An adaptive local-slope SVD filtering approach to enhance events on seismic sections

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SUMMARY

We present an adaptive singular value decomposition (SVD) filtering method for enhancement of the spacial coherence of the reflections and for the attenuation of the uncorrelated noise. The SVD filtering is performed on a small number of traces and a small number of samples collected around each data component. The method uses the local slope of the reflections to re-sample the data set surrounding each data component and the SVD filtering is locally applied to compute the filtered data. The filtered data component is obtained by stacking the components of the first K eigenimages along the slope. The method is applied in two steps: (i) before the SVD computation, the normal move-out (NMO) correction is applied to the seismograms, with the purpose of flattening the reflections. We use the local slopes equal to 90° to preserve the horizontal coherence of the primary reflections and (ii) for the second step the SVD filtering uses as input the filtered data of step-1 and the method is applied in the common-offset domain. Now the local slopes of the reflections are used in order to drive the SVD filtering. We illustrate the method using land seismic data of the Tacutu basin, located in the Northeast of Brazil. The results show that the proposed method is effective and is able to reveal reflections masked by the ground-roll.

Introduction

Singular value decomposition (SVD) is a coherency-based technique that provides both signal enhancement and noise suppression. It has been implemented in a variety of seismic applications. Freire and Ulrych (1988) apply the SVD filtering to the separation of upgoing and downgoing waves in vertical seismic profiling. Tyapkin et al. (2003) proposed to use the data alignment method of Liu (1999) to make the coherent noise horizontally aligned in one or more time sections of a common shot gather. The noise is represented by the first eigenimages and the remaining eigenimages represent the signal. Chiu and Howell (2008) proposed a method that uses SVD to compute eigenimages that represent coherent noise in a localized time-space windows. The data in the local windows is transformed into analytic signal and followed by a complex SVD to decompose the analytic signal into eigenimages that represent the coherent noise model. Melo et al. (2009) presented a filtering method for ground-roll attenuation that uses a 2-D time-derivative filter. Bekara and Baan (2007) proposed a local SVD approach to noise removal. In each data window the signal is horizontally aligned in time, and after SVD only the first eigenimage is retained. Then the procedure is repeated in the next data window using sliding windows with 50% overlap. Porsani et al. (2009) use SVD filtering to attenuate the ground roll. Before the SVD computation, normal move-out (NMO) correction is applied to the seismograms, with the purpose of flattening the reflections. SVD is performed on a small number of traces in a sliding window filtering approach. The output trace is the central trace of the first few eigenimages. Here we extend the Porsani et al. (2009) approach by using the local slope of the reflections in order to drive the SVD filtering. SVD is performed on a small number of traces and small number of samples around each data component which are obtained re-sampling the data along the local slope of the reflections.

Local Slope estimation

We consider a real data set $d(t,x_n)$, $t = 1,\ldots,N_t, n = 1,\ldots,N_x$. For the entire data set we obtain the 2D derivatives regarding t and x by using the method proposed by Melo et al. (2009).

Let L_x and L_t represent the number of elements of derivatives of time and x to be used in the local slope estimation. Around each data point $d(t,x_n)$ we collect, from $-L_t$ to L_t and $-L_x$ to L_x, the derivatives of time and x into a vector $\mathbf{z}$ and $\mathbf{x}$, respectively. The local slope estimation may be computed by solving the eigenvalue and eigenvector problem for a_j Porsani et al. (2000).

$$\begin{bmatrix} \mathbf{x}^T\mathbf{x} & \mathbf{x}^T\mathbf{z} \\ \mathbf{z}^T\mathbf{x} & \mathbf{z}^T\mathbf{z} \end{bmatrix} \begin{bmatrix} 1 \\ a_j \end{bmatrix} = \lambda_j \begin{bmatrix} 1 \\ a_j \end{bmatrix} \quad , \quad j = 1,2 \qquad (1)$$

Equation (1) relates to the total least square method. We remark that $a_1a_2 = 1$ implies the directions associated with $\theta_j = \arctan(a_j)$, $j = 1,2$, are orthogonal. The local slope θ_j of the reflection corresponds to the maximum value of λ_j.

SVD filtering

A windowed data set of $2L_x + 1$ traces and $2L_t + 1$ samples centered at $\{t,x_n\}$ is given by the matrix $\mathbf{D}^{t,n}$ with components

$$D^{t,n}_{tj} = d(t,x_{n+j}) \quad \begin{cases} t = -L_t,\ldots,0,\ldots,L_t \\ j = -L_x,\ldots,0,\ldots,L_x \end{cases}$$

It can be represented by the reduced SVD (Golub and Loan, 1996):

$$\mathbf{D}^{t,n} = \sum_{k=1}^{2L_x+1} \sigma_k \mathbf{u}_k \mathbf{v}_k^T \qquad (2)$$

where both the left singular vectors $\mathbf{u}_k$ and the right singular vectors $\mathbf{v}_k$ are orthogonal. The singular values are sorted such that $\sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_{2L_x+1} \geq 0$. In component form the SVD is

$$D^{t,n}_{tj} = d(t,x_{n+j}) = \sum_{k=1}^{2L_x+1} \sigma_k u_k(t) v_k(j). \qquad (3)$$

In the filtered output data set only the first K eigenimages and the components $\tilde{d}(t,x_{n+j})$ are being used. The filtered output is given by

$$\tilde{d}(t,x_n) = \frac{\sum_{j=-L_x}^{L_x} \left(\sum_{k=1}^{K} \sigma_k u_k(t) v_k(j)\right)}{2L_x + 1} \qquad (4)$$

Adaptive SVD filtering along the local slope

Equation (3) is used for values of n and t between the interval $L_x + 1 \leq n \leq N_x - L_x$ and $L_t + 1 \leq t \leq N_t - L_t$. For $n \leq L_x$, $n > N_x - L_x$, $t \leq L_t$ and $t > N_t - L_t$ the filtered output data are obtained directly from the first K eigenimages.

The result is a filtered data set $\tilde{d}(t, x_n)$ of the same dimension as the input data set where energy which is not coherent in the x-axis direction has been attenuated. Both the character and amplitude of the events are well preserved as they are represented by the first eigenimages which have the largest energy.

SVD filtering along the local slope

To apply the SVD filtering approach along the local slope we need to re-sample the data set. We have used linear interpolation to fill an auxiliary matrix $\mathbf{A}^{t,n}$ $-L_x \leq t \leq L_x$ and $-L_t \leq n \leq L_t$ which will be used in the SVD filtering. If $\theta \geq 45°$ the interpolation is done along the t-axis, otherwise it is performed along the x-axis. Figure 1 illustrates the original and the interpolated grid. The lines and columns of the auxiliary matrix will store the amplitudes along and across the reflectors, respectively.

Data results

We consider a real data set $d(t, x_n)$, $t = 1, \ldots, N_t, n = 1, \ldots, N_x$, where the primary reflections have been corrected for NMO so that they are horizontally aligned along the x-axis. In order to enhance coherent signals along the reflectors we perform a local SVD analysis in two steps. First we set the slope equal to 90° to enhance horizontal events and the SVD filtering is applied in shot gathers corrected for NMO. Second the the filtered data set is reorganized in common offset panels, the local slope is determined and the SVD filtering is applied.

The proposed method of SVD filtering was tested on a land seismic line. It contains 576 shots recorded at 4 ms sampling intervals. There are 96 channels per shot in a split-spread geometry with offsets 3.850-100-0-100-1050 m and 50 m between the geophones. The distance between the shots is of 50 m giving a low CMP coverage of 48 fold.

First a standard processing sequence was applied: geometry, edit, preliminary spherical divergence correction, standard velocity analysis and NMO correction. Due to the limited CMP coverage, the data were then resorted into shot gathers before the SVD filtering was applied. In the filtering process we used a 5-trace by 5-sample window ($L_x = 2$ in equation (3)) for the SVD analysis, and we kept the two most significant central eigentraces (K=1 in equation (4)).

Fig. 3 shows the shot gathers after inverse NMO correction. The result of the shot gather SVD filtering in Fig. 3a is shown in Fig. 3b. The ground roll is very well separated from the horizontal events. The result of SVD filtering applied to the common-offset panels is shown in Fig. 3c.

The amplitude spectrum of each trace was computed, and the average amplitude spectrum for the three shot gathers in Fig. 3 are compared in Fig. 2. Note that the SVD filtering removes a substantial part, but not all, of the low-frequency energy in the original gather.

Fig. 4 shows details of a common offset panel (offset=1500) after SVD filtering applied to shot-gather and common-offset domains. Fig. 4a shows the original data. The result of the SVD applied to the shot-gather domain (local slope is fixed as equal to 90°) is shown in 4b. The result of SVD filtering applied to the common-offset domain (using the local slope of reflections) is shown in Fig. 4c. The enhancement of the reflections along the local slope may observed comparing Figs. 4b and 4c.

The stacked section obtained from the original data is shown in Fig. 5a. This should be compared to the stacked section shown in Figs. 5b and 5c obtained by using SVD filtering on shot gathers (step-1), and common offset panels (step-2). Both results show enhancement of the reflections and significant attenuation of the ground-roll. However, the results obtained by adding step-2 are still better.

Conclusion

We have developed a new and efficient adaptive SVD filter method which enhances horizontal and dip events on seismic sections. The SVD filter process preserves the character and frequency content of the reflections and attenuate all other types of events. New applications and extensions for pre or post-stack seismic data, can be easily implemented. The method was successfully applied to ground-roll attenuation on a land seismic data set. In particular, ground-roll was virtually absent from the filtered pre-stack gathers.

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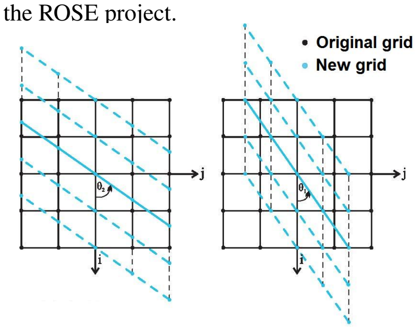

Figure 1: Interpolation grid along the local slope.

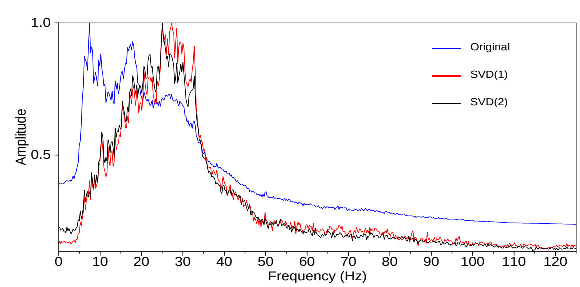

Figure 2: Average amplitude spectra of data shown in Fig. 3.

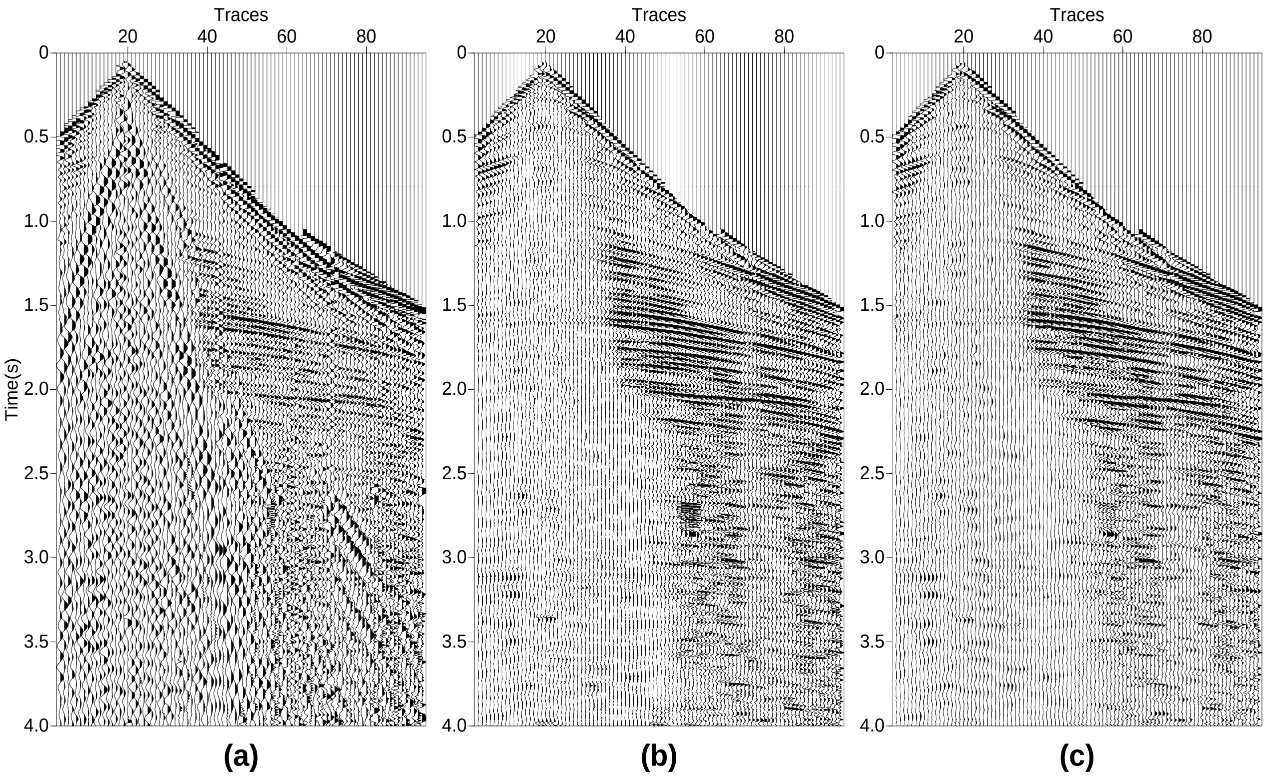

Figure 3: Comparison of SVD filtering after inverse NMO. Input data in (a), after first step of the SVD filtering (shot-gather domain), and after second step of SVD filtering (common offset domain) (c).

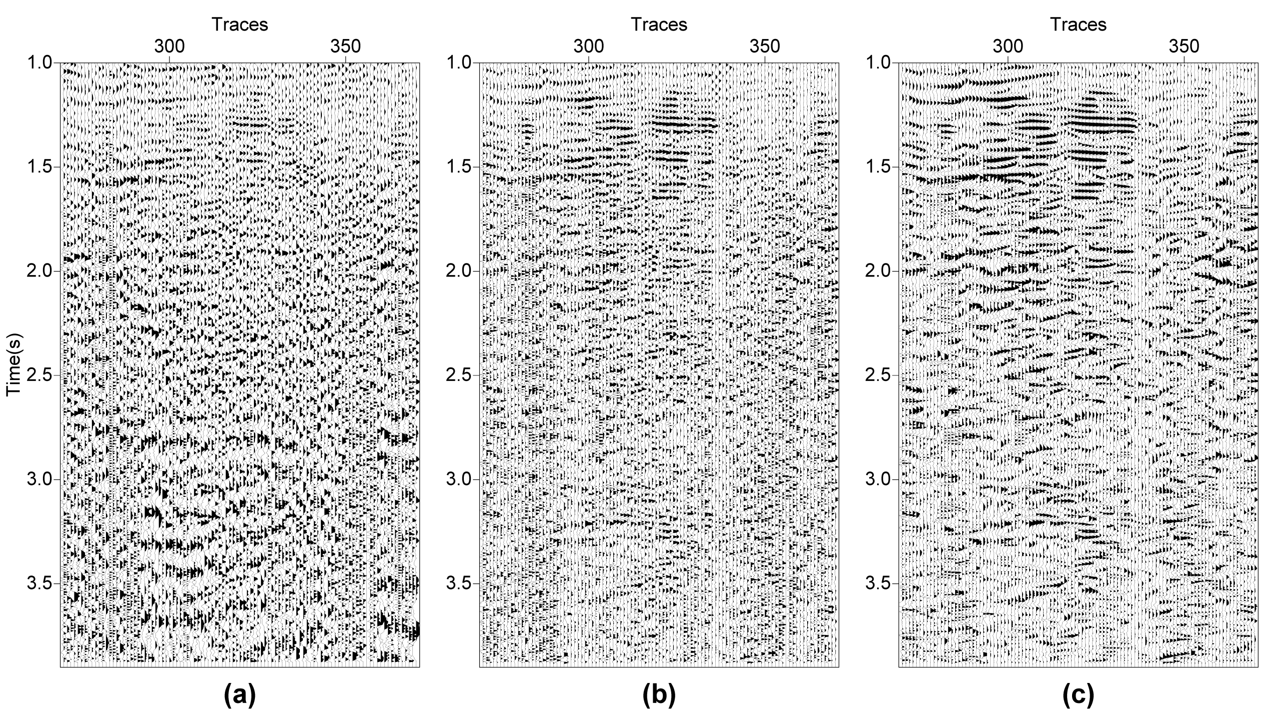

Figure 4: Details from a common offset sections. Original data (a), SVD filtered data (shot gather domain) (b) and SVD filtered data (common offset domain) (c).

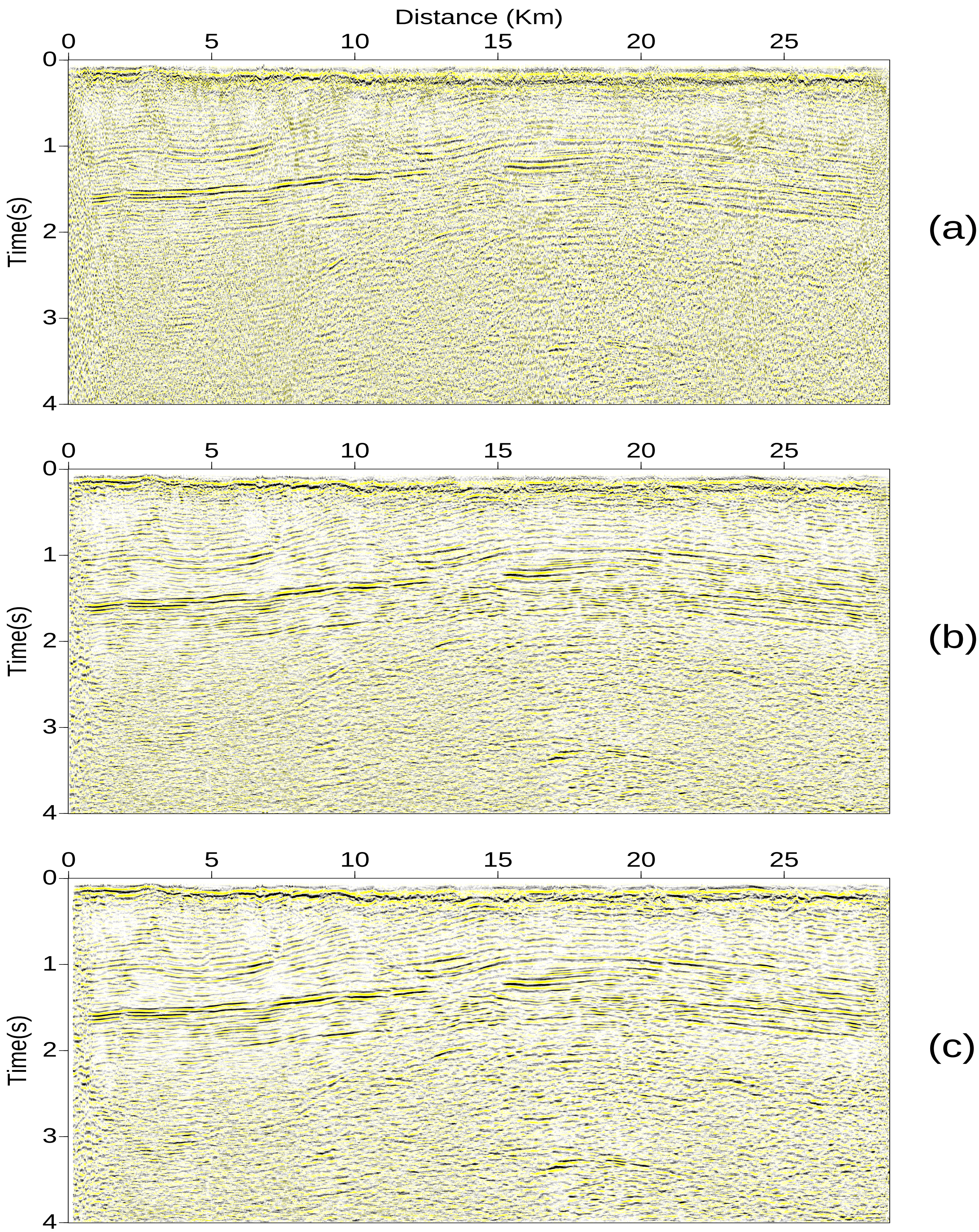

Figure 5: Stacked sections. Original data (a), SVD filtered data in the shot-gather domain (b) and SVD filtered data in the shot-gather domain followed by common-offset domain (c).

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