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Identifying *P*-phase arrivals with noise: An improved Kurtosis method based on DWT and STA/LTA

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ABSTRACT

A discrete wavelet transform (DWT) and short time average to long time average (STA/LTA)-based Kurtosis algorithm (W-S/L-K method) is proposed to pick the arrival time of the *P*-phase; this method advantageously combines the outstanding ability of retrieving the *P*-phase arrival information from wavelet coefficients at high resolutions with inherent reliability in obtaining the *P*-phase arrival time using the STA/LTA picking method. The W-S/L-K method uses local maximum amplitudes and local kurtosis onsets from the wavelet detail components to determine the *P*-phase arrival times reliably and accurately. It was tested and verified using microseismic data collected from the Yongshaba mine. The results show that the W-S/L-K method's rates of picking errors smaller than 5 ms, 10 ms, and 15 ms were 58%, 86%, and 97.5%, respectively, and the W-S/L-K method was able to pick higher quality *P*-phase arrival times than those determined using the Kurtosis, Skewness, STA/LTA, Kurtosis + STA/LTA, and Skewness + STA/LTA methods. The proposed method provides a reliable technique for accurately picking *P*-phase arrival times, especially for signals with low signal to noise ratios (SNRs), heavy tails, and spikes. Moreover, it is able to detect pure noise.

1. Introduction

Detection of *P*-phase and picking the *P*-phase arrival are elementary and important steps for event identification, location estimation, and source mechanism analysis in seismology (Gou et al., 2011; Alvarez et al., 2013; Yue et al., 2014; Li and Dong, 2014). Although an analyst can visually complete these tasks, manual detection and picking are quite time consuming and may be affected by the experience and subjectivity of the analyst (Galiana-Merino et al., 2008; Karamzadeh et al., 2013; Hafez et al., 2013, Li et al., 2016). In addition, large amounts of seismic data also increase the need for a reliable and automatic picking methodology. However, background and stationary noise often contaminate the seismic data (Dong et al., 2016a, 2016b), causing the detection and picking to be difficult and unreliable.

Motivated by these facts, various methods have been developed for automatic and accurate *P*-phase arrival identification. Allen (1978) and Earle and Shearer (1994) used simple amplitude and energy thresholds to pick the *P*-phase arrivals. VanDecar and Crosson (1990), Gibbons and Ringdal (2006), Gibbons et al. (2012), Senkaya and Karsli (2014), and Ait Laasri et al. (2014) applied cross correlation techniques to detect *P*-phase arrival, and it is rapidly becoming a standard method for identifying seismic signals from source regions with repeating seismicity. Lockman and Allen (2005), Hildyard et al. (2008), and Hildyard and Rietbrock (2010) designed the damped predominant period (T^{pd}) method. Hafez et al. (2009) and Gou et al. (2011) used spectrogram-based methods. Wang and Teng (1995), Zhao and Takano (1999), and Gentili and Michelini (2006) proposed an artificial neural network-based picking procedure. Furthermore, wavelet-based methods (Anant and Dowla, 1997; Simons et al., 2006; Galiana-Merino et al., 2007), polarization analysis (Vidale, 1986; Magotra et al., 1987; Kulesh et al., 2007), autoregressive techniques (Leonard and Kennett, 1999; Sleeman and van Eck, 1999; Zhang et al., 2003), fractal dimension methods (Boschetti et al., 1996; Jiao and Moon, 2000; Gholamy et al., 2008; Liao et al., 2010), pseudo-probabilities-based method (Ross and Ben-Zion, 2014a), local-maxima distribution (Panagiotakis et al., 2008), manifold-based approach (Taylor et al., 2011), singular-value-decomposition-based method (Kurzon et al., 2014), and higher order statistics (Saragiotis et al., 2002, 2004; Lokajíček and Klima, 2006; Galiana-Merino et al., 2008; Küperkoch et al., 2010; Nippress et al., 2010; Liu et al., 2014; Ross and Ben-Zion, 2014b; Baillard et al., 2014) have been proposed for automatically picking *P*-phase arrivals. A review can be found in Tselentis et al. (2012), who categorized the previous *P*-phase picking methods into energy ratio criteria, autoregressive methods, fractal-based methods, seismic polarity assumption, and other methods.

Higher order statistics provide a measure of the sharpness of a distribution, which can be an effective tool for identifying signals

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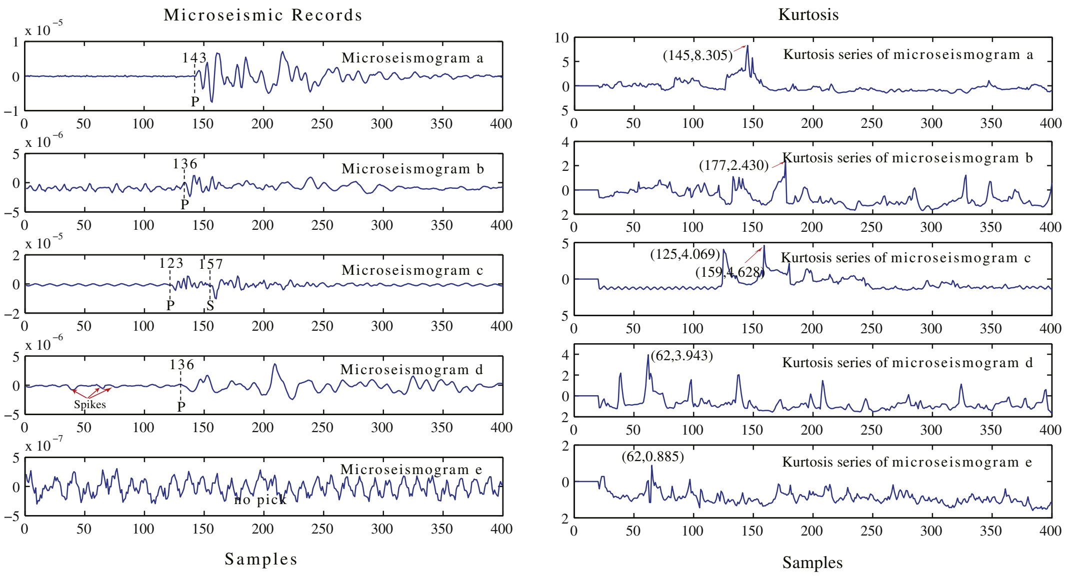

Fig. 1. Typical microseisms (left panel) and their corresponding kurtosis series (right panel). a: a microseism with a clear onset; b: a microseism with a low SNR; c: a microseism with a strong *S*-phase following the *P*-phase; d: a microseism with some spikes before the *P*-phase arrival; e: pure noise. The dashed lines in the microseismogram represent the arrival times that were picked manually. The numbers and values in the brackets are the possible onsets obtained using the Kurtosis method and the corresponding Kurtosis values, respectively.

with non-Gaussian features (Galiana-Merino et al., 2008). Saragiotis et al. (2002, 2004) applied higher order statistical functions to identify *P*-phase arrival times by introducing the Skewness and Kurtosis functions. Lokajíček and Klima (2006) discussed the influence of different higher order statistics on *P*-phase picking. Galiana-Merino et al. (2008) proposed the Kurtosis method using the stationary wavelet technique, and the global maximum slope of the Kurtosis values was chosen as the *P*-phase arrival. Küperkoch et al. (2010) selected the Kurtosis to replace the characteristic function (CF) of Allen's method (Allen, 1978). Nippress et al. (2010) used an STA/LTA function or the damped predominant period T^{pd} function (Lockman and Allen, 2005) to determine an initial picking region, and then refined the pick using a kurtosis CF. Liu et al. (2014) combined a fourth-order statistics algorithm with the Akaike information criterion for determining *P*-phase arrival. Ross and Ben-Zion (2014b) applied related filters to remove *P*-wave energy from seismograms and utilized STA/LTA and Kurtosis detectors in tandem to lock on the phase arrival. Baillard et al. (2014) presented a modified Kurtosis CF to improve the picking accuracy and used clustering and distribution analysis to reject erroneous picks. However, these kurtosis-based methods did not specifically consider spikes, heavy tails, and pure noise, which may cause large errors or failure when picking.

In this paper, we present an improved Kurtosis method, the W-S/L-K method, for *P*-phase arrival picking based on the discrete wavelet transform (DWT) and short time average to long time average (STA/LTA). The method relies on the extraction of frequency and wavelet domain characteristics of microseisms. It was tested and verified using microseismic data collected from the Yongshaba mine, and the results show that the proposed method can pick arrival times more accurately than the results obtained by the Kurtosis, Skewness, STA/LTA, Kurtosis + STA/LTA, and Skewness + STA/LTA methods. A further examination of the proposed method indicates that it provides a reliable technique for picking *P* arrival times, particularly for signals with low signal to noise ratios (SNRs), heavy tails, spikes, or pure noise.

2. The Kurtosis algorithm

The Kurtosis algorithm is a fourth-order statistic that is able to measure a signal's Gaussianity. Generally, positive Kurtosis values indicate peakedness and heavy tails, whereas negative Kurtosis values indicate flatness and light tails (DeCarlo, 1997). To obtain the kurtosis series of a microseism $x(n)$ $(n = 1, 2, \ldots, N)$, an M-sample sliding window is employed on the N-sample microseism. With the window sliding from M to N (assuming $M < N$), a series of

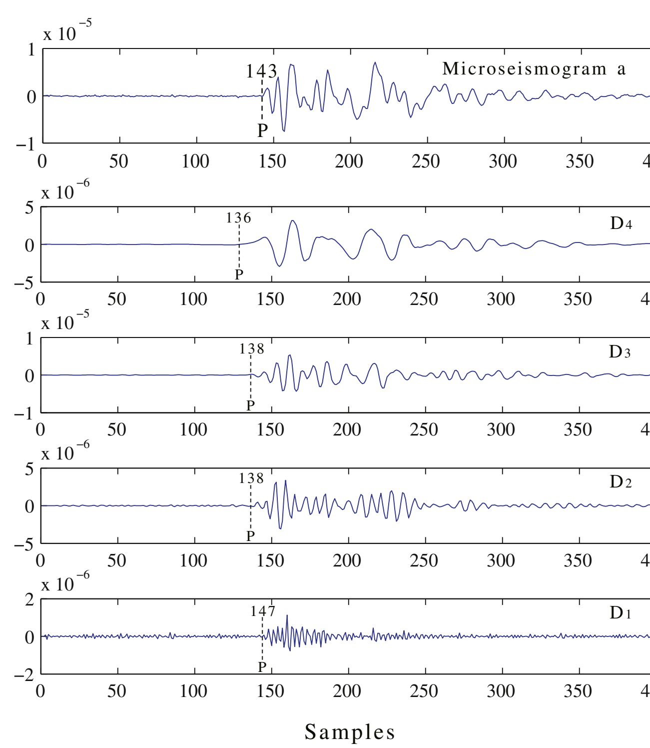

Fig. 2. Detail components of microseism “a” shown in Fig. 1. The dashed lines represent manual picks, and the numbers above the lines correspond to *P*-phase arrivals. D_i $(i = 1, 2, 3, 4)$ is the *i*th detail component.