



A hybrid method for strong low-frequency noise suppression in prestack seismic data

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ARTICLE INFO

Article history:

Received 12 January 2014

Accepted 24 June 2014

Available online 7 July 2014

Keywords:

Noise suppression

Low-frequency enhancement

Exploration

Seismology

Prestack gather

ABSTRACT

Low-frequency components are important portion of seismic data in exploration geophysics, and have great effects on seismic imaging of deep subsurface and full waveform inversion. Unfortunately, seismic data usually suffers from various kinds of noises and has low signal to noise ratio (SNR) in low-frequency band, although this situation has been improved by developments of acquisition technology. In this paper, we propose a low-frequency cascade filter (LFCF) in Fourier domain for strong low-frequency noise suppression in prestack gathers. LFCF includes a 1D adaptive median filter in f - x domain and a 2D notch filter in f - k domain, which is able to process high-amplitude swell noise, random noise, and seismic interference noise. We employ traces rearrangement and spike-detection mechanisms in adaptive f - x median filter, which can handle strong noise specifically, such as wide-spreading swell noise and tug noise. And a notch filter in f - k domain is designed to separate reflection signal and random noise by different apparent velocities. Through these means, our method can effectively attenuate low-frequency random and coherent noise while simultaneously protect the signal. Experiments on synthetic example and field data are conducted, and the results demonstrate that our method is practical and effective and can preserve signal down to 2 Hz.

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1. Introduction

The importance of low frequencies of seismic data has long been recognized by geophysicists in the seismic exploration industry. The major three potential benefits of extending the bandwidth of seismic data to well below 10 Hz are: 1) better imaging for deep exploration targets; 2) more accurate seismic inversion; and 3) higher vertical resolution (Dragoset and Gabitzsch, 2007; Lau et al., 2007; Martin and Stewart, 1994; Whitcombe and Hodgson, 2007). In practice, there are still a number of obstacles that must be overcome to extend the useful bandwidth of seismic data much below 10 Hz. The most difficult one is how to get a good SNR at low frequencies. There are two factors leading to the very low SNR seismic record at low frequencies. One is that the seismic sources have limited capacity to produce significant output power at low frequencies. The other is that the power level of the noise increases exponentially as frequency decreases in most acquisition conditions (Dragoset and Gabitzsch, 2007). Employing broadband source and recording technology can apparently contribute to alleviating this problem (Mougenot, 2006), but for complex acquisition environment and existing seismic records, signal processing is a more economic and practical solution. Current standard processing modules are not often

designed to preserve low-frequency signal due to hidden high-pass filters and short filtering operators (Mougenot, 2006).

The separation of signal and noise is a central issue in seismic data processing. The noise is both random and coherent in nature, with the coherent part often masquerading as signal. In general, if either the (desirable) signal components or the (undesirable) noise components of the seismic image resemble one or a few of the basis images of a particular transform, then the transform will be useful in separating the two. This is because these components will be represented compactly in the transform domain. Lateral continuity can be used to distinguish reflection events from background random noise. The prediction filter in f - x domain is a widely used seismic processing technique for random noise suppression (Canales, 1984). The idea behind f - x deconvolution is based on signal predictability. Singular value decomposition filter is also used to suppress random noise by detecting directions and energy of signal first and then enhance horizontal and non-horizontal events (Lu, 2006). Based on predictability in time-space domain, local polynomial fitting is employed to reconstruct seismic signal and thus eliminate random noise (Lu and Lu, 2009). Another simple and effective signal processing method is median filter, which can suppress noise, especially salt and pepper noise. Many noise suppressing algorithms have been developed based on median filter (Liu et al., 2009). But for direct t - x domain median filter, signal predictability has not been used and the detailed structure of signal is probably damaged. For coherent noise, such as seismic interference noise, a number of transform methods are

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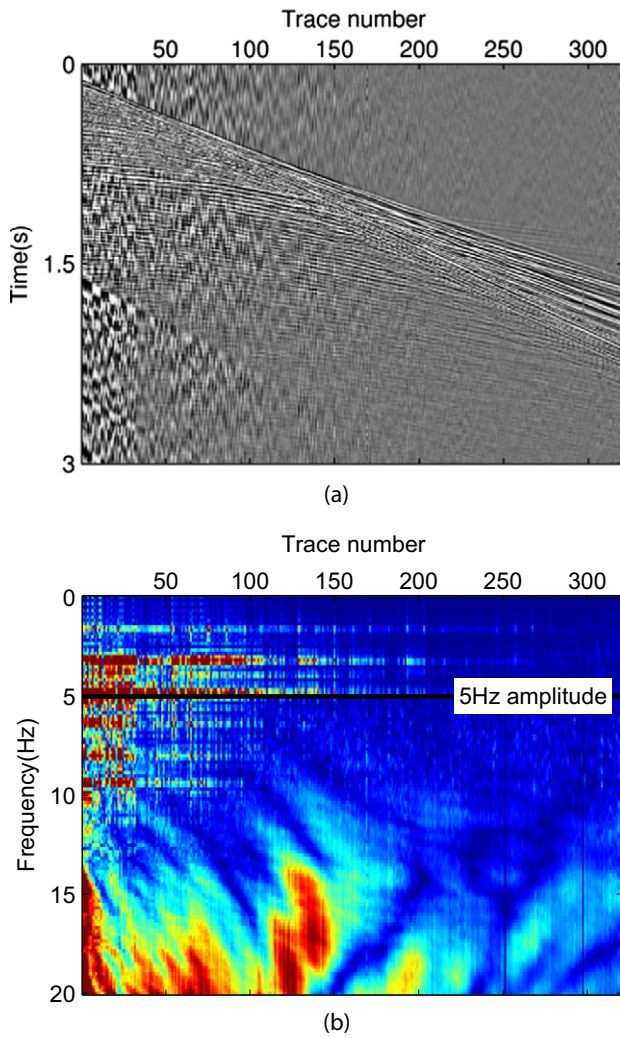


Fig. 1. An example of swell noise and its low-frequency characteristics. (a) A real marine common-shot gather suffers from swell noise at a number of neighboring near-offset traces; (b) the f - x spectra from 0 to 20 Hz show strong-amplitude noise exists at low frequencies.

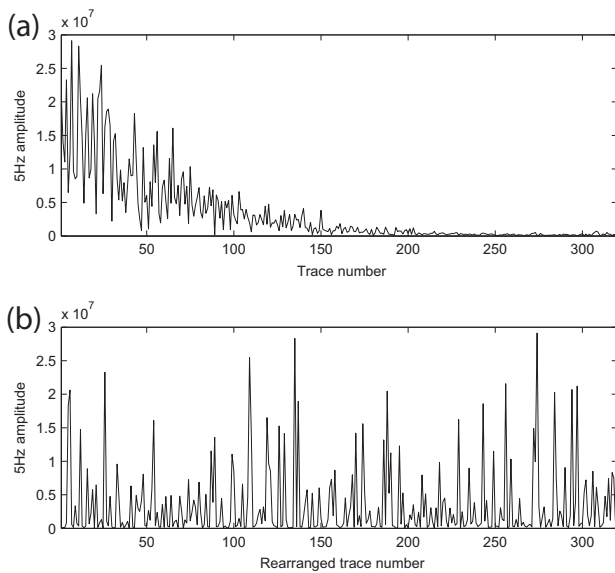


Fig. 2. An illustration of trace random rearrangement. (a) 5 Hz amplitude curve extracted from Fig. 1(b) at marked position; (b) after trace random rearrangement, swell noise disperses into isolated spike-like distribution.

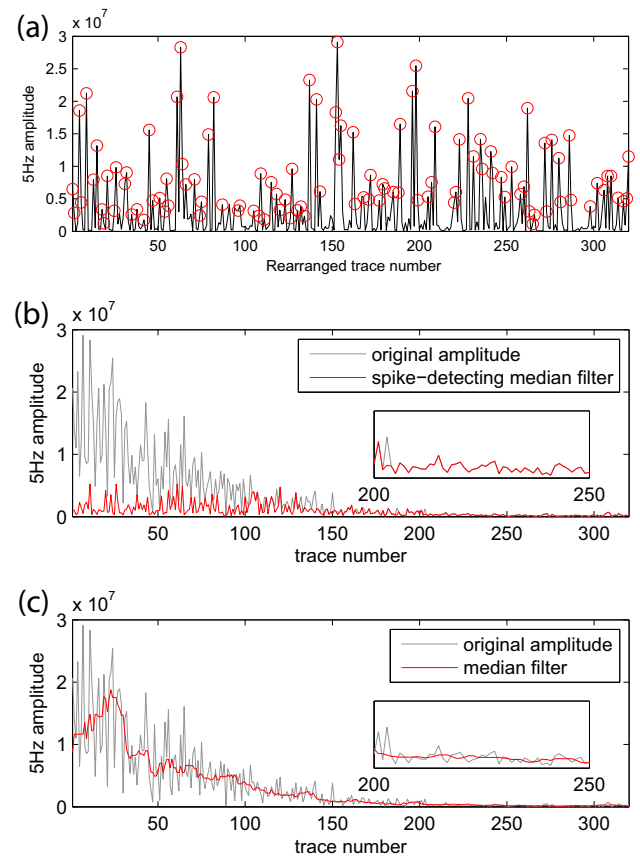


Fig. 3. Performance comparison between classic median filter (MF) and spike-detecting median filter (SDMF) with trace random rearrangement. Input rearranged data the same as in Fig. 2(b), (a) shows spike positions detected by the proposed method; (b) is SDMF's result, traces have been arranged back; (c) is MF's result. The embedded plots in (b) and (c) which display the traces range from 200 to 250 indicate weak signal protection property of SDMF.

used to separate signal and noise. Among these methods, the frequency–wavenumber (f - k) (Embree et al., 1963) and τ - p transforms are widely used. In general, coherent noise and signal are focused in different areas in the f - k (or τ - p) domain since they have different apparent velocity. Lu and Hu (2010) proposed a cascade filter to eliminate random and coherent noise based on predictability and apparent velocity of signal. But these approaches may retain unacceptable residual noise when strong space-neighboring amplitude of swell noise obscure signal predictability.

For marine towed streamer data, swell noise is a common problem that contains low frequencies from 2–15 Hz. Swell noise usually affects a number of neighboring traces with high amplitude. That often makes filtering incomplete and hard to achieve expected SNR. Elboth et al. (2009) studied mechanisms and distribution characteristics of swell noise, and proposed a time–frequency denoising method to separate signal and noise. Schonewille et al. (2008) developed an iterative f - x prediction filter to attenuate swell noise by repeating f - x filtering several times.

Similar to other types, seismic noise at low frequencies is both random and coherent. There are a lot of methods for low-frequency coherent noise (s.t. surface waves or ground roll) suppression based on its predictability (Lu et al., 2006). In fact, random seismic noise at low frequencies is also a persistent problem. In this paper, we proposed a novel cascade filter, which is able to process high-amplitude swell noise, random noise, and seismic interference noise. We employ traces rearrangement and spike detection mechanisms in f - x median filter,

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