An Improved Method for Picking Up Microseismical P Waves for Earthquake Monitoring by Communication Signal

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Abstract. Accurate pickup of microseismic P waves when they arrive is a key link in microseismic monitoring and the basis and prerequisite for realizing microseismic source positioning. Based on the STA/LTA algorithm, an improved P wave arrival time picking algorithm is proposed. First, use STA/LTA to pick up the time \( t_i \) of the same signal based on four different feature functions, use the minimum value \( \min(t_i) \) and maximum value \( \max(t_i) \) as the reference, and expand forward and backward by \( L/10 \) according to the signal length \( L \). The sampling points form the pick-up time window \( M \), and the AIC algorithm is used to pick up the accurate first arrival time of the signal under the pick-up time window \( M \). Taking manual picking results as the benchmark, and comparing and analyzing the results of automatic picking using the AIC algorithm, the experimental results show that the improved algorithm improves the accuracy of picking up microseismic signals with high signal-to-noise ratio by 4% (the error within ±3ms is accurate picking) The accuracy of low signal-to-noise ratio signal pickup is increased by 16% (the error is within ±10ms for accurate pickup).

Keywords: Microseismic signal, Pick up at first arrival, AIC, STA/LTA.

1. Foreword

Micro-seismic monitoring technology is widely used in oil and gas exploration and development, mine pressure monitoring and underground coal mine illegal mining monitoring and other engineering fields. In the micro-seismic monitoring system, the accuracy of the micro-seismic P-wave pick-up directly affects the accuracy of the micro-seismic source positioning. The method of picking up high-precision P-wave has always been a problem for scholars.

At present, the initial to the time of collection of micro-seismic P-wave mainly related methods, full-wave seismic phase analysis, artificial neural network method, STA/LTA method, AIC method/fractal dimension method and so on [1]. Stevenson first used STA/LTA length window ratio in 1976 for microwave pick-up [2]. The equality of the left country proposed to use multiple rolling window pick-up at first to the beginning, and successfully applied to seismic wave first-to-the-beginning pick-up [3]. Allen Rex V uses feature functions instead of microstructure data as input parameters to pick up P and S waves [4]. Bear et. improve Allen Rex V's algorithms, optimize their feature functions and set dynamic thresholds to pick up the first time, faster and more accurate than previous algorithms [5]. Japanese scholar Akihito proposed the AIC algorithm in 1973, which was initially applied by Takanami and others to pick up natural earthquakes at the beginning and achieve
good results [6]. Meada proposes the VAR - AIC algorithm for the problem of high-order matrix inverse computation of AIC algorithm. The algorithm does not need to calculate orders. This method improves the efficiency of first-to-last pick-up [7]. Song Weiqi and Lu Shichao overcome the disadvantages of traditional AIC susceptibility to noise interference by improving the W - AIC algorithm. This algorithm improves pick-up efficiency and accuracy [8]. Although the AIC algorithm can pick up the signal more accurately at the beginning of the time. However, because this algorithm is affected by the time window, it is easy to get the local very small value of the signal so generally will not be used alone [9] [10].

Due to the complexity of the underground environment, the collected microsonic signal usually has the characteristics of low signal-to-noise ratio, non-linearity, non-smoothness and so on. The above method is not very good for some low signal-to-noise ratio signals to pick up the first arrival. The accuracy of manual picking is easily influenced by subjective factors, and the pick efficiency is low. In order to solve these problems, an improved automatic pick-up method for micro-seismic p-waves is proposed. This method is based on the characteristic analysis of STA/LTA method and AIC method. First, the effect of feature function on the accuracy of STA/LTA algorithm is used to obtain the approximate time of the signal to determine a suitable pick window. In the determined time window, AIC algorithm is used to calculate the exact first-to-the-beginning to achieve accurate pick-up of the micro-seismic signal.

2. The principle of the first pick algorithm

2.1. Analysis of the principles of STA/LTA and AIC algorithms

The STA/LTA algorithm is a classic first-time pick-up method. The changes in amplitude, frequency, etc. of the signal are reflected by calculating the ratio of short window to long window in the time domain. The principle is shown in Figure1. First define the feature function $CF(i)$. Select the appropriate long $l_l$ and short windows $l_s$. If a microsonic signal arrives, the ratio of STA to LTA mutates. When its value is greater than the pre-set threshold $\phi$, the mutation point is treated as the first to the point of the microsonic event. The formula is as follows:

$$STA(i) = \frac{1}{l_s} \sum_{i=1}^{l_s} CF(i)$$  

$$LTA(i) = \frac{1}{l_l} \sum_{i=1}^{l_l} CF(i)$$  

$$\frac{STA(i)}{LTA(i)} = \frac{\frac{1}{l_s} \sum_{i=1}^{l_s} CF(i)}{\frac{1}{l_l} \sum_{i=1}^{l_l} CF(i)} \geq \phi$$
The principle of AIC algorithm pick-up at that time is characterized by the AR model by using the difference of statistical characteristics between the effective signal and the noise signal in the micro-seismic signal. Due to the different AR model orders for signals with different statistical characteristics, the difference in fitting between the noise signal and the valid signal will result in the AIC minimum. This is used as a basis for determining the arrival of micro-seismic signals. Meada et al. propose a simplified form of calculating AIC values as follows:

$$AIC(q) = q \log\{\text{var}(x[1,q])\} + (N - q - 1) \log\{\text{var}(x[q+1,N])\}$$

$\var(x[1,q])$ and $\var(x[q+1,N])$ represents the variance of the data segments of the two micro-seismic signals before and after the point $q$.

During the initial pick-up process, if there is a significant P-wave at the microsonic signal, a global minimum AIC value is obtained at the initial toe point. When the corresponding sampling point is the first arrival of the microsonic signal, the schematic of the first arrival of the pick signal is shown in Figure 2.

However, the signal noise of the micro-seismic signal is relatively low, there is no obvious first arrival. When calculating using AIC algorithm, if you choose the appropriate time window, we can calculate the minimum value point corresponding to the real first to the present time. However, if the
window selection is not appropriate, there will be several very small value points, easy to cause the micro-seismic signal at the beginning of the error pick-up.

2.2. Improved pick algorithm principle

Based on the analysis of the principle of AIC algorithm and STA/LTA algorithm, the micro-seismic signal has the characteristics of low signal-to-noise ratio and non-stable in view of the high precision requirement of AIC algorithm for time window. Combined with the STA/LTA algorithm to pick up the characteristics of the approximate time, a micro-seismic time-to-time pick-up method (hereinafter referred to as: S/L - AIC algorithm). The algorithm first uses four characteristic functions of the STA/LTA algorithm to pick up the first to the moment $t(i = 1, 2, 3, 4)$ of the same microsonic signal. The minimum $\min(t)$ and maximum $\max(t)$ values of the four first-to-the-moments are then used as the base. Expand $L/10$ sampling point forward and backward according to the length of the signal L to form a new pick window $M = [\min(t) - L/10, \max(t) + L/10]$. The minimum time window value is 0 when $\min(t) \leq L/10$. Finally, the time window M is calculated as the pick time window of the AIC algorithm.

3. Simulation experiments and analysis

The micro-seismic signal acquisition platform is mainly composed of vibration sensor, blasting vibration signal data acquisition and transmission module and upper computer. The vibration sensor uses the three-axis accelerometer SNV203 with high sensitivity characteristics and is installed at a depth of 80 meters underground by drilling well grout on the ground.

After the vibration sensor detection and identification, the micro-seismic signal is transmitted to the data acquisition and transmission module, which is transmitted to the upper computer via USB interface for display and storage. The experimental study of first-time pick-up was carried out by using two sets of micro-seismic signals collected. The first set of data is 25 high signal-to-noise-ratio blasting vibration signals. The second set of data is 25 low signal-to-noise ratio blasting vibration signals. The two groups are shown in figure 3.

![Figure 3. Blast vibration signals with a high and low signal-to-noise ratio](image)

As can be seen from figure 3, although the vibration signal of high signal-to-noise ratio is polluted by noise, it is obvious at the beginning of the year. For the low signal-to-noise ratio blasting vibration
signal, due to its serious influence by background noise, the initial jump point is flooded, it is not possible to accurately distinguish the signal's first to the starting moment.

The AIC algorithm and the S/L - AIC algorithm is used to verify the accuracy of the S/L - AIC algorithm at the beginning of the first-to-last pick-up of the two signals. The result pair of its picks is shown in Figure 4. The result pair of its picks is shown in Figure 4. Point A (6030 sample point) in Figure 4 (a) is the manual pick-up point. As a reference, the error is determined to be accurate pick-up within 5 sampling points for high signal-to-noise ratio signals. Point B (6027 sample point) in Figure 4 (b) is the first-to-last point picked up by the AIC algorithm. Point C (6030 sample point) in Figure 4 (c) picks up the first to the point of arrival for the S/L - AIC algorithm. The results show that the S/L - AIC algorithm has higher pick accuracy. The results picked up for the first set of high signal-to-noise ratio data are shown in Table 1.

![Figure 4. A comparison chart of the results picked up at the first arrival of the high signal-to-noise ratio signal](image)

| Picking algorithm for first arrival | Pickup accuracy within 5ms | Pickup accuracy within 3ms |
|-----------------------------------|-----------------------------|-----------------------------|
| AIC algorithm                     | 100%                        | 96%                         |
| S/L - AIC algorithm               | 100%                        | 100%                        |

As can be seen from Table 1, for high signal-to-noise ratio blasting vibration signals, both algorithms can accurately pick up the signal at the beginning of the signal when the pick-up error is within 5ms. When the error is reduced to less than 3ms, the accuracy of the S/L - AIC algorithm pick-up is higher than that of the AIC algorithm.

The low signal-to-noise ratio blasting vibration signal is processed by AIC algorithm and S/L - AIC algorithm, and the results are shown in Figure 5.
Figure 5. The low signal-to-noise ratio signal picks up the result comparison chart at the first arrival.

Point A (4703 sample point) in Figure 5 (a) is manually picked up to the point in time for reference. Figure 5 (b) is the first arrival of the AIC algorithm pick-up. Because the AIC algorithm is too large, it incorrectly picks the global minimum C point (10466 sampling point). Local very small value point B (4706th sampling point) is near the signal's true arrival. For the S/L - AIC algorithm, the D point is accurately picked (4710th sampling point). The traditional AIC algorithm can accurately pick up the first arrival of the low signal-to-noise ratio signal due to the large selection of the window. The results picked up for the second set of high signal-to-noise ratio data are shown in Table 2.

Table 2. The result of the low signal-to-noise ratio signal at first arrival

| Picking algorithm for first arrival | Pickup accuracy within 10ms | Pickup accuracy within 5ms |
|-----------------------------------|-----------------------------|-----------------------------|
| AIC algorithm                     | 80%                         | 68%                         |
| S/L - AIC algorithm               | 96%                         | 88%                         |

As can be seen from Table 2, the pick accuracy of S/L - AIC algorithm is significantly higher than that of AIC algorithm, and under different error criteria, S/L - AIC algorithm is about 18% higher than AIC algorithm pick accuracy.

4. Summary

Through the analysis of STA/LTA and AIC primary pick-up algorithm, it is concluded that the STA/LTA algorithm has the characteristics of simple calculation, fast running speed and strong real-time. And AIC algorithm can accurately calculate to the point in time, vulnerable to the influence of time window selection. According to the real-time monitoring needs of the source location system with strong real-time and high accuracy, a new micro-seismic P-wave pick-up algorithm is proposed. The blast vibration signal with high and low signal-to-noise ratio was simulated by MATLAB using the algorithm and AIC algorithm. The results show that the S/L - AIC algorithm picks up more
accurately to the vibration signal with high signal-to-noise ratio, which is less error standard. For low signal-to-noise ratio blasting vibration signals, the accuracy of S/L - AIC algorithm pick-up was significantly higher than that of traditional AIC algorithms, and the accuracy of pick-up was increased by about 18%. For the complex environment underground, the algorithm is more effective for the extraction of micro-seismic signals with low signal-to-noise ratio, which further lays the foundation for improving the accuracy of seismic source positioning.

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