Physica A 391 (2012) 2106–2110

Contents lists available at SciVerse ScienceDirect

Physica A

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

Seismic denoising using curvelet analysis

M.S. Oliveira [a], M.V.C. Henriques [a], F.E.A. Leite [b], G. Corso [c], L.S. Lucena [a,*]

[a] Departamento de Física Teórica e Experimental, International Center for Complex Systems, Universidade Federal do Rio Grande do Norte, 59078–970, Natal, RN, Brazil

[b] Universidade Federal Rural do Semi-Árido, Campus de Angicos 59515–000, Angicos, RN, Brazil

[c] Departamento de Biofísica e Farmacologia, Centro de Biociências, Universidade Federal do Rio Grande do Norte, 59078–972, Natal, RN, Brazil

ARTICLE INFO

Article history:
Received 1 April 2011
Available online 17 April 2011

Keywords:
Seismic data
Ground roll
Curvelet analysis
Noise suppression
Wavelet transform
Oil reservoirs

ABSTRACT

A curvelet is a new and effective spectral transform, that allows sparse representations of complex data. It has many applications in several fields, including denoising, wave propagation in disordered media and pattern recognition. This spectral technique is based on directional basis functions that represent objects having discontinuities along smooth curves. In this work we apply this technique to the removal of Ground Roll, which is an undesired feature signal present in seismic data obtained by sounding the geological structures of the Earth. In this methodology the original seismic data is decomposed by curvelet transform in scales and angular domains. For each scale the curvelet denoising technique allows a very efficient separation of the Ground Roll in angle sections. The precise identification of the Ground Roll pattern allows an effective erasing of its coefficients. In contrast to conventional denoising techniques we do not use any artificial attenuation factor to decrease the amplitude of the Ground Roll coefficients. We have estimated that, depending on the scale, around 75% of the energy of the strong undesired signal is removed.

1. Introduction

The curvelet transform is a new multiscale transform with strong directional character that provides an optimal representation of objects that have discontinuities along edges [1–3]. The curvelets are localized not only in the spatial domain (location) and the frequency domain (scale), but also in angular orientation, which is a step ahead compared to Wavelet Transform [4]. They are multiscale and multi-directional techniques and this new important directional parameter provides a surprising angular geometric property with a high degree of orientation which identifies the directional singularities [3].

The Ground Roll is a coherent noise present in land-based seismic data. The Ground Roll is the signature of a surface wave (Rayleigh dispersive wave) with low frequency, low phase and group velocities [5]. As a surface wave component, these waves do not contain information from the deeper subsurface structures associated with oil reservoirs. An important characteristic of the Ground Roll is that its intensity can be stronger than the waves carrying the relevant information that come from reflections in geologic strata. Moreover, in the seismic image the Ground Roll is mixed and masks the relevant geologic information, imposing the necessity to remove this undesirable component.

An example of seismic data strongly contaminated by Ground Roll noise is shown in Fig. 1(a). This seismic data was obtained from the *Center for Wave Phenomena* of the *Colorado School of Mines* [6] and corresponds to the record number 25. This figure shows a seismic section of a land-based data with 90 traces (one for each geophone) and 2048 samples per trace.

* Corresponding author.
E-mail addresses: liacir.lucena@gmail.com, liacir@dfte.ufrn.br (L.S. Lucena).

0378-4371/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.physa.2011.04.009

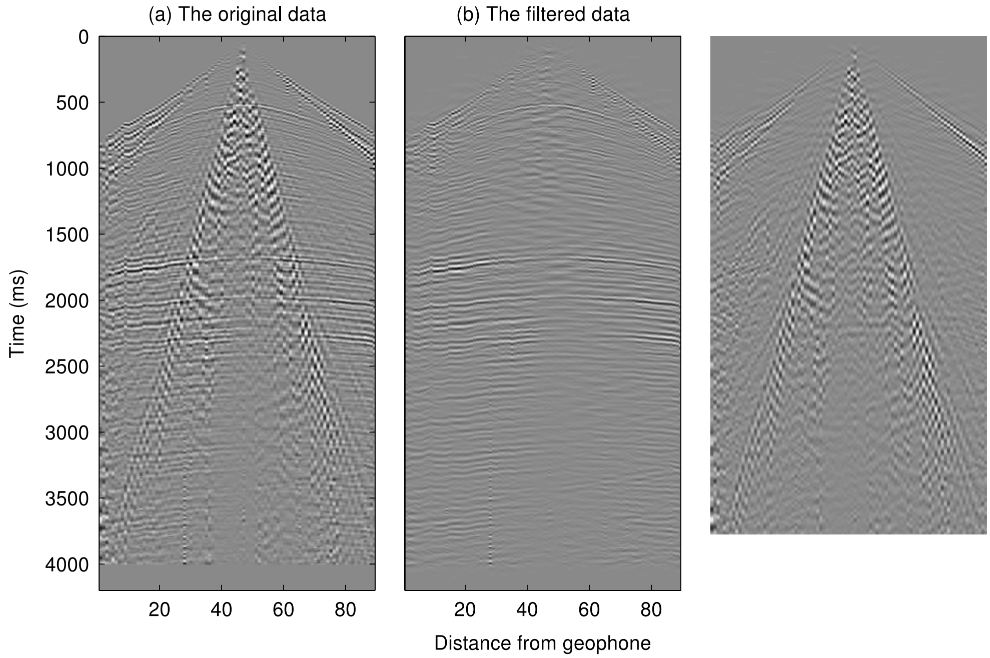

Fig. 1. A seismic data with 90 traces and 2048 samples per trace. The original data is shown in (a), the Ground Roll pattern is overlapped to the relevant geologic data. In (b) we show the seismic reflectors, the true geologic information of the strata. In (c) we depict the extracted part of the signal, the Ground Roll showing a typical fan-like structure with oblique straight lines.

The horizontal axis in Fig. 1 corresponds to the offset distance between source and receiver, the vertical axis represents the time of the traveling sonic wave (in ms) which is an indirect measure of the depth.

Ground roll filtering in seismic images has a long history in the oil industry. At the beginning the filtering was performed by attenuating low frequencies in the Fourier domain [5]. The utilization of wavelet transform has improved the technique by optimizing the region where the attenuation is performed [7], or by choosing the best basis to decompose the seismic data [8,9]. Even more sophisticated methods to disentangle Ground Roll from geologic information by splitting the seismogram into pieces and applying subsequent decomposition were investigated [10,11]. A very clever idea of determining an optimal attenuation factor using a hybrid combination of wavelet transform and Principal Component Analysis was presented in [12].

All these methods have two points in common: first, the decomposition of the traces of the signal using a uni-dimensional spectral technique: Fourier or Wavelet Transform. Second, the use of an attenuation factor to remove part of the undesirable frequencies (or scales and tones) in the transformed space. In these cases, the attenuation is always done in a blind way. When an attenuation factor is fixed there is no guarantee that all the information is preserved or that part of the signal was not removed in the denoising operation. The attenuation is based on the rough assumption: if the noise is concentrated in a given range of frequencies (or scales) we should decrease the amplitude of the coefficients corresponding to these frequencies (or scales). Indeed, the attenuation is performed without a complete knowledge of the data.

The directional characteristic of the curvelet transform allows an optimal identification and further removing of the Ground Roll of the seismic image. Using this curvelet feature we present here a surgical removal denoising technique, in contrast to a partial attenuation. That means, instead of attenuating frequencies (or scales) where the Ground Roll is mainly present, we erase the directional coefficients inside these scales.

The paper is organized as follows. In Section 2, we briefly introduce the basics of curvelet transform theory. In Section 3, we present in some detail our filtering methodology for Ground Roll removing using curvelet transform. In Section 4 we apply the denoising technique to a seismic data contaminated by Ground Roll noise and discuss the energy balance between noise and signal across the scales. Finally, in Section 5, we show the main results and discuss the article in a broad context.

2. Mathematical background

In this section, we briefly introduce the mathematical background used in our filtering methodology: the curvelet transform. This section is also important for fixing the mathematical notation that we shall use throughout the paper.

The Curvelet transform is a recent multiscale analysis developed by Candès and Donoho [1]. A curvelet at scale j is an oriented object whose support is the rectangle of width 2^{-j} and length $2^{-j/2}$ that obeys the parabolic scaling relation *width* $\approx$ *length*^{2} [13]. The curvelets are described by a triple index j (scale), l (orientation) and $k = (k_1, k_2)$ (spatial location). The basic curvelet elements are obtained by parabolic dilatation, rotations and translations of a specific function $\phi_{j,l,k}$ [1].