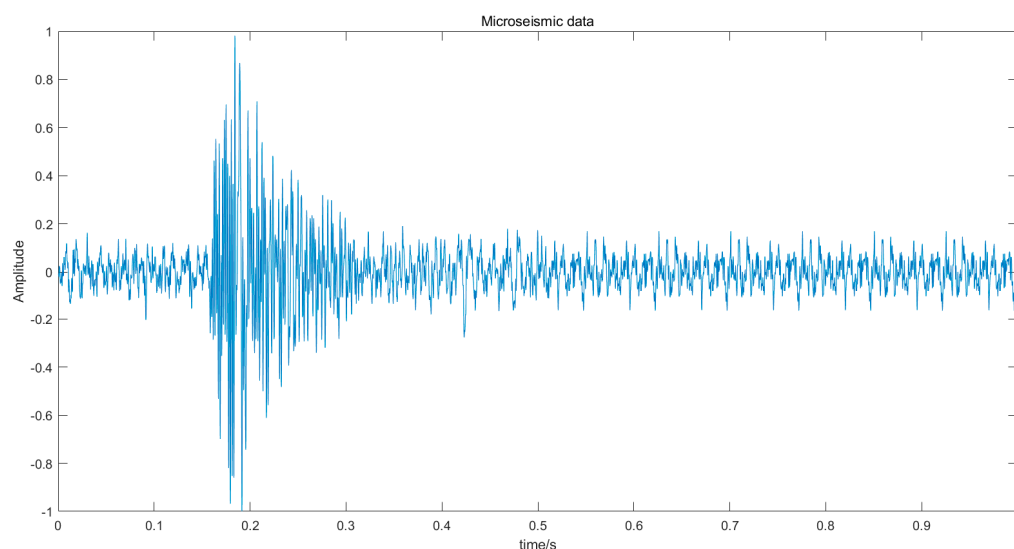
Taking the coral tungsten mine of Guangxi Guihuacheng Co., Ltd. as the research object, the coral tungsten mine of Guangxi is located in the territory of Coral Town, Zhongshan County, and its geographical center coordinates are 111° 21' 13" east longitude, 24° 20' 02" north latitude. A total of

40 microseismic monitoring stations are arranged in the goaf or around the stope in the middle section of 75m, 35m and -5m, among which 16 monitoring points are arranged in the middle section of 75m, respectively, at 0# perforation, 2# perforation, 4# perforation, 3# perforation, 5# perforation and 7# perforation. A total of 8 monitoring points were arranged in the middle section of 35m, which were arranged at 0# perforation, 1# perforation and 3# perforation. A total of 16 monitoring points were arranged in the middle section of -5m, which were arranged in 0# perforation, 2# perforation, 4# perforation, 3# perforation, 5# perforation and 7# perforation. The layout plan of the microseismic monitoring network is shown in Figure 1, where the triangle is the microseismic station and the number is the sensor number.

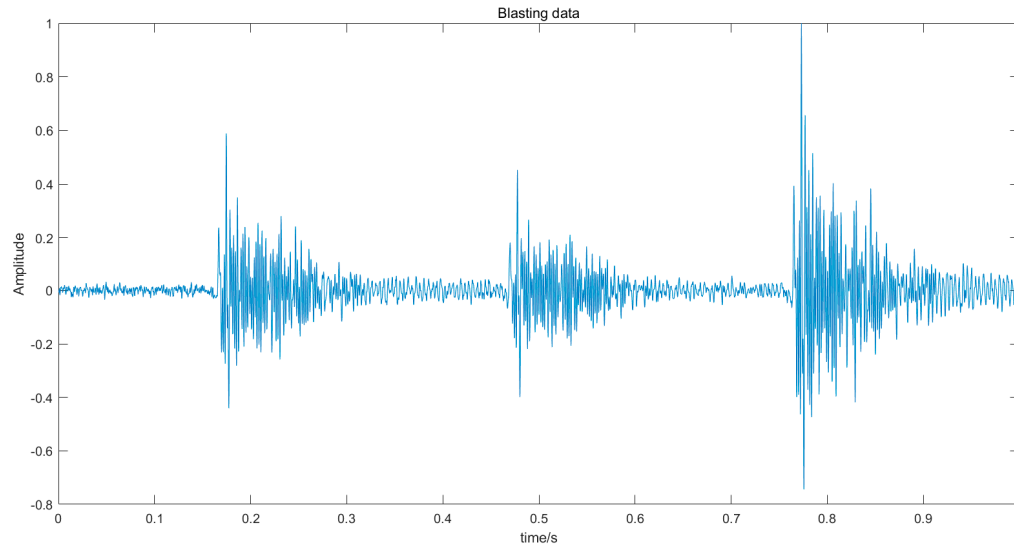


**Figure 1.** Layout Plan of Microseismic Monitoring Network for Guangxi Coral Tungsten Mine.

Typical microseismic signals collected by the microseismic monitoring system are shown in Figure 2, and typical blasting signals are shown in Figure 3.



**Figure 2.** Typical microseismic signal from underground mines in Guangxi Coral Tungsten.

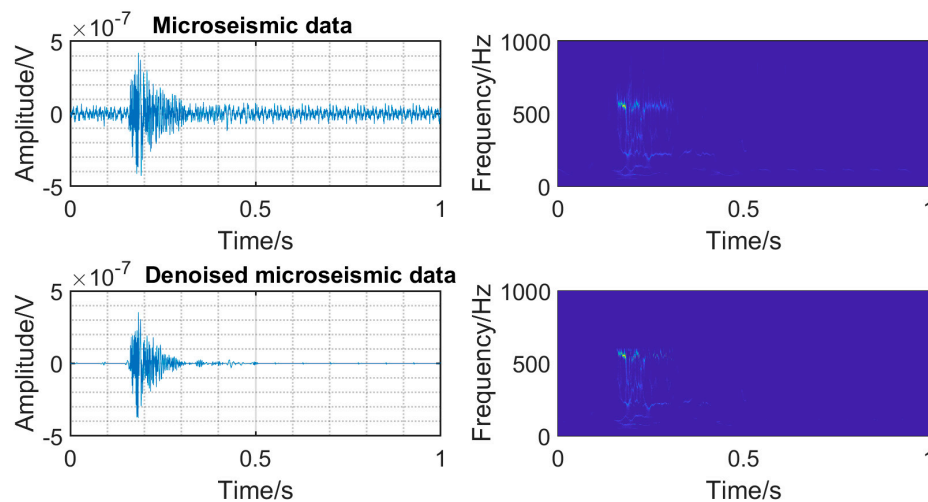


**Figure 3.** Typical blasting signal from underground mines in Guangxi Coral Tungsten.

### 3. Method

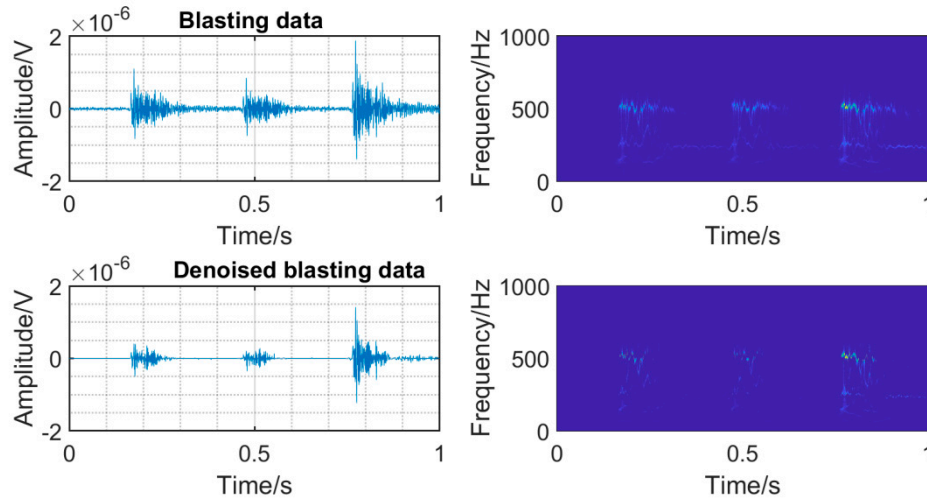
#### 3.1. Noise reduction method

The time-frequency analysis was carried out on the original microseismic monitoring data, and the threshold filtering of wavelet coefficient in the time-frequency domain was adopted (Zeng Zhiyi et al., 2023) to reduce the noise wavelet coefficient. Time domain diagram and time frequency diagram of original signal and denoise microseismic signal underground mine are shown in Figure 4. Time domain diagram and time frequency diagram of original signal and denoise blasting signal underground mine are shown in Figure 5. The SNR of mine microseismic waveform was increased from 9.0768 of the original waveform to the highest 21.2767 (SNR is the ratio of the amplitude root mean square of the waveform in a short time window with the first arrival time as the center), and the SNR of mine blasting waveform was increased from 14.06782 of the original waveform to the highest 27.1316. And the background noise in the same frequency band with the signal can be removed well, which is conducive to the recognition and accurate picking of P-phase onset time.



**Figure 4.** Time domain diagram and time frequency diagram of original signal and denoise microseismic signal underground mine.





**Figure 5.** Time domain diagram and time frequency diagram of original signal and denoise blasting signal underground mine.

### 3.2. STA/LTA method

STA/LTA method is the most widely used automatic picking method at present. Its main principle is to pick up P-phase onset time according to the change trend of the long-short mean value of the microseismic characteristic function, give a sliding long time window, take a short time window in this window, and set the characteristic function  $CF(i)$ . The P wave arrival time is judged by the ratio of the short window signal characteristic function mean (STA) and the long window signal mean (LTA). When the ratio is greater than the preset arrival threshold (Thr), the corresponding time is the P-phase onset time. STA mainly reflects the average value of microseismic signals, and LTA mainly reflects the average value of background noise. At the arrival time of microseismic signal, STA changes faster than LTA, and the corresponding STA/LTA value will have a significant increase. When the ratio is greater than Thr, a microseismic event can be determined to occur, so as to achieve the purpose of automatic detection and picking up P-phase onset time of microseismic. The STA/LTA algorithm formula (Allen, 1978) is as follows:

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

$$LTA(i) = \frac{1}{nl} \sum_{j=i-nl}^i CF(j) \quad (2)$$

Where,  $i$  is the sampling time,  $ns$  is the length of the short-time window,  $nl$  is the length of the long-time window, and the characteristic function is  $CF(i)$ , which generally represents the amplitude and energy of the microseismic shape.

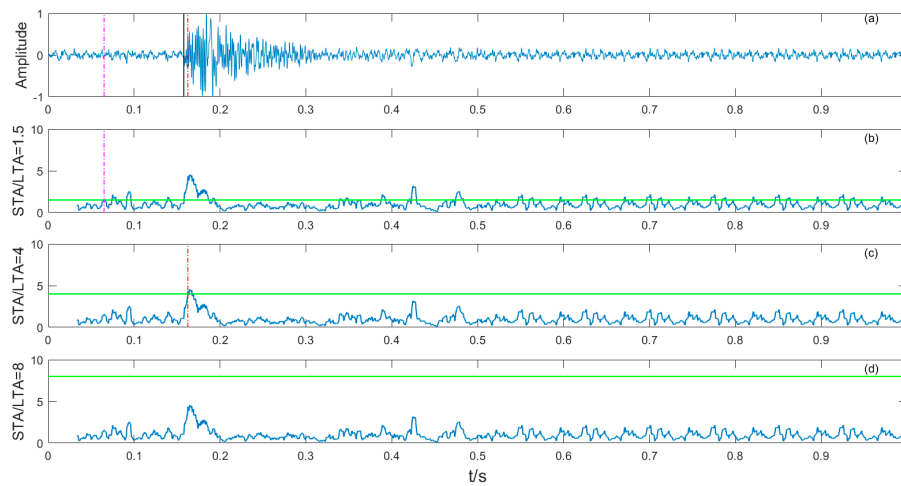
The expression of  $Thr(i)$  is

$$Thr(i) = \frac{STA(i)}{LTA(i)} \quad (3)$$

When  $Thr(i)$  is greater than a certain threshold  $\lambda$ , the corresponding time is the time.

Because the data processor needs to deal with a large number of low SNR original microseismic signals, the selection of low SNR microseismic signals when verifying STA/LTA method, the selection of feature function and time threshold is the key of the algorithm, which plays a decisive role in the accuracy of the picking results.  $CF(i)$  takes the square of the amplitude, when the threshold  $\lambda$  is 1.5, 4, 8 respectively, and the picking effect is shown in Figure 6. The original blasting waveform is shown in Figure 6(a), and the STA/LTA function when the threshold  $\lambda$  is 1.5, 4, 8 respectively are shown in Figure 6(b) (c) (d). The black solid line is the manually picked P-phase onset time, the pink dashed

line is the automatically picked P-phase onset time when the threshold is 1.5, and the red dashed line is the automatically picked P-phase onset time when the threshold is 4. When the threshold is 8, the P-phase onset time is not picked up, it can be seen that the accuracy of the selection of the threshold  $\lambda$  directly determines the quality of the STA/LTA method. Although the STA/LTA method can quickly and automatically pick up the P-phase onset time, the picking precision depends on the accuracy of the time threshold selection. In general, the short-time window length is set to 2-3 times the main period of the microseismic signal, and the long-time window length is 5-10 times the short-time window length (Liu Han et al., 2014). After repeated testing and comparative analysis, the short-time window length in this paper is 100 sampling points, the long-time window length is set to 8 times the short-time window length, and the threshold  $\lambda$  is set to 4.



**Figure 6.** (a) The original microseismic signal; (b) STA/LTA function  $\lambda$  of 1.5; (c) STA/LTA function  $\lambda$  of 4; (d) STA/LTA function  $\lambda$  of 8.

### 3.3. AIC method

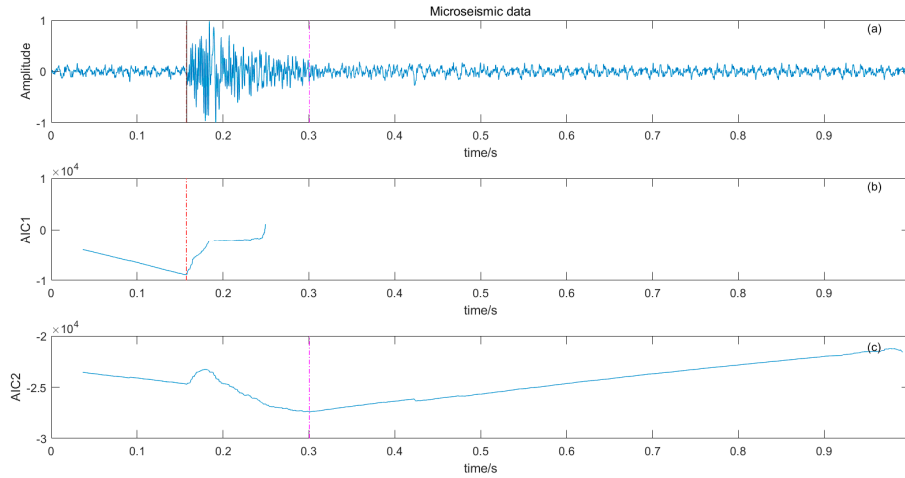
AIC is based on the concept of entropy, derived from information theory and maximum likelihood principle, and used to estimate the complexity of the model and measure the goodness of the model fit. Because the statistical characteristics of noise and microseismic signal are very different, the two signals have the worst fit at the junction of microseismic signal and noise, and the AIC value of this junction is the smallest, that is, the P-phase onset time of microseismic event. Given a microseismic data  $Y$  of length  $N$ , assuming that the  $i$ -th point is the best boundary between the noise component and the microseismic signal component, the signal is divided into two segments at the  $i$ -th point, and the corresponding AIC value can be approximated as (Zhang Huanlan et al., 2013; Zhang Da et al., 2021).

$$AIC(i) = i \cdot \lg(\text{var}(Y[1, i])) + (N - i - 1) \cdot \lg(\text{var}(Y[i + 1, N])) + C \quad (4)$$

Where  $\text{var}$  represents the variance of the data,  $Y[i+1, N]$  is the amplitude of the signal in the window length  $N-(i+1)$ , and  $C$  is the constant.

The selection of low SNR microseismic signal picking results is shown in Figure 7(a) is the original microseismic signal, the black solid line is the arrival time of manually picking P-wave, the red dashed line is the location of the local minimum of AIC function, and the pink dashed line is the location of the global minimum of AIC function, (b) the time window adopts the AIC function from the first 0.12s to the last 0.12s. In the case that the time window just includes the waveforms before and after the arrival of the microseismic signal, the AIC function changes at the first arrival time, and the local minimum is the global minimum, and the picking accuracy is high at that time. (c) The time window adopts the AIC function from the first 0.12s to the last 0.83s, and the position where the global minimum appears changes. The results show that the local minimum obtained by AIC method

is suitable for the situation where the approximate time window of P-phase onset time is known, and can be used in combination with STA/LTA method.



**Figure 7.** (a) The original microseismic signal; (b) The time window adopts the AIC function from first to front 0.12s to back 0.12s; (c) The time window adopts the AIC function from first to front 0.12s to back 0.83s.

### 3.4. Skewness and kurtosis method

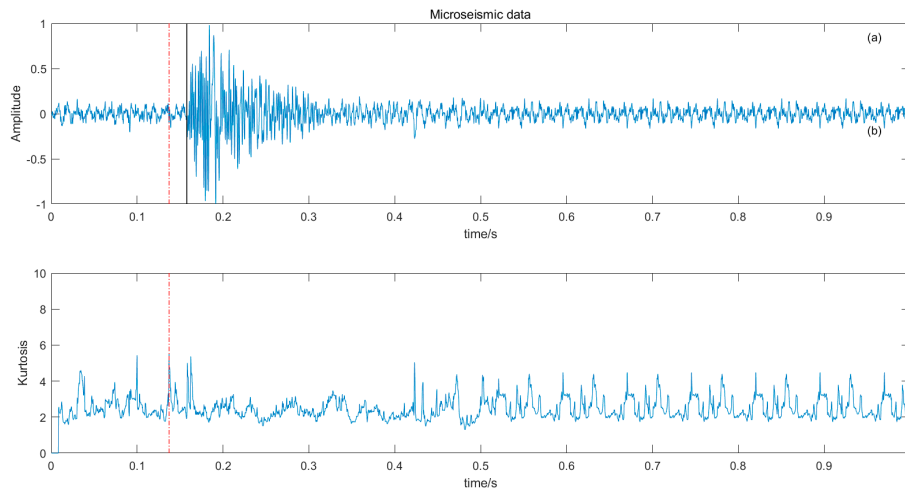
Skewness and kurtosis are one of the important methods to measure the Gaussian characteristics of microseismic recordings. Based on the assumption that microseismic signals are non-Gaussian and background noise records are Gaussian (Saragiotis et al., 2002), The Skewness and Kurtosis features of signal amplitude are used as the feature functions of the initial arrival pick-up of microseismic signals, and the P-phase onset time is picked up by using the position information of the extreme value of skewness and kurtosis, and the formula is as follows

$$S(i) = \frac{1}{W} \sum_{j=i}^{i+W} \left[ \frac{Y(j) - \bar{Y}}{\sigma} \right]^3 \quad (5)$$

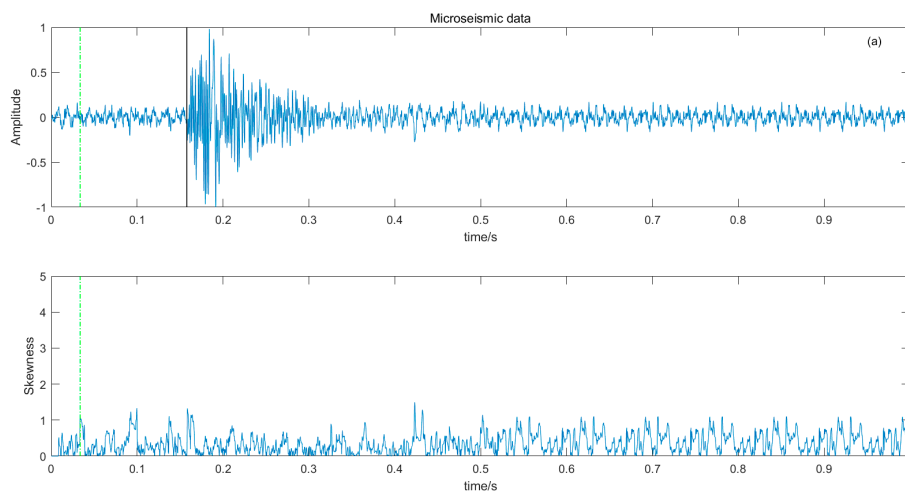
$$K(i) = \frac{1}{W} \sum_{j=i}^{i+W} \left[ \frac{Y(j) - \bar{Y}}{\sigma} \right]^4 - 3 \quad (6)$$

Where,  $W$  time window length,  $\bar{Y}$  and  $\sigma$  time window amplitude mean and standard deviation. The length of the time window  $W$  should not be too large or too small, and should try to just contain microseismic signals. The time window is too long, resulting in reduced sensitivity, and conversely, some high-amplitude noises are misidentified, reducing the picking accuracy. There is a big difference between the P-phase onset time picked by kurtosis and skewness directly and the P-phase onset time (black solid line) manually, The results are shown in Figure 8 and Figure 9.





**Figure 8.** (a) Original microseismic signal; (b) Kurtosis function.

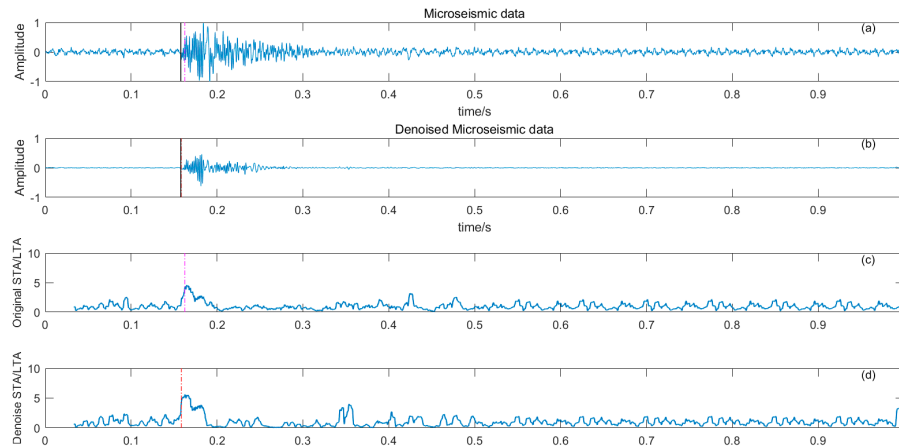


**Figure 9.** (a) The original microseismic signal; (b) Skewness function.

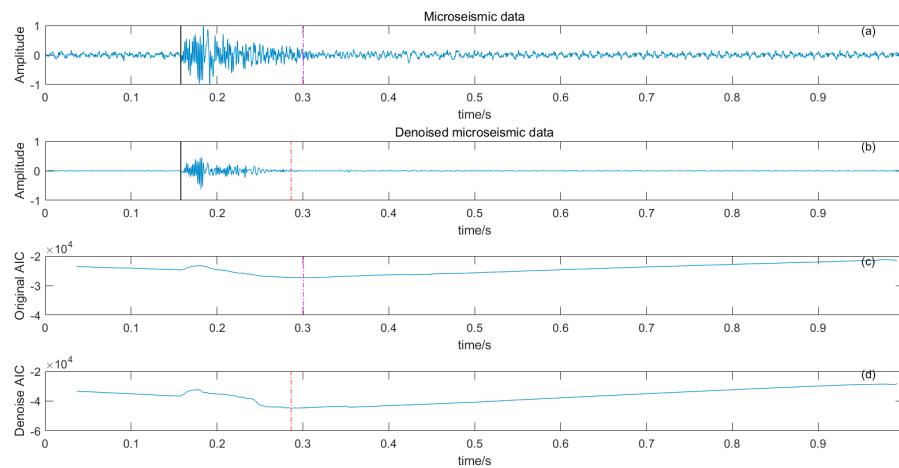
### 3.5. Noise reduction and multiple detection indexes method

Based on the time-frequency analysis of the original microseismic monitoring data, the wavelet coefficient threshold filtering in time-frequency domain is adopted to reduce the noise wavelet coefficient, remove the background noise in the same frequency band as the signal, improve the signal to noise ratio of the mine microseismic shape, and establish the P-phase onset time automatic picking model based on denoising and STA/LTA, AIC and PAI-S/ K indicators. The time picking effect of time-frequency domain wavelet coefficient threshold denoising combined with STA/LTA method is shown in Figure 10. (a) is the original microseismic shape, (b) is the filtered microseismic signal, (c) is the original STA/LTA function, (d) is the filtered STA/LTA function, and the black solid line is the manually picked P-phase onset time. The pink dashed line is the automatic P-phase onset time of the original waveform, and the red dashed line is the automatic P-phase onset time pickup position of the filtered micro-shock shape. It can be seen that the accuracy of the filtered waveform pickup is greatly improved compared with the manually picked P-phase onset time (black solid line). As shown in Figure 11, (a) is the original microseismic shape, (b) is the filtered microseismic shape, (c) is the original AIC function, and (d) is the filtered AIC function. The black solid line is the manually picked P-phase onset time, the pink dashed line is the automatically picked P-phase onset time of the original waveform, and the red dashed line is the automatically picked P-phase onset time of the filtered microseismic shape. Both the original microintegral signal and the filtered microseismic

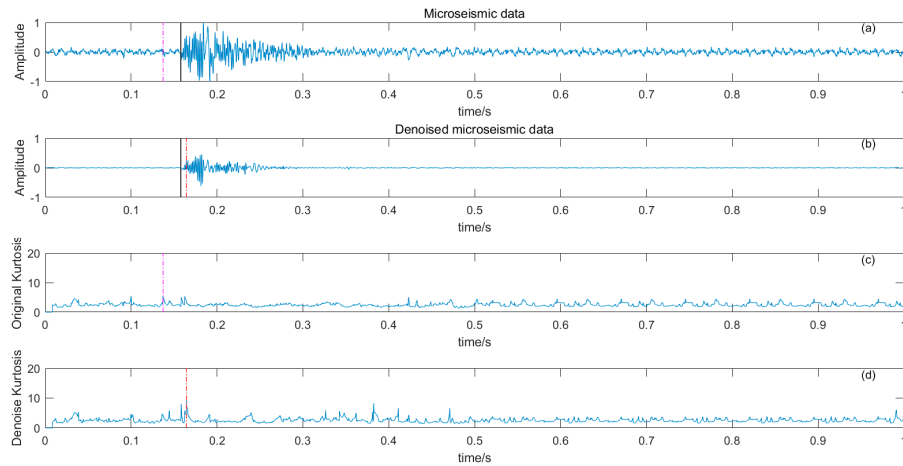
signal fall into the global minimum when using AIC function alone to pick up the P-phase onset time, and the error is larger than that when manually picking up the P-phase onset time (black solid line). Figure 12 and Figure 13 show the arrival time picking effect of kurtosis K function and skewness S function respectively. It can be seen that, when using kurtosis K function or skewness S function alone, compared with manually picking P-phase onset time (black solid line), the P-phase onset time (red dashed line) of filtered data is smaller than that of the original micro-seismic P-phase onset time (pink dashed line). However, it is still impossible to accurately pick up the P-phase onset time.



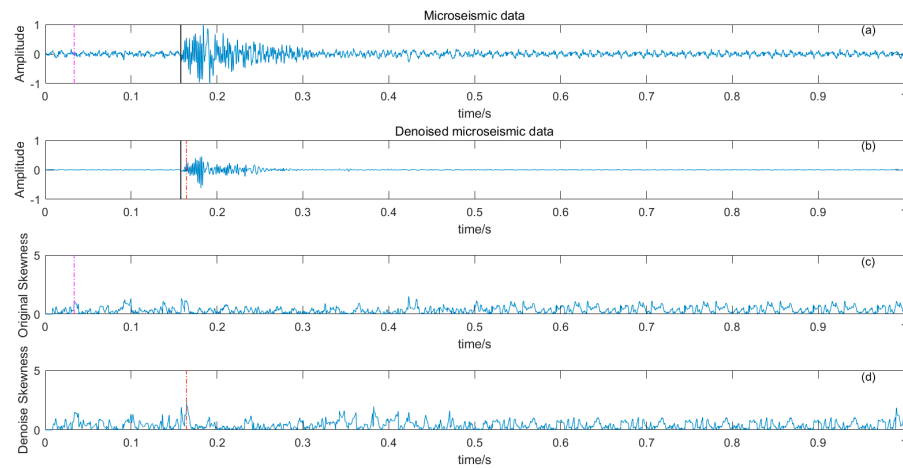
**Figure 10.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original STA/LTA function; (d) Denoised STA/LTA function.



**Figure 11.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original AIC function; (d) Denoised AIC function.

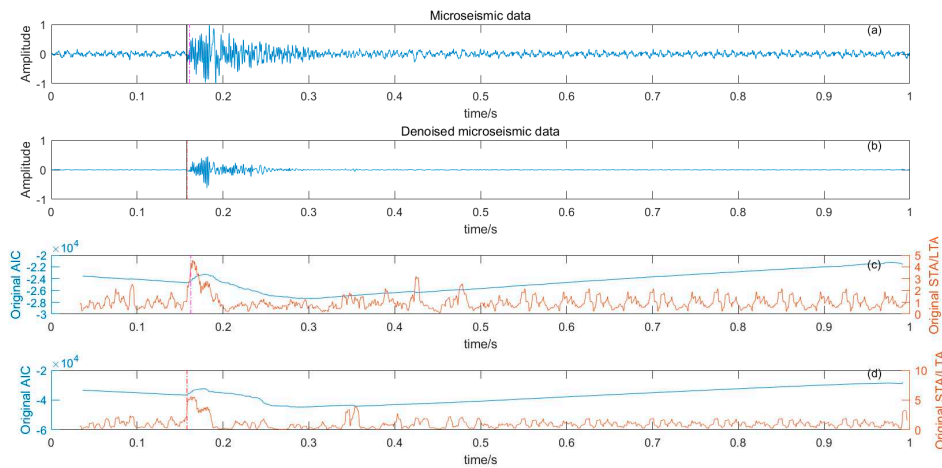


**Figure 12.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original kurtosis K function; (d) Denoised kurtosis K function.

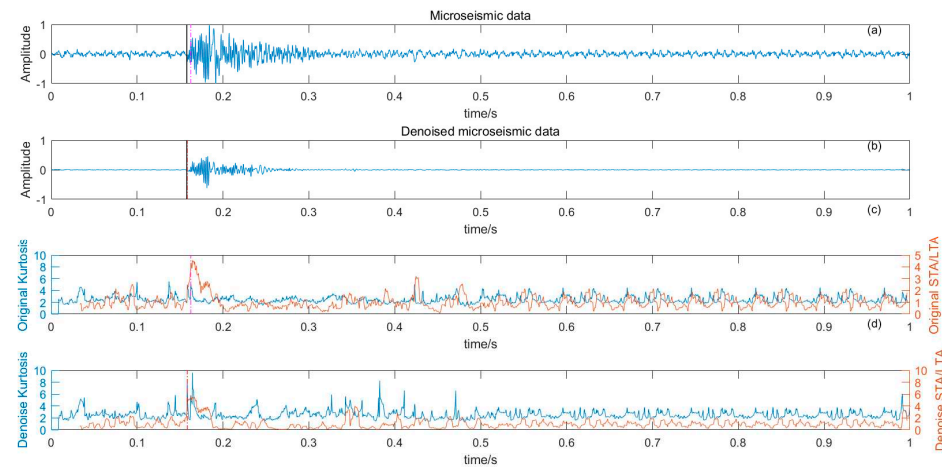


**Figure 13.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original skewness S function; (d) Denoised skewness S function.

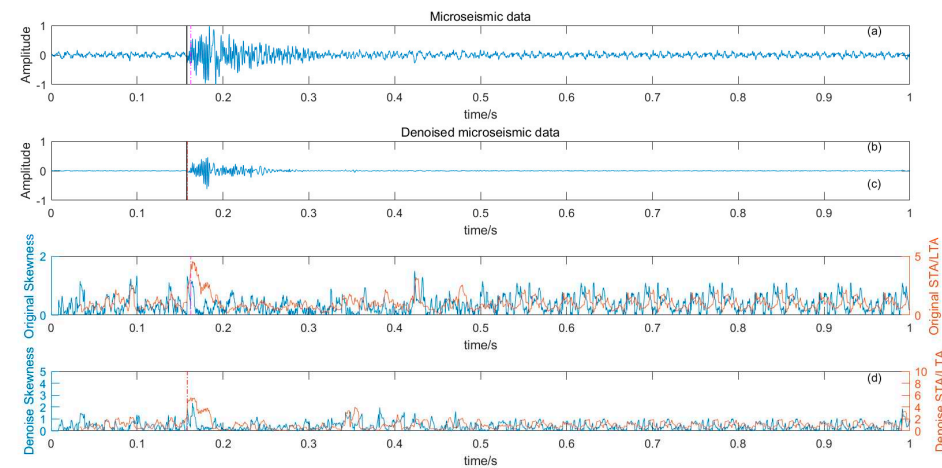
Figure 14 shows the P-phase onset time picking results of the detection model after filtering, STA/LTA and AIC function are combined. It can be seen that the accuracy of P-phase onset time (red dashed line) of the filtered data is greatly improved compared with that of the original microseismic P-phase onset time (pink dashed line), and the problem of falling into the global minimum when AIC function is used alone is avoided. Figure 15 shows the P-phase onset time picking effect of the detection model after combining filtering, STA/LTA and kurtosis K function. It can be seen that the accuracy of the P-phase onset time (red dashed line) of the filtered data is greatly improved compared with that of the original micro-seismic P-phase onset time (pink dashed line). Figure 16 shows the P-phase onset time pick up effect of the detection model after combining filtering, STA/LTA and skewness S function, and the P-phase onset time pick up accuracy is greatly improved.



**Figure 14.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original STA/LTA-AIC function; (d) Denoised STA/LTA-AIC function.



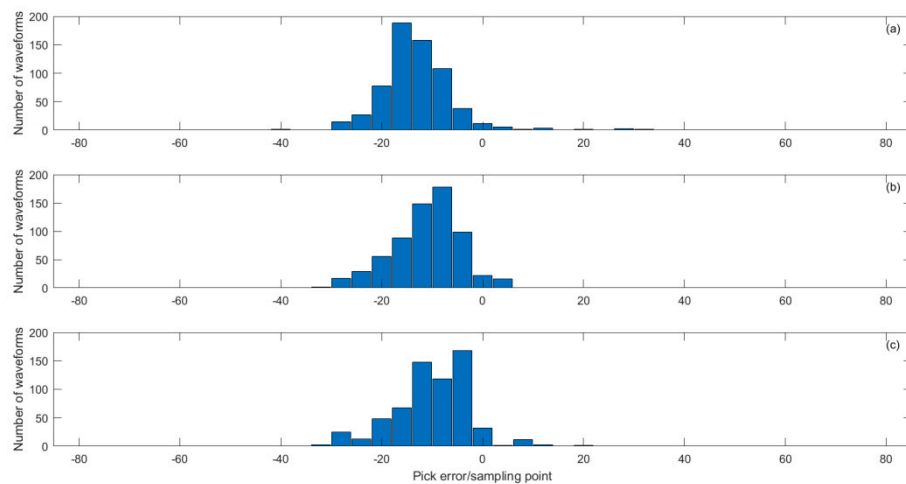
**Figure 15.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original STA/LTA-K function; (d) Denoised STA/LTA-K function.



**Figure 16.** (a) Original microseismic signal; (b) Denoised microseismic signals; (c) Original STA/LTA-S function; (d) Denoised STA/LTA-S function.

#### 4. Results

The short-short window (STA/LTA) ratio method has a good effect on the recognition of P-phase onset time of signal after noise reduction, but the automatic P-phase onset time picking accuracy is not high enough, and it is difficult to select an accurate threshold, while AIC picking method has high local picking accuracy. Therefore, the P-phase onset time picking detection model combined with filtering, STA/LTA and AIC function is chosen as one of the picking methods in this paper. In addition, the detection model combining denoising, STA/LTA with kurtosis K function or skewness S function can realize the precise pickup of microseismic signal P-phase onset time when the kurtosis and skewness of microseismic records meet the discrimination threshold at the same time. From the picking results in Figure 14 to Figure 16, it can be seen that the three P-phase onset time picking detection models all have higher accuracy, meet the requirements of microseismic location accuracy, and can save labor costs and improve efficiency. In order to better demonstrate the accuracy of the automatic picking method, the automatic picking results of multiple microseismic signals collected by the microseismic monitoring system of coral Tungsten Mine in Guangxi were compared with the manual picking results, and the statistical distribution of errors (automatic picking results minus manual picking results) between the results of three P-phase onset time detection models and the manual picking results were obtained, as shown in Figure 17. (a) for the detection model error by the combination of denoise, STA/LTA and AIC function; (b) for the detection model error by the combination of denoise, STA/LTA and kurtosis K function; (c) for the detection model error by the combination of denoising, STA/LTA and skewness S function; It can be seen from the figure that the overall picking errors of the three picking methods are small, mainly distributed in the range of -25 to 0 sampling points. Considering that the sampling rate of the data acquisition system is 6000Hz, the corresponding time pick error is 0 ~ 4.17ms. The first arrival result of the automatic picking method is generally smaller (time advance) than that of the manual picking, which is reasonable, because the artificial picking is generally based on the position of the amplitude maximum point, and then picks up the P-phase onset time near the position, so the first arrival result may be too large. The P-phase onset time of manual pickup will increase with the decrease of SNR.



**Figure 17.** (a) The P-wave time picking and detecting model error combined with denoising, STA/LTA and AIC function; (b) The P-wave time picking and detecting model error combined with denoising, STA/LTA and kurtosis K function; (c) The P-wave time pick-up combined with denoising, STA/LTA and skewness S function detects the model error.

#### 5. Conclusion

In this paper, the wavelet coefficient threshold denoising method in time-frequency domain, STA/LTA method, AIC method, PAI-S/K method based on skew and kurtosis are studied, and the P-phase onset time automatic picking model based on denoising and multiple detection indexes is



established, and the P-wave arrival time automatic and accurate picking is realized. And through the analysis of the P-phase onset time automatic picking effect of the microseismic signals collected by the microseismic monitoring system of coral Tungsten Mine in Guangxi, the following conclusions are drawn:

(1) When the signal-to-noise ratio is low, the P-phase onset time pick up and detection model combined with denoising, STA/LTA and AIC function is adopted; the P-phase onset time pick up and detection model combined with denoising, STA/LTA and kurtosis K function is adopted; the P-wave time pick up and detection model combined with denoising, STA/LTA and skew S function has strong anti-interference ability. More reliable when picked up.

(2) STA/LTA method can quickly pick up the P-phase onset time, and the practical application is still very wide. The selection of the threshold is the key of the algorithm, and the picking accuracy is extremely dependent on the accuracy of the selection of the threshold. AIC method relies on the correct selection of the window when calculating the local minimum point of AIC function. When the time window just contains the initial arrival of the microseismic P wave, this method has a high accuracy. This method is suitable for the situation where the approximate position of the P wave's arrival time is known.

(3) This paper proposes an automatic P-phase onset time picking method based on denoising and multiple detection indexes. In the case of serious signal interference such as background noise, power frequency interference and manual activity in the mining site, the picking accuracy can still be guaranteed, which is of great significance for the processing and analysis of microseismic monitoring data.

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