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Improved modified energy ratio method using a multi-window approach for accurate arrival picking

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ABSTRACT

To identify accurately the location of microseismic events generated during hydraulic fracture stimulation, it is necessary to detect the first break of the P- and S-wave arrival times recorded at multiple receivers. These microseismic data often contain high-amplitude noise, which makes it difficult to identify the P- and S-wave arrival times. The short-term-average to long-term-average (STA/LTA) and modified energy ratio (MER) methods are based on the differences in the energy densities of the noise and signal, and are widely used to identify the P-wave arrival times. The MER method yields more consistent results than the STA/LTA method for data with a low signal-to-noise (S/N) ratio. However, although the MER method shows good results regardless of the delay of the signal wavelet for signals with a high S/N ratio, it may yield poor results if the signal is contaminated by high-amplitude noise and does not have the minimum delay. Here we describe an improved MER (IMER) method, whereby we apply a multiple-windowing approach to overcome the limitations of the MER method. The IMER method contains calculations of an additional MER value using a third window (in addition to the original MER window), as well as the application of a moving average filter to each MER data point to eliminate high-frequency fluctuations in the original MER distributions. The resulting distribution makes it easier to apply thresholding. The proposed IMER method was applied to synthetic and real datasets with various S/N ratios and mixed-delay wavelets. The results show that the IMER method yields a high accuracy rate of around 80% within five sample errors for the synthetic datasets. Likewise, in the case of real datasets, 94.56% of the P-wave picking results obtained by the IMER method had a deviation of less than 0.5 ms (corresponding to 2 samples) from the manual picks.

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Contents

1. Introduction

Hydraulic fracture stimulations are widely used to enhance oil and gas recovery in low permeability reservoirs, as well as to enhance the circulation of water during geothermal power generation. Microseismic monitoring is crucial to delineate the propagation of fractures generated

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during the hydraulic fracture stimulation. By monitoring fracture information, including the azimuth, height, length and flow of fluid, the cost of well completion can be reduced, and the productivity of oil and gas extraction can be enhanced.

Accuracy of P- and S-arrival time picks is one of the factors that can reduce the uncertainty in the estimation of the hypocenter. However, accurately identifying the arrival times of the P- and S-wave signals is challenging because the recorded data contain high-amplitude noise, which makes it difficult to characterize the signal. In addition, since the amount of microseismic data is typically much greater than that of vertical seismic profiling, and crosswell seismic tomography, it is very time-consuming to identify the arrival times of P- and S-waves manually. Therefore, accurate automatic detection of the appearance of the signal in noisy data is required.

Several automatic arrival time identification methods have been reported using energy-based methods (Coppens, 1985; Allen, 1978; Munro, 2004; Chen and Stewart, 2005; Han et al., 2009; Han, 2010, Sabbione and Velis, 2010) as well as statistical approaches (Sleeman and van Eck, 1999; Bose et al., 2009; Akram, 2011). There have also been reports of algorithms that use fractal-based methods in the time-domain (Sabbione and Velis, 2010). Akram and Eaton (2016) well reviewed all these arrival-time picking methods including a correlation based method and neural networks for downhole microseismic data. Of the representative statistical approaches, an autoregressive-Akaike information criterion method (AR-AIC), which uses the difference of stationarity between the signal and noise, has been used to detect P and/or S phases (Sleeman and van Eck, 1999). However, the AR-AIC method does not perform well if the signal-to-noise ratio (S/N) is low and the arrival signal is ambiguous. Recently, attention has focused on methods that use differences in amplitude between the signal and the noise in the time domain. One such method is the short-term-average to long-term-average (STA/LTA) (Allen, 1978; Munro, 2004), which consists of calculating the L1 or L2 norm for short- and long-term moving time windows. This method yields good results for data with a high S/N ratio. However, the results are poor or inconsistent with a low S/N ratio. In addition, the computational costs are high because the LTA window is typically quite long.

A multiple-window algorithm (Chen and Stewart, 2005) using three moving windows was reported, which is similar to the classical STA/LTA method using an L1 norm. With this method, absolute amplitudes for

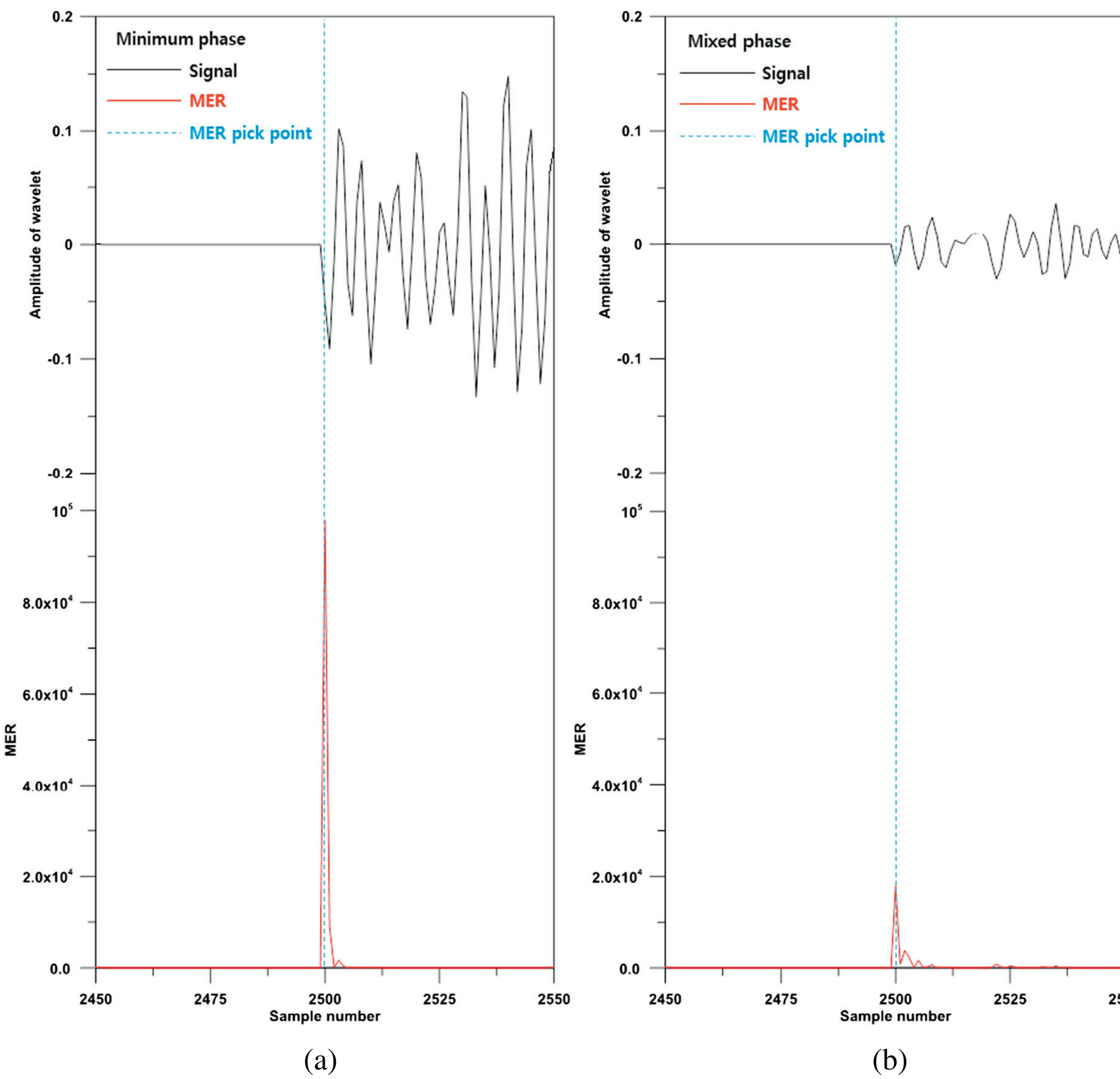

Fig. 1. Results obtained using the MER method. (a) A noise-free signal with the minimum delay (top) and the distribution of the MER value for the data (bottom). (b) A noise-free signal with a mixed delay (top) and the distribution of the MER value for the data (bottom). The preceding and following window length for MER performance is 200 and 600 samples, respectively.

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