Journal of Applied Geophysics 116 (2015) 146–155

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

The seismic random noise attenuation method based on enhanced bandelet transform

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ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form 1 March 2015
Accepted 2 March 2015
Available online 5 March 2015

Keywords:
Seismic random noise attenuation
Nonsubsampled
Contourlet transform
Bandelet transform

ABSTRACT

The 2D separable wavelet transform used in bandelet transform, has low angular resolution and suffers from aliasing. We propose an enhanced bandelet transform, which replaces the 2D separable wavelet transform used in bandelet transform with nonsubsampled contourlet transform (NSCT, NSCT can decompose 2D signal to a series of bandpass directional components). Based on the enhanced bandelet transform, we developed a new seismic random noise attenuation method. The method is applied to synthetic seismic data and field data. The numerical results show that our method can outperform the random noise attenuation method based on bandelet transform.

1. Introduction

Random noise attenuation plays an important role in seismic processing and interpretation. A good seismic random noise attenuation method not only attenuates random noise as much as possible, but also keeps the uncontaminated signal intact. Many noise attenuation methods have been proposed and already used in geophysical exploration, such as f–k filter (Treitel et al., 1967; Gelisli and Karsli, 1998), f–x prediction filter (Harris and White, 1997), Karhunen–Loeve transform (Jones and Levy, 1987), singular value decomposition (Freire and Ulrych, 1988; Bekara and van der Baan, 2007; Porsani et al., 2010), time-frequency transform (Gao et al., 2004, 2006; Hai-tao et al., 2009), diffusion filter (Fehmers and Hocker, 2003; Lavialle et al., 2007) and median filter (Bednar, 1983; Duncan and Beresford, 1995; Liu et al., 2006).

In recent years, many multi-scale geometric transforms have been proposed, such as ridgelet transform (Do and Vetterli, 2003), curvelet transform (Starck et al., 2002; Candes et al., 2006), contourlet transform (Do and Vetterli, 2005; da Cunha et al., 2006) and bandelet transform (Le Pennec and Mallat, 2000, 2005a,b; Peyre and Mallat, 2005; Mallat and Peyre, 2008). The noise attenuation methods based on these transforms were proposed and widely used in geophysical exploration (Neelamani et al., 2008; Chun et al., 2009; Kang et al., 2009; Yang et al., 2009; Qianzong et al., 2010). These methods mainly use different kinds of transform to obtained coefficients, and do the noise reduction by some operation on the coefficients in transform domain. Finally inverse transform is used to obtain the denoised results. Therefore, the performances of these methods are greatly affected by the adopted transform.

The 2D separable wavelet transform (WT), whose wavelet function is constructed by the tensor product of two independent 1D wavelet functions and one scaling function, can only specify three directions: horizontal, vertical and oblique (Mallat, 2008). It can capture point singularities optimally. Therefore, it plays an important role in signal compression. For the downsampling in the 2D separable WT and its low angular resolution, it is insufficient to represent linear information precisely.

Do and Vetterli proposed a multi-scale and multi-directional transform named contourlet transform (CT) (Do and Vetterli, 2005), which can effectively capture the linear information such as edges, contours and other geometric information. CT is constructed by Laplacian pyramid (LP) and directional filter banks (DFB): The former captures discontinuous points while the latter links them into linear structures. However, the subsampling operations in LP and DFB make CT lack of shift-invariant property, which causes serious aliasing. Nonsubsampled contourlet transform (NSCT) proposed by Cunha, Zhou and Do (da Cunha et al., 2006), uses nonsubsampled pyramid filter banks (NSPFB) and nonsubsampled directional filter banks (NSDFB) to decompose 2D signal. Thus, NSCT is a fully multi-scale, multi-directional and shift-invariant transform.

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http://dx.doi.org/10.1016/j.jappgeo.2015.03.002
0926-9851/

The noise attenuation methods based on these transforms use different characteristics of the signal and the noise in transform domain to attenuate the noise. Suppose the noisy seismic data S is comprised by pure seismic signal S_{pure} and random noise:

$$S = S_{pure} + \text{noise}. \tag{1}$$

Due to the linearity of these transforms, the noisy seismic signal in transform domain can be expressed as:

$$XT(S) = XT\left(S_{pure}\right) + XT(noise). \tag{2}$$

$XT(S)$ stands for X-let transform to S. Generally, pure seismic signal has good spatial and temporal correlations, while random noise does not have spatial and temporal correlations. Thus in X-let transform domain, the value of $XT(S_{pure})$ is big and the number of nonzero $XT(S)$ is small, while the value of $XT(noise)$ is small and the number of nonzero $XT(noise)$ is large (probably equal to the number of $XT(S)$). Consequently, it can be included that the noise attenuation performance is greatly dependent on the rate of the number of $XT(S_{pure})$ with large value to the total number of $XT(S)$. The rate is determined by the used X-let transform: Small rate means the coefficients $XT(S_{pure})$ are more condensed in transform domain, leading to better noise attenuation performance.

A synthetic signal is shown in Fig. 1(a). The vertical component of 2D separable WT, CT and NSCT are shown in Fig. 1(b), (c) and (d). We sort the coefficients' square with descending order and denote these reordering coefficients' square as $RC[n]$. Assume N is the number of coefficients. We accumulate the $RC[n]$

$$ACCU[m] = \sum_{n=1}^{m} RC[n] \tag{3}$$

until we find a count M who satisfies

$$ACCU[M-1] = \sum_{n=1}^{M-1} RC[n] < 0.85 * ACCU[N], \tag{4}$$

and

$$ACCU[M] = \sum_{n=1}^{M} RC[n] > 0.85 * ACCU[N]. \tag{5}$$

Then the rate aforementioned can be computed by the count M and the number of coefficients N. The rates corresponding to 2D separable WT, CT and NSCT are 0.131, 0.123 and 0.106, respectively. NSCT provides the lowest rate among them. For the downsampling operations in 2D separable WT and CT, the significant aliasing effect can be easily observed in Fig. 1(b) and (c). The geometric ambiguities in some regions

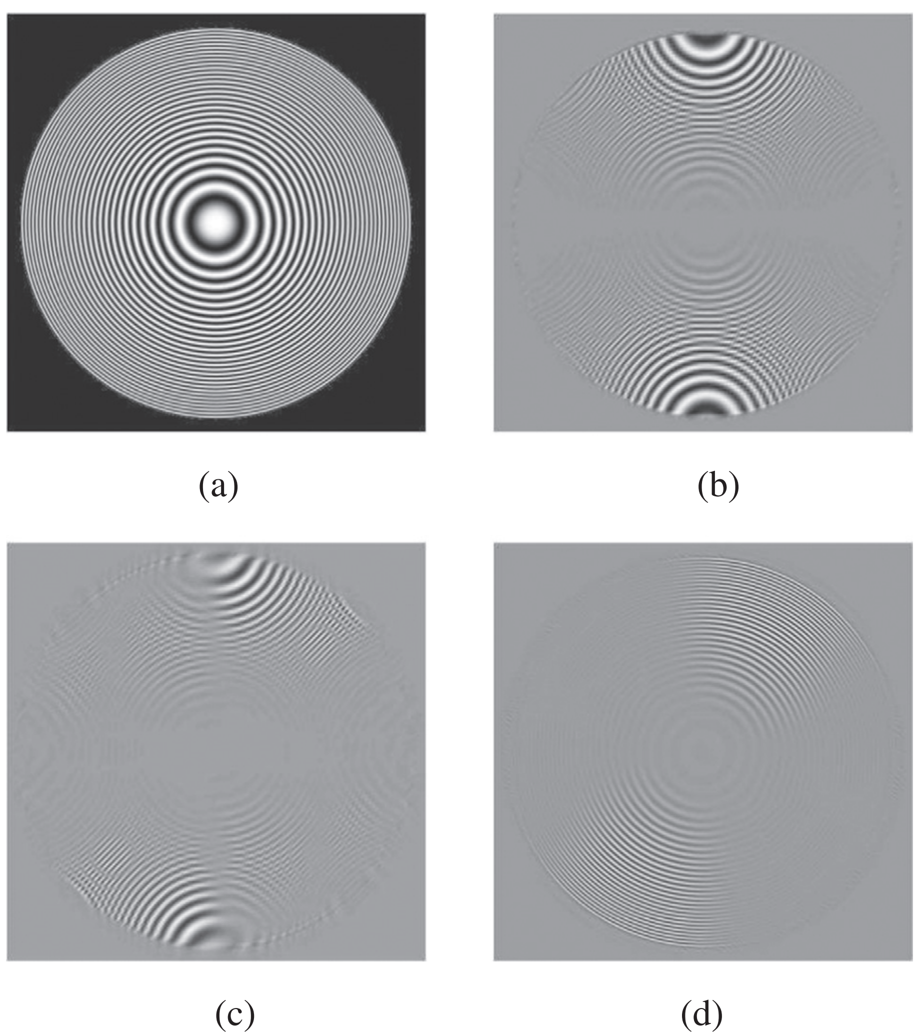

Fig. 1. Subbands of a synthetic signal (a) synthetic signal; (b) 2D separable wavelet transform; (c) Contourlet transform and (d) Nonsubsampled contourlet transform.