The Curvelet Transform for ground-roll suppression

Ariane Jevaux Souza*, Reservoir Inference group /UENF, Brazil
Luiz Geraldo Loures, Reservoir Inference Group /UENF, Brazil

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Abstract

Ground roll is artifacts produced by surface waver on the land acquisition of seismic data. This artifact is a unwanted high-amplitude dispersive coherent noise very low group velocity. We present a methodology for ground rool suppression based on 2D curvelet transform, and show a result of an application on shot gather contaminated by a strong ground roll and guided waves.

Introduction

Ground roll is one type of Rayleigh wave that arises because of the coupling of compressional waves (P) and the vertical component of shear waves (SV) that propagate along the free surface. This coherent noise is recognized by low frequency, strong amplitude, and low group velocity. It is the vertical component of dispersive surface waves. Ground roll can have strong backscattered components because of lateral inhomogeneities in the near-surface layer, Grant and West (1965).

In the field, receiver arrays are used to eliminate ground roll, but the suppression of such a noise have not been reached for techniques of projection of acquisition parameters in the field. Techniques of denoising by digital filters have been developed.

The ground-roll suppression is an important issue on seismic land processing. Some techniques for ground roll suppression are based on based on dip filtering, Yilmaz (2007). Among the techniques of ground roll elimination, we can described filter pass-band and fk filter.

In this work we apply the curvelet transform for the removal of the ground roll. Curvelet transform is a geometric multi scale transformation with a optimal disperse representation of seismic data. We will present a short introduction of curvelet transform and show the result.

The curvelet transform

Curvelet transform was introduced by Candès and Donoho (2000). The curvelet transform can be defined by a pair of windows W(r) (a radial window) and V(r) (an angular window).

$$\sum_{j=-\infty}^{\infty} W^2\left(2^j r\right) = 1, r \in \left(\frac{3}{4}, \frac{3}{2}\right), \quad (1)$$

$$\sum_{l=\infty}^{\infty} V^2\left(t - l\right) = 1, t \in \left(-\frac{1}{2}, \frac{1}{2}\right). \quad (2)$$

A wedge represented by U_j is supported by W and V, the radial and angular windows. U_j is defined in the Fourier domain by

$$U_j\left(r,\theta\right) = 2^{-3j/4} W\left(2^{-j} r\right) V\left(\frac{2^{\lfloor j/2 \rfloor}\theta}{2\pi}\right). \quad (3)$$

Then we can defined the curvelet transform as a function of $x = \left(x_1, x_2\right)$ at scale 2^{-j}, orientation θ_t, and position $x_k^{(j,l)}$ by

$$\varphi_{j,l,k}\left(x\right) = \varphi_j\left(R_{\theta_t}\left(x - x_k^{(j,l)}\right)\right), \quad (4)$$

where R_θ is the rotation in radians.

The discrete version implemented in this work uses a 'wrapping' algorithm. This approach uses a spatial grid to translate curvelets at each scale and angle, assuming a regular rectangular grid. This method applies a 2D fast Fourier transform to the image. For each scale and angle, a product of *Uj* is obtained (see Eq. (3)). The result is then wrapped around the origin. The 2D inverse fast Fourier transform is then applied, resulting in discrete curvelet coefficients.

The discrete curvelet transform, was implemented in four steps: an application of the 2D fast Fourier transform of the image, a formation of a product of the scale and angle windows, a wrapping of this product around the origin, and an application of a 2D inverse fast Fourier transform. The discrete transform could have been calculated by sub-banding the image with wavelet decomposition and then applying a ridgelet transform, according with Dettori and Semler (2007). The approximate scales and orientations can be seen in Fig. 1. Curvelets are supported by a generic 'wedge'; the shaded area provides an example of such a 'wedge'.

The curvelet transform can be calculated to various resolutions of scales and angles. The parameters for the digital implementation of the curvelet transform are number of resolutions and number of angles at the coarsest level.

These were bound by the following two constraints: the maximum number of resolutions depends on the original image size, and the number of angles at the second coarsest level must be at least eight and a multiple of four.

The curvelet is a directional transform, with represents edges and singularities along curves with needle-shaped elements, with directional sensitive and smooth counters.

What makes curvelet transform interesting and actually motivated their development is that they provide a mathematical architecture that is ideally adapted for representing objects which display *curve punctuated smoothness*—smoothness except for discontinuity along a general curve with bounded curvature—such as images with edges, for example.

In Dettori and Semler (2007) is take the comparison of wavelets, ridgelet and curvelets for some tissue of interest and the results show the curvelets produce clearly outperforms all wavelets and ridgelets.

A difference between the curvelets and wavelets is basically the curvelets is more efficiently in problems as these examples:

- Optimally representation of objects with edges;
- Optimally sparse representation of wave propagators;
- Optimal image reconstruction in severely ill-posed problems.

The curvelet transform has a property of sparsity, i.e. most of the energy of the signal is localized in just a few coefficients (sparsity). A curvelet is localized functions that are oscillatory in one direction and are smooth in the other. Basic properties of curvelet transform are:

- multiscale, with frequency support on dyadic coronae in the 2D Fourier plane.
- multidirectional, with angles that corresponded to the centers of the wedges (for every other resolution doubling, the number of angles doubles).
- anisotropic, obeying the following scaling width x length.
- local, allowing for thresholding, which locally adapts to the non stationary signal.

By virtue of their multi scale and multidirectional construction, curvelets sparsely represent seismic data. Not only do individual curvelets capture the main characteristics of wave fronts locally, but they also jointly capture the seismic energy effectively.

In this work we use the wrapping curvelet package from CurveLab to implement tools for seismic denoise.

Curvelet Processing workflow

Figure 2 represents a flow of the algorithm of curvelet transform based on the wrapping technique we adopted.

Processing in steps

For the ground roll filtering from the seismic data we have developed a three steps flow based on curvelet transform. The first steps we take filter the random noise in the data. After this step we do an analysis on the curvelet domain to localize the scale and dip of the ground-roll at the curvelet domain. After locate where is the noise what want removal, the scale and dip, rebuild it data without the noise. Thus before do the inverse curvelet transform, filtering such noise.

Results

Figure 3 represents samples of shot gathers of a land data with the strong ground-roll. Figure 6 are the data from the Figure 3 represented on 6 scales on the curvelet domain. The Figure 7 represent the scale 5, decomposed on different angles, were we can define the ground roll angle for its suppression after the curvelet transform. Figure 4 represent the data after the filtering and Figure 5 the noise suppressed from the data.

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Conclusions

The main energy of the ground roll was suppressed from the noisy data, keeping the energy of the signal with the proposed methodology based on the curvelet transform.

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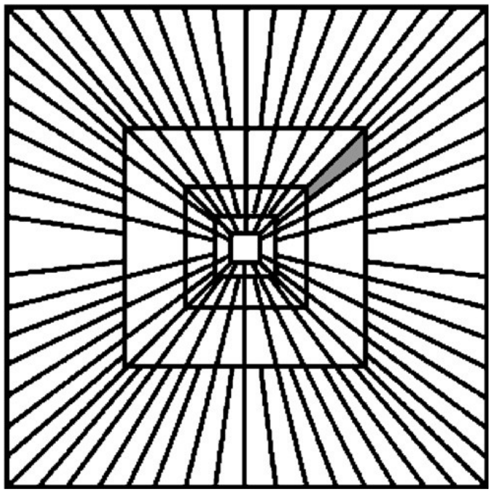

FIGURE 1: Discrete curvelet partitioning in tiling by the wedges.

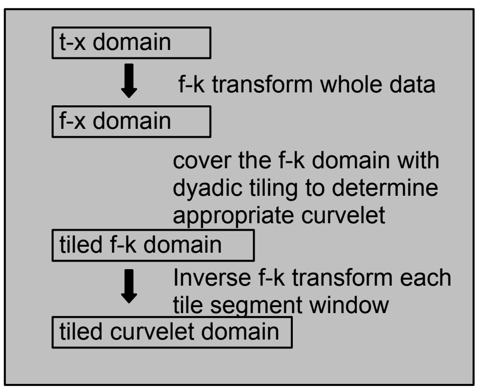

FIGURE 2: Work flow of the curvelet transform algorithm.

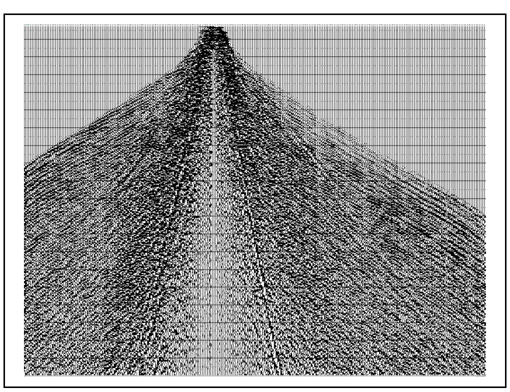

FIGURE 3: Shot gathers samples from a land data, with strong ground roll.

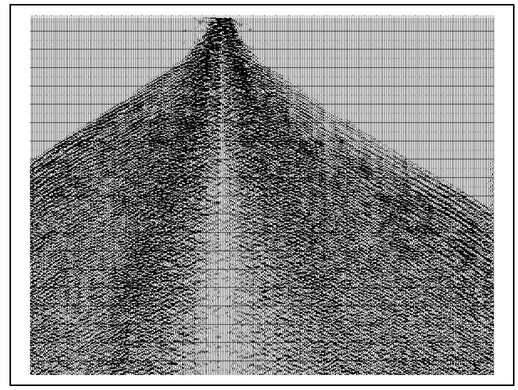

FIGURE 4: Seismic data from the Figure 3 after the ground roll suppression with curvelet transform.

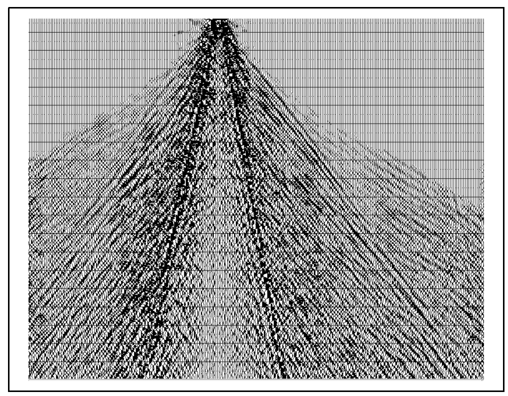

FIGURE 5: The ground-roll suppressed from the data on the Figure 3.

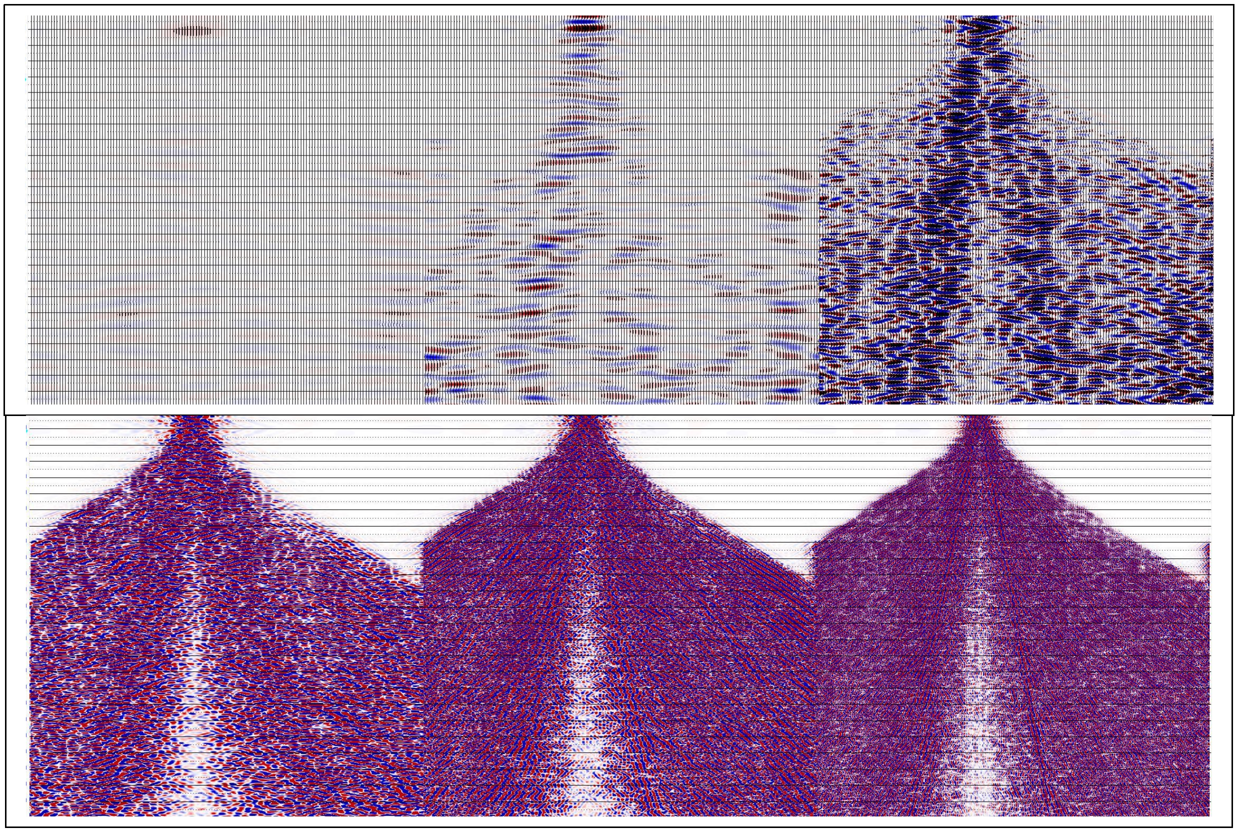

FIGURE 6: The scales representation of the seismic data from Figure 3 at the curvelet domain.

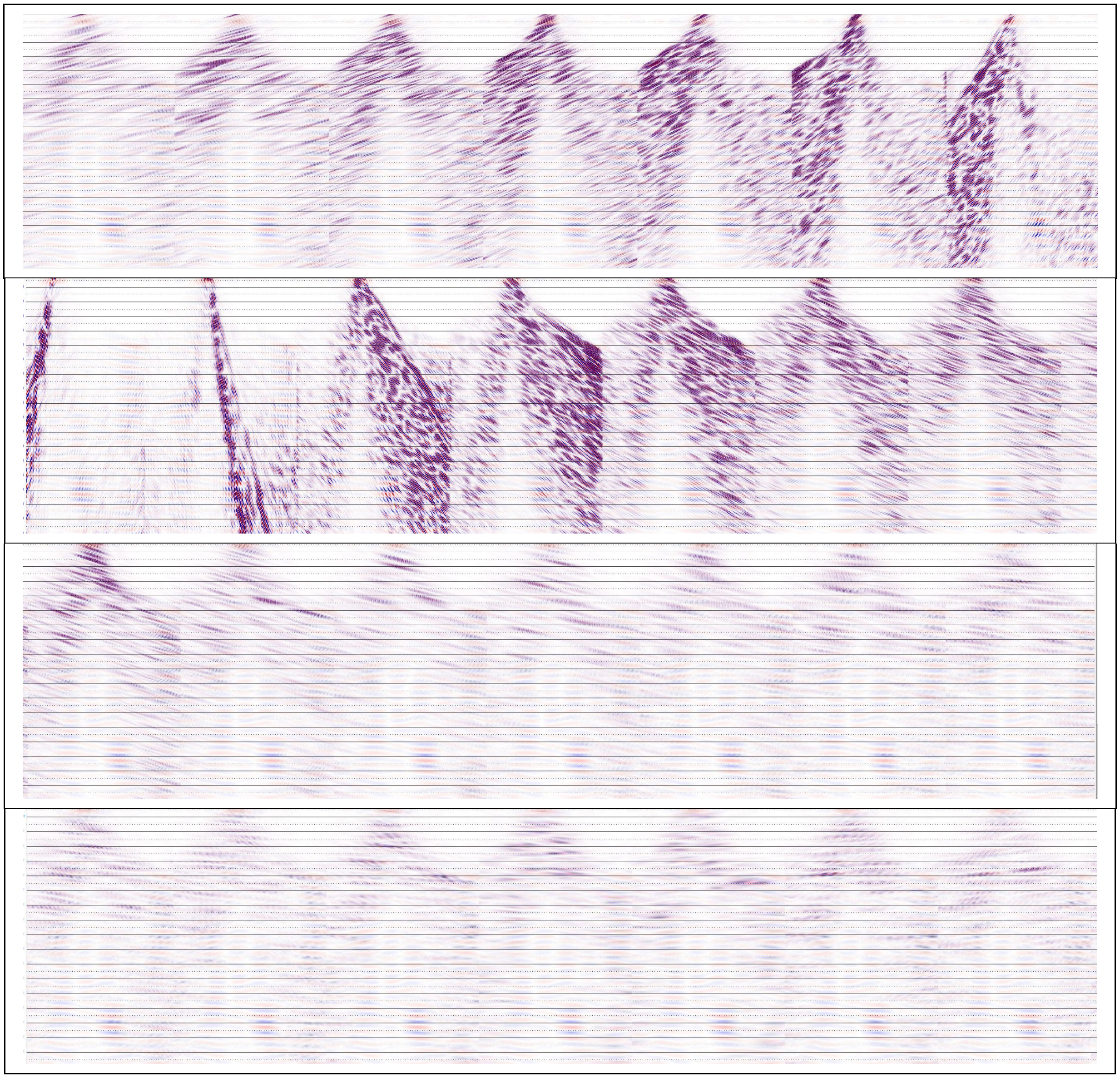

FIGURE 7: Decomposition of the scale 5 of the seismic data on the angles of the curvelet transform.