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Amplitude-preserving iterative deblending of simultaneous source seismic data using high-order Radon transform

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ABSTRACT

The high-order Radon transform is adopted to eliminate incoherent noise that appears in common receiver gathers when simultaneous source data are acquired. An iterative scheme is designed to separate the blended seismic data. During each iteration, the blending noise is first estimated by the high-order Radon transform and then removed from the pseudo-deblended data by simple subtraction. A high-order Radon transform was proposed combining the superposition property of the Radon transform and the Amplitude-versus-Offset or AVO-preserving property of the orthogonal polynomial transformation. It can effectively attenuate the noise and improve the signal-to-noise ratio (SNR) better than the conventional Radon denoising method. To demonstrate that the proposed algorithm has a good accuracy and efficiency, we compared the denoising effectiveness between the high-order Radon transform and the conventional Radon transform. Synthetic and field data examples confirm that the high-order Radon transform produces more accurate data estimates than the conventional Radon transform.

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1. Introduction

Seismic acquisition looks for a balance between economic efficiency and the quality of acquisition. In traditional seismic data acquisition, adjacent sources are fired with large time intervals in order to avoid overlap in the time domain, which leads to some shortcomings. Considering the economics, the number of sources is often reduced in order to improve the collection efficiency. However, the source sampling deficiency can lead to spatial aliasing in the seismic data, which will impair the quality of processing and imaging of the seismic data. To solve this problem, several researchers have proposed the concept of simultaneous source acquisition (Moerig et al., 2013; Blacquière et al., 2008; Berkhout et al., 2009; Qu et al., 2014; Chen, 2015b; Chen et al., 2015d; Xue et al., 2016a; Chen et al., 2017b; Zhou, 2017) and have applied this technique in seismic exploration (Bagaini, 2006; Aaron et al., 2009), particularly in marine seismic exploration (Beasley et al., 1998; Beasley, 2008; Qu et al., 2015; Wu et al., 2015; Gan et al., 2015b; Zu et al., 2016b).

Simultaneous source acquisition breaks the limitation of the large time intervals and high cost by firing more than one source with a small time dither. However, the key to its application is dealing with the intense crosstalk noise between adjacent shots. There are two approaches to solving this problem. One approach is by direct imaging and waveform inversion (Berkhout et al., 2012; Guitton and Díaz, 2012; Bai et al., 2016a,b; Xue et al., 2016b) which requires a sufficiently accurate subsurface velocity model and sets a higher demand for robust velocity analysis (Chen et al., 2015c; Gan et al., 2016d; Ebrahimi et al., 2017, 2016), but few field examples are reported. The other approach is called deblending (Panagiotis et al., 2012; Wu, 2014), which separates the blended data into single shot data as if it is acquired without blending, so that the data can be processed in conventional ways. In this study, we introduce a method of deblending.

There are two main categories of deblending methods: the filtering methods (Chen, 2014; Jiao et al., 2015) and the inversion methods (Abma et al., 2010; Chen et al., 2015a). Filtering methods assume that signals are coherent, but blended noise is not coherent in some domains (such as the common midpoint domain, common receiver domain, and common offset domain). Thus, the deblending method can be straightforwardly transformed in to a noise attenuation problem (Chen and Ma, 2014; Gan et al., 2015a; Huang et al., 2015; Yang et al., 2015b; Gan et al., 2016a; Chen et al., 2016b; Huang et al., 2016a; Li et al., 2016a,b; Chen, 2017). Researchers have

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proposed many different filtering methods to separate the blending interference. Hampson et al. (2008) implemented a simple dip filter to remove the interference according to the slope differences between simultaneous sources in the shot domain. Mahdad (2012) separated the simultaneous source in the common receiver domain using the iterative f-k filter. Huo et al. (2012) and Chen (2014) proposed the denoising method by median filtering in the midpoint domain. Gan et al. (2016c) separated the simultaneous source using a structural-oriented median filter in the flattened dimension. Chen and Fomel (2015) proposed a two-step filtering approach to remove blending interference without harming the useful signals. However, as the filtering method may cause complex changes of wave field, distortion, or space aliasing, deblending through inversion methods usually leads to a better separation result (Borselen et al., 2012; Abma and Ross, 2013).

The key to the inversion method is the estimation of the desired unblended data. Due to the ill-posed nature of such estimation problems, a regularization term is usually required (Doulgeris et al., 2010; Chen, 2015a; Qu et al., 2016; Zu et al., 2016c). Several researchers have proposed different iterative approaches based on the sparsity constraints in some sparse transform domains (Gan et al., 2016b; Chen et al., 2015b; Wu et al., 2016; Zhong et al., 2016) or predefined low-rank matrices (Huang et al., 2016a,b,c; Zhang et al., 2016; Chen et al., 2016c,d; Huang et al., 2017). Doulgeris et al. (2010) introduced an iterative estimation and subtraction scheme that combines the properties of the filtering and inversion methods and the characteristics of the blending noise difference in different domains. Ibrahim and Sacchi (2014) adopted the robust Radon transform to eliminate erratic incoherent noise that arises in common receiver gathers. Chen et al. (2014) proposed an iterative deblending method based on seislet-domain shaping regularization.

In the existing separation methods, the inversion of a conventional sparse domain can suppress some blending noises. However, since these methods do not consider the Amplitude-versus-Offset or AVO character of the seismic data, the precision of these methods are insufficient and may cause non-ignorable errors in the result. Therefore, in this study, we propose an iterative algorithm based on a high-order sparse Radon transform (HOSRD) to separate the simultaneous source data, which combines the superposition property of the Radon transform and the amplitude preservation effect of the orthogonal polynomial transformation. The benefits of our method are that it can easily be implemented and is effective in deblending the seismic data, which are demonstrated by both synthetic and field examples.

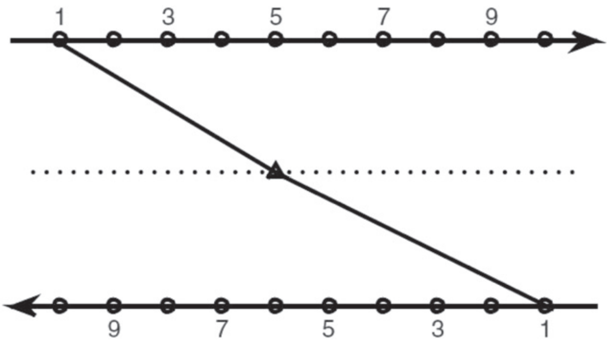

Fig. 1. The OBC data acquisition geometry. The horizontal arrows denote the sailing directions of the shooting sources. The little circles stand for the position of different shots. The dotted line indicates the cable line, and the triangle represents a receiver collecting data from both sources.

2. Deblending using high-order Radon transform

2.1. Simultaneous acquisition model

Currently, two vessels are often used to realize the simultaneous source acquisition. One of the sources shoots in the conventional way, avoiding the layout of different shots. Different from a conventional acquisition, the other source also shoots the same as the first source pseudo synchronously. This acquisition scheme can be formulated as

$$\mathbf{D}^{obs} = \mathbf{D}_1 + \mathbf{T}\mathbf{D}_2, \tag{1}$$

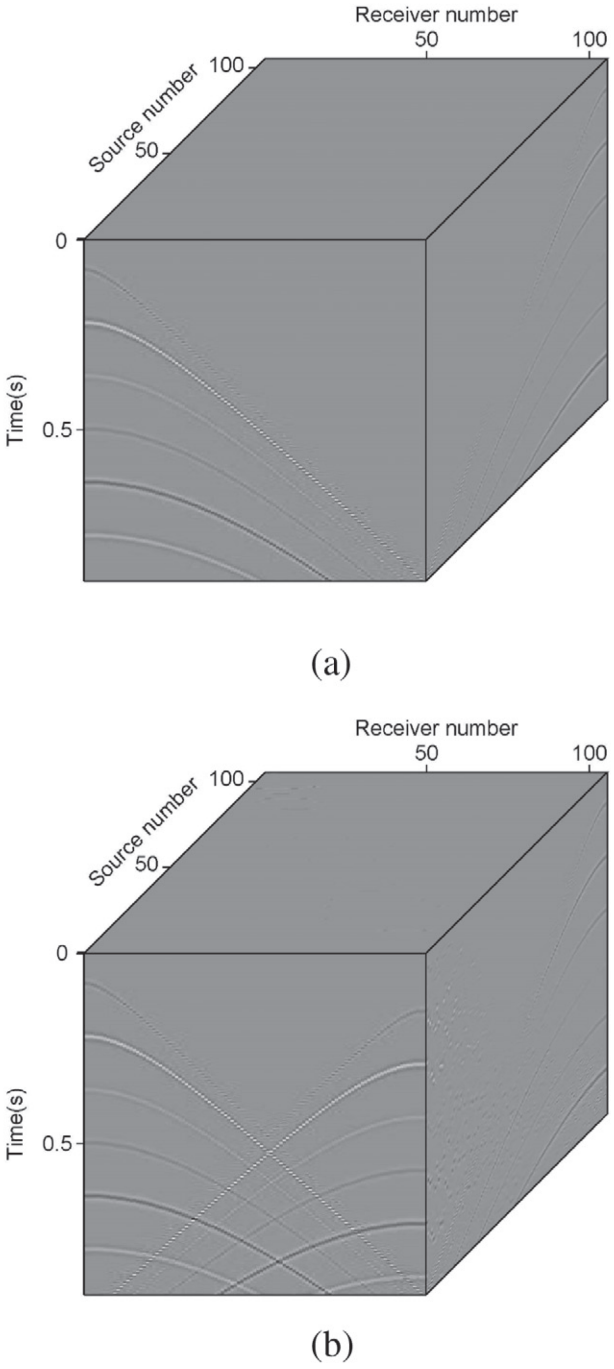

Fig. 2. Synthetic data cube. (a) Original gather. (b) Pseudo-deblended gather.

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