Singular value decomposition and multichannel predictive deconvolution applied to multiple attenuation of Jequitinhonha basin

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Abstract

In this work, it is proposed the use of singular value decomposition and multichannel predictive deconvolution to multiple attenuation. Each method kept its modus operandi; however, in order to improve the results, the deconvolution was applied only on the short offsets, whilst the SVD was applied to the whole data. The results obtained by using this method on the 2-D marine seismic data from an acquisition on Jequitinhonha basin were satisfactory, since the multiple reflections were attenuated, and the amplitude of the reflectors was conserved.

Introduction

The seismic data processing aims to increase the signal-to-noise ratio, in order to improve the subsurface imaging and, therefore, the geological interpretation. It is well known that there are many kinds of noise that affect the seismic signal quality, but, when it comes to marine data, the most important one is due to multiple reflections, whose attenuation is the subject of this work. In order to so, it was employed both multichannel predictive deconvolution method and SVD filter method.

Predictive deconvolution consists of calculating the coefficients in the prediction-error filter, and then applying the filter to the data (Porsani and Ursin, 2007). Thereby it is obtained, as a result, a set of traces whose predictable parts were removed. This is accomplished by least squares estimation of the aforementioned coefficients, which can be done e.g. by the Levinson's principle (Levinson, 1947).

The multichannel version of this method, on the other hand, has the same modus operandi, and can also be applied to predict and remove multiple reflections from the input data (Galbraith and Wiggins, 1968; Cassano and Rocca, 1973; Taner, 1980; Koehler and Taner, 1985; Taner et al., 1995; Dragoset and Jericevic, 1998; Lokshtanov, 1998; Rosenberger et al. 1999). However, instead of scalar coefficients, matrices are used (Treitel, 1970).

Singular Value Decomposition (SVD) is a filtering method that decomposes the input data into a finite weighted sum of rank-one matrices, whose initial terms carry the most flattened coherent data, and preserves the amplitude and phase relations, and the spatial correlation of the seismic events. It can be used in the stacking process to highlight the reflectors, and to reduce noises, such as ground roll, which is its common use (Freire, 1986; Freire & Ulrych, 1988; Bekara & Baan, 2007; Porsani et al., 2009). The present work, however, proposes its use for multiple attenuation.

In this study, the method was applied to the data from a 2-D marine acquisition on Jequitinhonha basin, which is located in the south coast of Bahia, in front of Jequitinhonha river mouth.

Multichannel predictive deconvolution

The seismic trace, x_t, may be represented by a stationary, autoregressive model,

$$\mathbf{x}_t = -\sum_{j=1}^{N} \mathbf{x}_{t-j}\mathbf{A}_{N,j} + \mathbf{e}_t \tag{1}$$

where -$a_{N,j}$ are the coefficients in the prediction-error filter and e_t are the prediction errors (references). Thus,

$$\mathbf{E}_N = \begin{bmatrix} \mathbf{e_{N,0}} \\ \vdots \\ \mathbf{e_{N,M}} \\ \vdots \\ \vdots \\ \mathbf{e_{N,M+N}} \end{bmatrix} = \begin{bmatrix} \mathbf{x_0} & 0 & \cdots & 0 \\ \vdots & \mathbf{x_0} & \ddots & \vdots \\ \mathbf{x_M} & \vdots & \ddots & 0 \\ 0 & \mathbf{x_M} & \ddots & \mathbf{x_0} \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & \mathbf{x_M} \end{bmatrix} \begin{bmatrix} \mathbf{I} \\ \mathbf{A_{N,1}} \\ \vdots \\ \mathbf{A_{N,N}} \end{bmatrix}$$

$$= \begin{bmatrix} \mathbf{X} & 0 & \cdots & 0 \\ 0 & \mathbf{X} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \mathbf{X} \end{bmatrix} \begin{bmatrix} \mathbf{I} \\ \mathbf{A_{N,1}} \\ \vdots \\ \mathbf{A_{N,N}} \end{bmatrix} \tag{2}$$

where,

$$\mathbf{X} = \begin{bmatrix} x_{10} & \cdots & x_{K0} \\ \vdots & \dots & \vdots \\ x_{1M} & \cdots & x_{KM} \end{bmatrix} = \begin{bmatrix} \mathbf{x_0} \\ \vdots \\ \mathbf{x_M} \end{bmatrix} \tag{3}$$

By solving the above system of equations for A_N by means of least squares method, the coefficients of the predictive filter can be determined (Porsani and Ursin, 2007).

Singular Value Decomposition (SVD)

The SVD consists in determining three matrices that satisfy the condition:

$$\mathbf{A} = \mathbf{U}\Sigma\mathbf{V}^T \tag{4}$$

where $\mathbf{U}$ and $\mathbf{V}$ are orthonormal matrices and Σ, the matrix of the singular values.

This equation is the most common form of the SVD, but it can also be represented as a sum:

$$\mathbf{A} = \sum_{j=1}^{N} \sigma_j \mathbf{u}_j \mathbf{v}_j^T = \sum_{j=1}^{N} \widetilde{\mathbf{A}}_j \qquad (5)$$

where $\mathbf{u}_j$ and $\mathbf{v}_j$ are columns and rows of matrices $\mathbf{U}$ and $\mathbf{V}$, respectively, and σ_j, is the corresponding singular value of the matrix Σ. Moreover, the product of the jth elements of $\sigma_j \mathbf{u}_j \mathbf{v}^t_j$ represents the jth eigenimage $\widetilde{\mathbf{A}}_j$ of the matrix A (Freire, 1986). Once the sum is finished, the whole matrix is reconstructed, without data loss.

Methodology and Results

Based on the theory of both methods, it is expected that: SVD attenuates less coherent data, which are those less flattened , if the all eigenimages but the first are subtracted from the original signal; and multichannel predictive deconvolution attenuates predictable periodic signals.

Hence, if SVD is applied to a normal moveout corrected data and only its first eigenimage is kept, only the flattend events remain. Since the multiple reflections are not normalized by the NMO correction, they are attenuated (Figure 3a). However, in short offsets, all hyperbolas are nearly flattened (Figure 1b), which means that the aforementioned attenuation, in this case, may not be as effective as it should be. Nevertheless, the multichannel predictive deconvolution may be used in this case, since this flattening improves the prediction of the multiple reflections. Therefore, the SVD can be used to attenuate multiple events in long offsets whilst the multichannel predictive deconvolution can be used in the short offsets, thereby improving the multiple attenuation (Figure 3b).

In order to evaluate this method, it was used a 2-D marine data from an end-on acquisition on Jequitinhonha basin with 1751 traces, recording time of 7s, and 701 CMP with 60 traces each. To do the data processing, it was used the Seismic Unix (SU), which is maintained by the Center for Wave Phenomena (CWP) of Colorado School of Mines (CSM).

The SVD method can be summarized as follows:

- Pre-processing (geometry, trace editing and mute);
- Sorting the data based on the CMP order (Figure 1a);
- Velocity analysis;
- NMO correction (Figure 1b);
- Applying SVD method (Figure 2);
- Inverse NMO correction (Figure 3a).

Therefore, by applying the steps above, the multiple reflections in long offsets are attenuated. Moreover, this output is the input of the second method, whose steps are summarized as follows:

- Multiple velocity analysis;
- Multiple moveout (MMO) correction, which is mandatory to multiple prediction;
- Splitting the data into long and short offsets;
- Applying multichannel predictive deconvolution only on the short offsets;
- Concatenating the long and short offsets;
- Sorting the data based on the CMP order;
- Inverse MMO correction (Figure 3b);
- NMO correction;
- Applying gain followed by stacking (Figure 4b).

In this study, the best results were obtained by applying the SVD method with 3 traces and the predictive deconvolution with 7 channels. By analyzing the original and filtered stacked data, it can be seen that the multiple reflections were satisfactorily attenuated, as can be seen in the interval between 2 and 3 seconds. Moreover, even though the multiple reflections were attenuated, the amplitude of the reflectors were conserved.

Conclusions

In the present work, it was presented a method to multiple attenuation, that uses SVD and multichannel predictive deconvolution. Since the SVD is more effective to long offsets, whilst the aforementioned deconvolution, to short offsets, it could be shown that the use of both could improve the multiple attenuation. Thus, as can be seen by the analysis of all figures, the results obtained are satisfactory, since its main goal was achieved and the amplitude of the reflectors was conserved. It is also expected that the results of this method may be greater if a more refined processing is done, such as determining a more precise velocity field.

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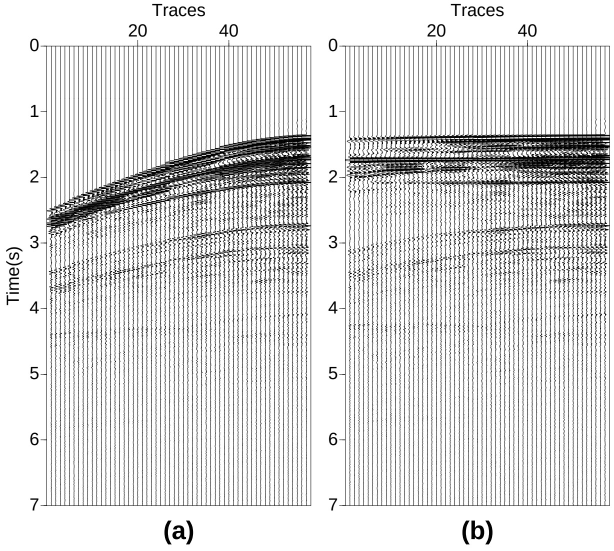

Figure 1: *(a) Original CMP is presented. (b) Same CMP after NMO correction.*

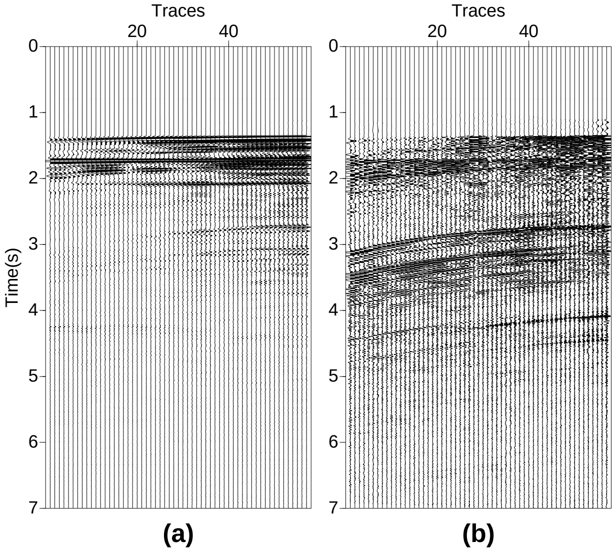

Figure 2: *(a) First eigenimage of the corrected CMP. (b) Residual data.*

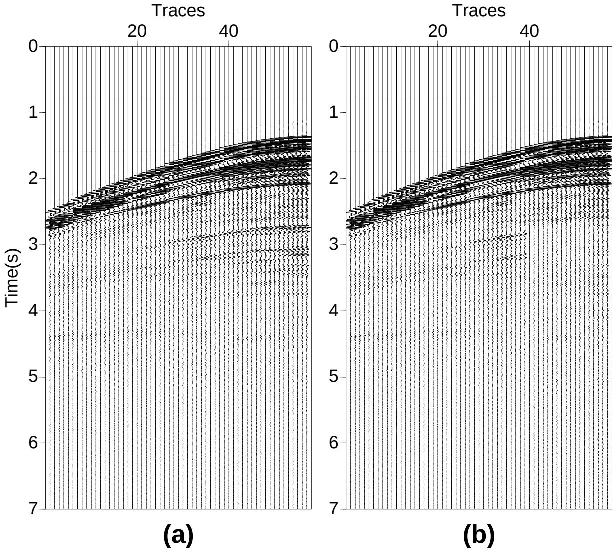

Figure 3: *(a) First eigenimage after inverse NMO correction. (b) Same corrected data after deconvolution.*

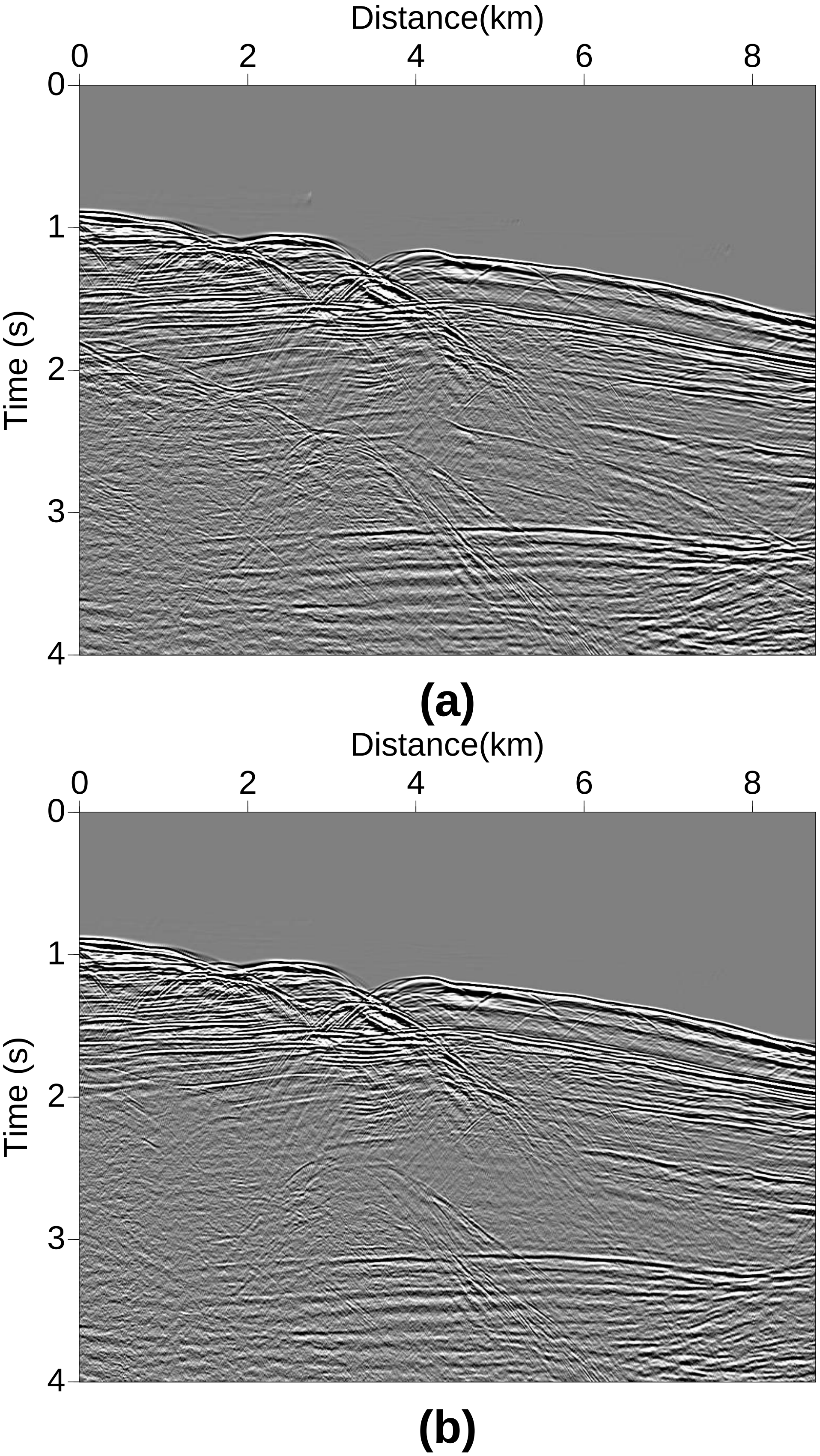

Figure 4: *(a) Original stacked data; (b) Stacked data after filtering*