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Separation of simultaneous sources using a structural-oriented median filter in the flattened dimension

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ABSTRACT

Simultaneous-source shooting can help tremendously shorten the acquisition period and improve the quality of seismic data for better subsalt seismic imaging, but at the expense of introducing strong interference (blending noise) to the acquired seismic data. We propose to use a structural-oriented median filter to attenuate the blending noise along the structural direction of seismic profiles. The principle of the proposed approach is to first flatten the seismic record in local spatial windows and then to apply a traditional median filter (MF) to the third flattened dimension. The key component of the proposed approach is the estimation of the local slope, which can be calculated by first scanning the NMO velocity and then transferring the velocity to the local slope. Both synthetic and field data examples show that the proposed approach can successfully separate the simultaneous-source data into individual sources. We provide an open-source toy example to better demonstratethe proposed methodology.

1. Introduction

Wide-azimuth acquisition geometry can improve the illumination of subsalt structures, which helps improve the quality of seismic imaging. However, wide-azimuth acquisition suffers from the low-efficiency problem, resulting from the large temporal shooting interval between two consecutive shots. The large temporal shooting interval is needed to ensure that no interference exists between adjacent shots. The principal purpose of simultaneous source acquisition is to accelerate the acquisition of a larger-density seismic dataset that allows the temporal or spatial overlap between different shots, which saves numerous acquisition cost and increases data quality. The improved seismic data with denser spatial sampling can also help improve the seismic imaging quality of the subsalt structure. The benefits of the new technique are compromised by the intense interference between different shots (Berkhout, 2008). One way for solving the problem caused by interference is by first-separating and second-processing strategy (Chen et al., 2014a), which is also called deblending (Akerberg et al., 2008; Abma et al., 2010; Huo et al., 2012; Mahdad et al., 2011, 2012; Blacquiere and Mahdad, 2012; Beasley et al., 2012; Doulgeris et al., 2012; Bagaini et al., 2012; Li et al., 2013; Ibrahim and Sacchi, 2014; Chen and Ma, 2014; Chen et al., 2014b; Berkhout and Blacquiere, 2014; Chen, 2014, 2015; Qu et al., 2015; Zu et al., 2015). Another way is by direct imaging and inversion of the blended data by attenuating the interference during inversion process (Verschuur and Berkhout, 2011; Dai and Schuster, 2011; Xue et al., 2014; Chen et al., 2015b; Gan et al., 2014). Currently, deblending is still the dominant way for dealing with simultaneous-source data.

There are generally two types of deblending approaches that have been reported in the literature: (1) treating deblending as a noise attenuation approach (Huo et al., 2012; Chen and Ma, 2014; Chen et al., 2014b; Chen, 2014; Chen and Fomel, 2014, 2015), (2) treating deblending as an inversion problem (Mahdad et al., 2011; Abma et al., 2010; Chen et al., 2014a; Gan et al., 2015b). For the filtering based approaches, most of the approaches are based on a median filter. Chen et al. (2014b) proposed to use a common midpoint domain for deblending, because of the better coherency of useful signals and also because the near-offset useful events follow the hyperbolic assumption and thus can be flattened using normal moveout (NMO) correction. A simple median filtering (MF) can be applied to the NMO corrected common-midpoint (CMP) gathers to attenuate blending noise. Chen (2014) proposed a type of MF with spatially varying window length. The space-varying median filter (SVMF) does not require the events to be flattened and is also better applied in the midpoint domain. Huo et al. (2012) used a multidirectional vector median filter after resorting the data into common midpoint gathers. For inversion based approaches, because of the ill-posed property of the inversion problem, there should be some constraint to regularize the inversion

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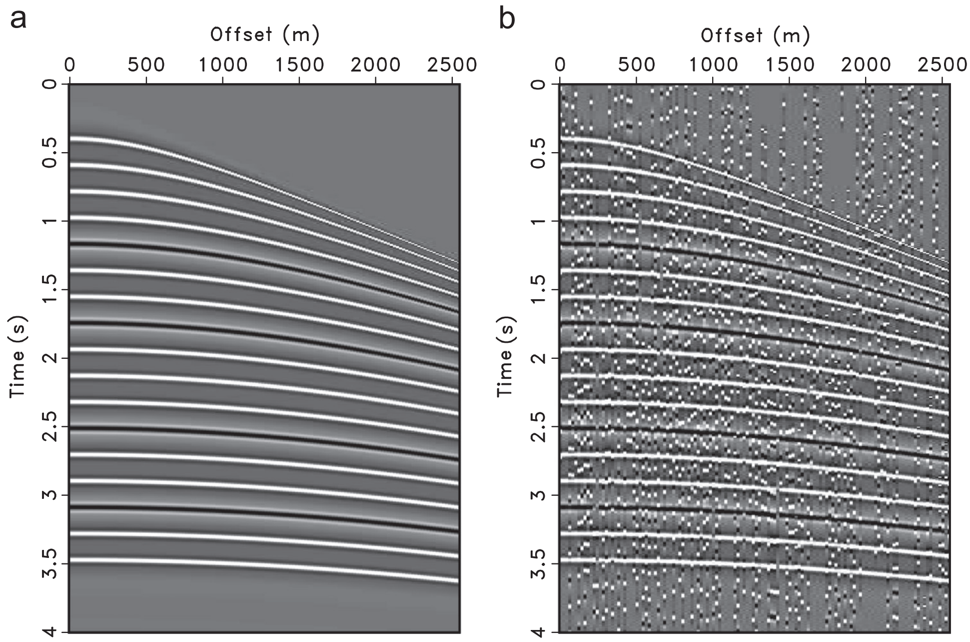

Fig. 1. Synthetic example in common midpoint domain. (a) Unblended data. (b) Blended data.

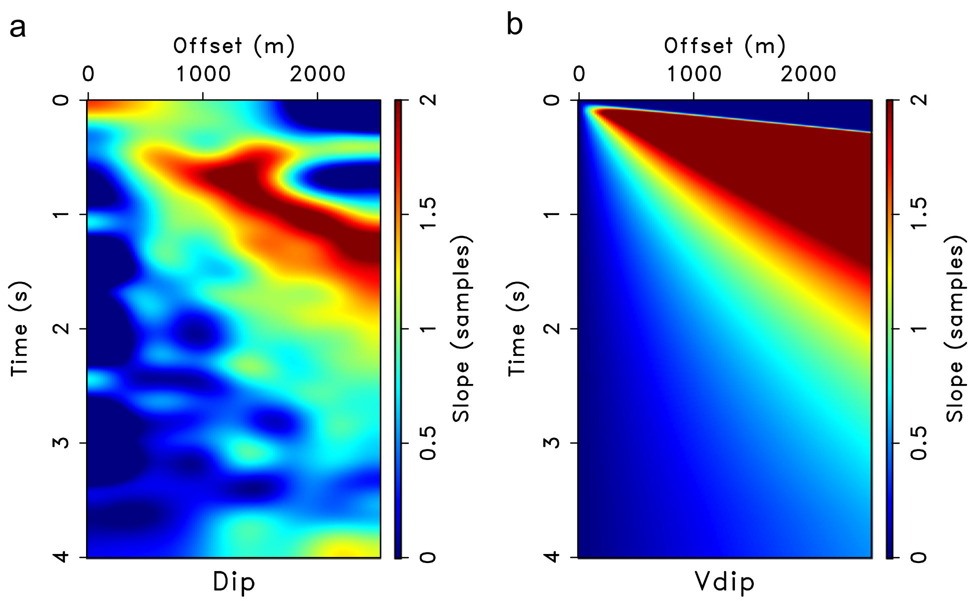

Fig. 2. Local slope maps using (a) PWD, (b) velocity-slope transformation.

problem. Akerberg et al. (2008) used sparsity constraint in the Radon domain to regularize the inversion. A sparsity constraint was also used by Abma et al. (2010) to minimize the energy of incoherent events present in blended data. Lin and Herrmann (2009) connected a curvelet-based sparse inversion algorithm with the emerging field of compressive sensing. Bagaini et al. (2012) compared two separation techniques for the dithered slip-sweep (DSS) data using the sparse inversion method and *f–x* predictive filtering (Canales, 1984), and pointed out the advantage of the inversion methods over the filtering based approaches. In order to deal with the aliasing problem, Beasley et al. (2012) proposed the alternating projection method (APM), which chooses corrective projections to exploit data characteristics and is claimed to be less sensitive to aliasing than alternative approaches. Mahdad and Blacquiere (2010) proposed a coherence-based inversion approach to deblending of the simultaneous-source data. The convergence properties and the algorithmic aspects of the method were discussed by Doulgeris et al. (2012) and Mahdad et al. (2012), respectively. Although the inversion-based approaches have been demonstrated to obtain better deblending performance (Bagaini et al., 2012), it usually takes many iterations to process the data. Currently, the most efficient way for deblending is using some types of median filtering. However, most of the median filtering approaches are directly borrowed from the signal-processing field and do not utilize the structure information of seismic data.

In this paper, we propose a novel type of MF that makes use of the structural features of seismic data by means of first flattening the seismic record in local spatial windows and then applying MF along the flattened dimension. The flattening operator is constructed by predicting the neighbor traces following the local slope. One concern for such flattening processing is the estimation of an accurate-enough local slope map, which can be solved by first scanning the NMO velocity and then transferring the velocity to the local slope in the common midpoint domain. We first