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Contourlet based seismic reflection data non-local noise suppression

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ABSTRACT

In this paper, we propose a non-local, transform domain noise suppression framework to improve the quality of seismic reflection data. The original non-local means (NLM) algorithm measures similarities in the data domain and we generalize it in the nonsubsampled contourlet transform (NSCT) domain. NSCT gives a multiscale, multiresolution and anisotropy representation of the noisy input. The redundancy information in NSCT subbands can be utilized to enhance the structures in the original seismic data. Like the wavelet transform, NSCT coefficients in each subband follow the generalized Gaussian distribution and the parameters can be estimated using appropriate techniques. These parameters are used to construct our proposed NSCT domain filtering algorithm. Applications for synthetic and real seismic data of the proposed algorithm demonstrate its effectiveness on seismic data random noise suppression.

1. Introduction

Noise suppression in seismic reflection data is a crucial problem, and the filtering results directly affect the subsequent data processing and geology interpretation. Various denoise techniques, such as the Fourier domain based methods listed by Yilmaz (2001), have been proposed to attenuate random and coherent noise in seismic applications in the past decades. Other filtering methods like Karhunen–Loeve transform (Hunt and Kubler, 1984), 2D frequency-spatial deconvolution (Canales, 1984) and multichannel singular spectrum analysis (Oropeza and Sacchi, 2011) have been used for seismic noise removal and have achieved good results. Shan et al. (2009) compared the effect of three multiscale analysis filtering methods: wavelets, curvelets and contourlet transform. Schimmel et al. (2011) adopted cross correlations to extract signal from ambient noise data. These methods are based on assumptions of noise character in seismic data or transform domains. Generally, there is no clear separation between signal and noise, so it is difficult to establish criteria for seismic noise suppression in any domain. Median filtering (Arias-Castro and Donoho, 2009) and bilateral filtering (Tomasi and Manduchi, 1998) are derived from image denoising field that utilizes local image information in a local neighborhood to estimate the denoised value. Similar objects may not be necessarily spatially or frequency close, but they can occupy different locations in the original image or seismic data. The non-local means filter (NLM) proposed by Buades et al. (2005) assumes that, the redundancy information in the original image can be utilized to enhance the structures within a small window by averaging the many similar windows that are also within that image. The performance of this filter is better than most traditional denoising methods in a wide variety of applications (Darbon et al., 2008; Descoteaux et al., 2008; Giraldo et al., 2009; Manjon et al., 2008; Protter et al., 2009; Schall et al., 2008; Yang et al., 2010). Bonar and Sacchi (2012) introduced it in seismic poststack data random noise removal. However, the main drawbacks of the original NLM algorithm concentrate on enormous computing time, difficult to catch neighborhood similarities and select proper filter parameters. Numerous attempts have been proposed in the literature to overcome these limits and here we don't discuss it in detail.

The above mentioned denoising applications perform the NLM in original data domain and most of the recent works also use a different domain where to measure similarities. For example, Souidene et al. (2006) calculated the non-local neighborhoods in lifting wavelet transformed domain and Azzabou et al. (2007) applied NLM by computing an adapted dictionary. Zhang et al. (2010) combined the translating invariant shearlet feature descriptors with non local calculation model to compose a new NLM. Other translating invariant transform based NLM such as nonsubsampled contourlet transform (LI et al., 2012; Wan and Tao, 2011), and scale-invariant feature transform (SIFT) also has been used (Lou et al., 2009). The traditional NLM filter utilizes redundant information of the spatial domain (data domain) to weight similarities between blocks with different gray values. It is suitable for natural image but may not be appropriate for seismic data. First the seismic data is not redundant enough, and there are many irregular texture types within it. Then the wealth of detail information may be seen as interferences and underestimated in the traditional NLM filtering. Even so, Bonar and Sacchi (2012) showed NLM's ability to handle

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sharp discontinuities or curved event within seismic profile when compared to traditional f-x deconvolution. However, for some transform domain data the effective information is classified according to certain rules of transform itself. And the details that have little spatial resemblance in seismic data can be strengthened in the transform domain. At the same time, random noises have similar projection on different basis functions of the transform. The desired transform should have properties like redundancy, directionality and anisotropy. The similarity weight measurement in NLM algorithm will become more accurate after the transform. Nonetheless it is still necessary to consider the differences between the original data with the nontransformed data, and the NLM algorithm need to be generalized.

In this study, we constructed a generalized NLM (GNLM) in nonsubsampled contourlet (NSCT) domain for seismic reflection data noise suppression since NSCT can preserve the boundary and texture information effectively and increase the data redundancy greatly. NSCT is a fully shift invariant, multiscale, and multidirection expansion that has a fast implementation (Cunha et al., 2006). Like the wavelet transforms (WT), coefficients in NSCT detail subband follow the generalized Gaussian distribution (GGD). We estimated the scale and shape parameter of GGD and utilized these parameters to construct our GNLM in detail subband of NSCT. Our experiments showed that the proposed approach might serve to reduce random noise when the traditional NLM and wavelet based NLM might fail. However, the intention of this paper is not to provide a comprehensive comparison of methods for SNR enhancement but to present a new avenue to design seismic denoising method that combines NLM and NSCT. If the seismic data to be processed does not totally satisfy the assumptions of a popular method, an effective representation tool makes it meet that the assumptions should be adopted. Then many classical image denoising approaches can be applied to seismic data after an effective transform domain representation. The rest of this paper is organized as follows. Section 2 introduces the background knowledge of the nonsubsampled contourlet transform and non-local means filtering method. The proposed non-local seismic data noise suppression in NSCT domain is described in Section 3. Experimental results and discussions for synthetic data at various degrees of additive Gaussian noise are given in Section 4. Real seismic reflection data examples are also shown in this section. Section 5 concludes the paper.

2. Nonsubsampled contourlet transform and non-local means filtering

Many directional transforms based on multiscale geometric analysis theory have been introduced in recent years. These representation tools contain ridgelet, curvelet and contourlet transform. Ridgelet transform is proposed by Candes (1998), which is a multidirectional wavelet representation that is implemented by Radon transform and wavelet transform. Ridgelet captures the linear discontinuities validly, but behaves insufficiently when describing the curve discontinuities. To better preserve the curve information, curvelet transform (Starck et al., 2002) is developed in the continuous domain. Curvelet decomposition is obtained by filtering and then applying a windowed ridgelet analysis. The total constructions require a rotation transform, which makes the implementation of the transform on discrete images very challenging. Contourlet transform (CT) was developed as an improvement over two dimensional separable wavelets to catch linear discontinuities instead of point discontinuities (Do and Vetterli, 2005). The primary goal of the CT construction is to obtain a redundant expansion for input data with a high degree of directionality and anisotropy. But it suffers from lack of translation invariance and loss of effectiveness in applications such as seismic reflection data noise suppression. An effective way to overcome this drawback is using NSCT.

2.1. Nonsubsampled contourlet transform and its subband distribution

In filtering applications, an effective data multiscale representation should have good directionality feature as well. Meanwhile, transform with translation invariant property can avoid artifacts and make the filtered results more natural. The NSCT has been developed from CT, which is constructed by Laplacian pyramid (LP) and direction filter bank (DFB). The LP captures point discontinuities with a wavelet style in the original data and DFB links those discontinuities at the same scale into a linear structure. The total transform gives a multiscale, multiresolution and anisotropy representation of the input. Fig. 1b depicts the above contour capture process in a synthetic seismic data shown in Fig. 1a. The black rectangles represent the support size of spatial basis function at different scales. To conquer the implicit oversampling and achieve a shift invariant filtering structure, nonsubsampled pyramid (NSP) which removes the dowsamplers, and nonsubsampled DFB (NSDFB) constructed by eliminating the downsamplers and upsamplers in the DFB, are combined in the NSCT. An example of two levels NSCT is

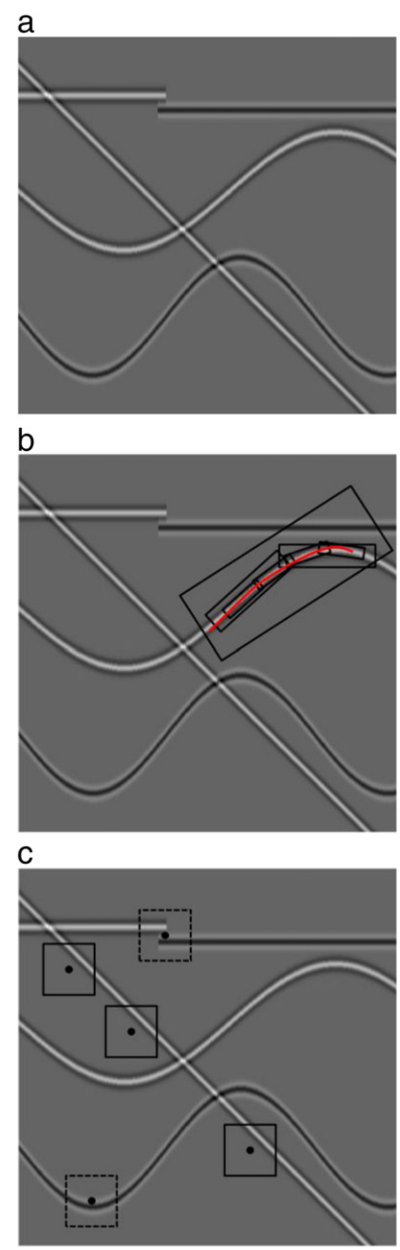

Fig. 1. (a) Synthetic seismic data, (b) Contour capture processing of contourlets, (c) schematic of the non-local means filtering.