



Filter KL/SVD for ground roll noise attenuation
 Pedro Henrique Cáceres Figueiredo, CPGeo e UFRN, Brasil
 Liacir dos Santos Lucena, UFRN, Brasil
 Gabriel de Almeida Araújo, CPGeo e UNP, Brasil

Copyright 2009, SBGf - Sociedade Brasileira de Geofísica

This paper was prepared for presentation during the 11th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, August 24-28, 2009.

Contents of this paper were reviewed by the Technical Committee of the 11th International Congress of the Brazilian Geophysical Society and do not necessarily represent any position of the SBGf, its officers or members. Electronic reproduction or storage of any part of this paper for commercial purposes without the written consent of the Brazilian Geophysical Society is prohibited.

Abstract

In geophysics there are several steps in the study of Earth, one of them is the seismic records processing. These records are obtained through observations made on the surface, being useful to obtain information about the structure and composition of inaccessible zones in high depths. Most of the tools and techniques developed for such studies have been applied in academic research. The major problem in seismic processing is the undesired energy, registered by receivers that do not bring any information about the reflectors, that could mask the information and / or generate mistaken information about the subsurface. This unwanted energy is known as seismic noise. Attenuate this noise to improve a signal that indicates a reflection without losing desirable signal is quite complicated. This project aims to the attenuation of noise generated from surface waves, especially the ground roll, which shows a pattern characterized by low frequencies, low speeds and strong amplitudes. The Karhunen-Loève Transform is a great tool for identification of standards based on the eigenvalues eigenvectors. The Transform will be used with the singular value decomposition as it is a great technique for mathematical manipulation of data. The algorithm of the filter KL/SVD was designed to run within the graphics card, using the architecture CUDA.

Introduction

The noises caused by the propagation of seismic waves in the regions near the earth's surface are typically much stronger than the reflections, harming the algorithms used in seismic processing. These events are mainly the direct wave, the ground roll, the multiple of the flat reflections and the reverberation of refractions in the zone of intemperism is characterized by low-speed compared to the speed of the layer below it. The attenuation of noise is required before the application of algorithms such as the deconvolution, estimating that the seismic trace is composed only for a random series, the coefficients of reflections, convolved with the signature of the source. This paper discusses the use of filter KL/SVD in the attenuation of ground roll.

Method

The Karhunen-Loève Transform, or simply KL Transform is very used to identify patterns in the sense of coherence of signals. The Transform is used to improve the signal/noise of the seismic trace. The philosophy of the method is to replace a group of neighboring lines by another group composed of traits without the first components of larger eigenvalues. This group brings together the main features of statistical characteristics of consistency (correlated), the largest singular values, the factors of greatest correlation. Imagine a matrix $A_{m \times n}$, consisting of n lines with m samples per line, where the element A_{ij} is the record of the amplitude geophone j in time i , and $m < n$. The the vectors X_i represent the lines, and the vector Y_j , the columns of A .

$$A = [Y_1 Y_2 Y_3] \cdot [X_1 X_2 X_3]^t \quad (1)$$

$$A_{ij} = X_{ij} \cdot Y_{ji} \quad (2)$$

A symmetric matrix Γ , which has real and orthonormal eigenvalues, and order $m \times m$, can be defined from the data matrix A , that is:

$$\Gamma = A \cdot A^t \quad (3)$$

Where Γ is the covariance matrix and its values are defined positively. In multivariate terms, the matrix of covariance (or variance-covariance matrix) is defined as the matrix that contains in its main diagonal the variances of the columns and other elements in the covariance. A KL transform of a matrix A is given by a matrix $\Psi_{m \times n}$:

$$\Psi_{m \times n} = U^t \cdot A \quad (4)$$

Where the columns of the matrix U are eigenvectors of Γ , U_i is the normalized eigenvectors from eigenvalues λ_i where $\lambda_1 > \lambda_2 > \lambda_3 \dots$ of a covariance matrix Γ .

$$U = [U_1 U_2 \dots U_m] \quad (5)$$

The original data can be recovered:

$$A = U \cdot \Psi \quad (6)$$

$$\Psi = [X_1 X_2 X_3]^t \quad (7)$$

$$A = \sum A_i = \sum U_i \cdot X_i \quad (8)$$

Thus the matrix A is implied between the column of the vector U_i and the line of vector X_i . The eigenvectors U_i are called empirical eigenvectors with good orthogonal modes or KL modes, the matrix $A_i = U_i X_i$ the i -th term of the eigenimage of A . In the context of the major component analyzed, the eigenvectors U_i define the major components whereas the line vectors X_i of the of KL (Ψ) Transform contains the numbers of the i -th major component.

The sum of the eigenvalues λ_i can be seen as a measure of the total energy of the data, so each λ_i is the energy of the empirical mode i represented by vector U_i . Thus the energy E of the matrix A , is the sum of the eigenvalues of the matrix Γ .

$$E = \sum \lambda_i \quad (9)$$

$$E_i = \frac{\lambda_i}{\sum \lambda_i} \quad (10)$$

λ_i can be interpreted as the energy captured by the i -th eigenvector empirical U_i , E_i is the relative energy on the i -th mode KL. An important property of the KL expansion is that we can build a matrix A_k using only k eigenvalues and eigenvectors for best approximation of the data matrix A . We use the matrix Ψ_k retaining the first K rows of the matrix Ψ and then turning to zero $m-k$ remaining lines, thus:

$$A_k = U \Psi_k \quad (11)$$

Where $k < m$ is the best approximation of A by a matrix of rank K with $k < r$ (Rank (A) = r). This property is said to be optimal and leads implementation of data compression and reduction in size, allowing the approximation of the data matrix A by a matrix lower A_k with minimal loss of information.

In the case of ground roll, it shows a pattern where the amplitudes are stronger than the reflected signal, low speed and concentration of energy at low frequencies, spreading is close to the ground. Thus it is understood that noise is contained in the consistency of data, having to use the KL transform to remove, so make the matrix Ψ_k where are turned to zero the first K rows of Ψ Transform and the rest are null.

$$A'_k = U \Psi'_k \quad (12)$$

Such that A'_k will be a filtered version of the matrix A , where the largest k eigenvalues of the covariance matrix of Γ (the most consistent modes) were removed. The expansion of the matrix of seismic data in eigenimages and singular values, known as singular value decomposition in (SVD) is applied at different stages of processing seismic data. The idea is to decompose the data into images based on the eigenvalues and autovetores, where this whole or sum of these images reflect the data again. Each eigenimages is given by the scalar product of basis vectors. The eigenimages and singular values associated are calculated based on the concepts of linear algebra related to eigenvectors and eigenvalues of covariance matrices

correspondents. An appropriate choice of the number and indices of eigenimages used in the decomposition is the basis for a new method of two-dimensional filtering of coherence.

The main characteristic of the decomposition in singular values is the ability of the method to determine the position or the degree of singularity of a matrix. When dealing with seismic data this uniqueness is reflected in the degree of correlation between the traces of the record. The lower the rank, the greater the correlation between the traces with the information of the matrix of input data are concentrated in few eigenimages, which will be associated with large singular values. Every matrix can be written as $A \in IR^{m \times n}$:

$$A = U \Sigma V^t \quad (13)$$

Where U is an orthogonal matrix of type $m \times n$, and its columns are eigenvector U_i of a covariance matrix Γ , and are called empirical eigenvectors or KL modes. The matrix $\Sigma \in IR^{m \times n}$ is real, diagonal and rectangular, the same type of A ($m \times n$), such that the main diagonal are not negative numbers with elements $\sigma_i = \sqrt{\lambda_i} = 1, 2, 3, \dots, r$ being r the rank of matrix Σ . By convention, the order to the singular values is determined from the largest to smallest, with $\sigma_i > \sigma_2 > \sigma_n > 0$. The columns of the orthogonal matrix $V \in IR^{n \times n}$ correspond to the n eigenvectors of matrix $A^t A$ with not-null eigenvalues.

$$A_k = U \Sigma V^t = \begin{bmatrix} u_1 & \dots & u_k \end{bmatrix} \begin{bmatrix} \sigma_1 & & \\ & \ddots & \\ & & \sigma_k \end{bmatrix} \begin{bmatrix} v_1^t \\ \vdots \\ v_k^t \end{bmatrix} \quad (14)$$

$$A_k = \sigma_k u_k v_k = \sigma_k Q_k \quad (15)$$

The diagonal elements of σ are the singular values. The columns of u are the left singular vectors. The columns of v are the right singular vectors. Rank (A) = r , being r the number of not-null singular values.

Results

The separation and/or extraction of seismic events with KL/SVD depends crucially on the degree of horizontal correlation between the traces of the record. The ground roll shows a correlation over a strong inclination caused by the low speed. In these situations it is advisable that a process prior to application of the filter, to remove the traces static or dynamically, in relation to one another and place the desired signal in a pattern horizontalized as possible. This will concentrate most of the information in the first eigenimages. After application of filtering KL/SVD returns to the original position of the reflectors, providing a contrast to the previous shift. In this article we used the technique Linear move out (LMO) to horizontalisation of events to be filtered by dividing the distance by the speed of each trait predominant noise (Figures 1 and 2).

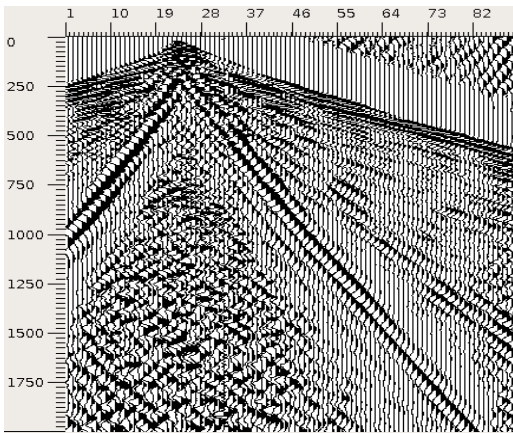


Figure 1. Input data

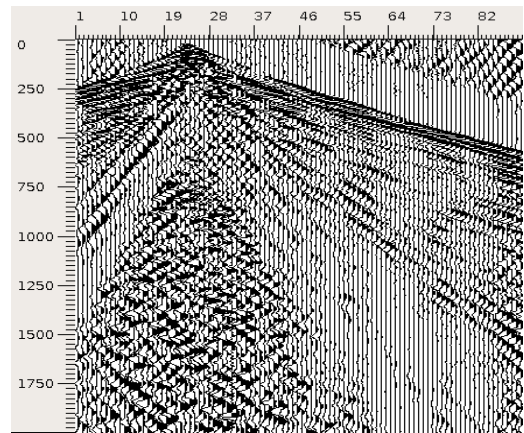


Figure 4. Filtered Data

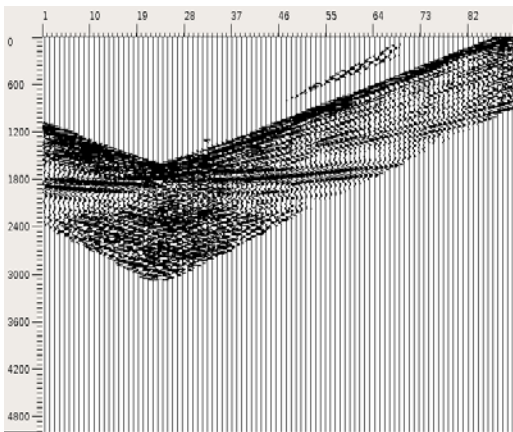


Figure 2. Input data LMO corrected, with 800m/s

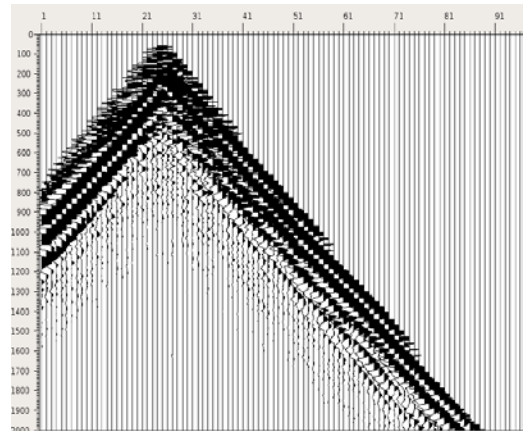


Figure 5. Part of the filtered data

To know which eigenvalues are associated with the ground roll, we can apply the method of trial and error, and visually see the pictures before and after filtration. Another more technical method used in this work is analyzing the graphic of amplitudes and eigenvalues in ascending order and identifying the number of eigenvalue where there is a sharp drop in the slope of the curve. Look at the chart of Figure 3 in which this fall is given in the first eigenvalues. In this example, was chosen to null the first four elements before adding the sum of eigenimages that resulted in the filtered matrix that is shown in Figure 4.

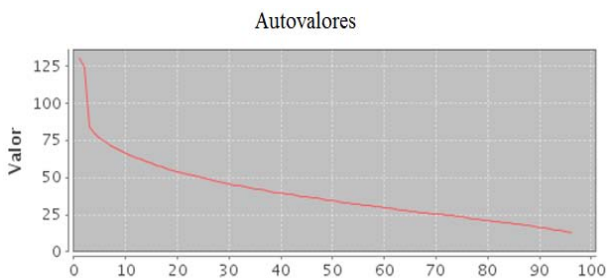


Figure 3. Table of eigenvalues

Conclusions

The algorithm developed in this paper possess as distinguishing its development in CUDA architecture, where the processes are performed in parallel on the graphics card, significantly reducing the processing time data in up to 10 times with respect to other types of computer architectures, providing a technological improvement in the field of geophysics.

The filter KL/SVD has been applied in real data(that shows a high incidence of ground roll) presenting satisfactory results in all practical tests to which was submitted by achieving the noise attenuation.

Acknowledgments

References

Leite, F. E. A., UFRN, 2007, Análise estatística de padrões sísmicos: Decomposição em multiescala, Tese de Doutorado.

Freire, S.L.M., UFBA, 1986, Aplicações do método de decomposição em valores singulares no processamento de dados sísmicos, Tese de Doutorado.

Lopez, L. C., Londono, E. G., Kazmierczak, T. S., 2005. Using the Karhunen-Loève transform to suppress ground roll in seismic data. Earth Sciences Research Journal. Vol. 9, no 2, 139 - 147.

Montagne, R., Vasconcelos, G. (2006a); An optimized Filter for seismic data using the Karhunen-Loève transform and a minimum-energy criterium. Physical Review E, 74, 01016213.

Montagne, R., Vasconcelos, G. (2006b); Thermodynamic criteria for optimal suppression of coherent noise in seismic data using the Karhunen-Loève transform. Physica A, 371, pp. 122 - 125.

Yilmaz, O. (1987); *Seismic Data Processing*. Society of Exploration Geophysicists, Tulsa (USA).