Empirical Mode Decomposition and Spectral Balance to attenuate the Ground roll.

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Abstract

This paper presents techniques to reduce this noise, based on the empirical modes decomposition and spectral balancing. The breakdown in empirical ways is to decompose the seismic trace in Intrinsic Mode Functions, which are symmetric functions with local mean zero and the same number of zeros and extreme. But the spectral balancing propose the equalization of data of the frequency bands which generates balanced trace by adding the trace decomposed into each frequency band. Therefore, the attenuation of the ground roll increases, consequently the signal to noise ratio of the line. The numerical results obtained from the seismic line Takutu Basin illustrate the performance of the proposed methodology. When considering the results, we have the guarantee of the value of the proposed method, which increases the signal/noise given since attenuates effectively the ground roll.

Introduction

In order to portray an image that is not contaminated by ground roll, terrestrial seismic processing presents a great challenge. This type of noise is closely linked to the propagation of surface waves of the Rayleigh type. The ground roll is said to be coherent by the fact to know its characteristics of low frequencies and high amplitude (Yilmaz, 2001). In the seismogram, in a common shot section, it has a typical characteristic of a cone, in which it masks the reflections, considerably reducing the signal-to-noise ratio of the die.

In this work, we will use the Empirical Modes (DME) technique combined with Spectral Balancing, with the main objective of attenuating the Ground roll. Such a decomposition method analyzes non-stationary and non-linear signals as an alternative to solving Fourier transform problems. The DME method works dash by decomposing the wide frequency bands into several strokes with narrow frequency bands, which are the IMFs. The basic principle of the method is to make use of the partial reconstruction of the signal, that is, the sum of the IMFs with only the frequency bands referring to the information of the desired signal. Generally, the first IMFs are related to part of the signal of great interest, so we can perform a filtering by eliminating the noise-related IMFs to reconstruct the signal with the sum of only the IMFs of interest.

The result obtained after the application of the DME is a decomposition of the original signal into panels associated to each of the IMFs, conserving in each panel, features of the original data decomposed to different frequency bands.

The application of Spectral Balancing results in a leveling of the frequency spectrum and can be applied in pre-stacked or post-stacked data, improving the temporal and spatial resolution of the data. As a consequence of the process, it amplifies the high frequencies and attenuates the lower frequencies, attenuating the Ground Roll effectively. Spectral decomposition of seismic data helps, for example, in the analysis of stratigraphic structures or fractured reservoirs.

Two software applications were used to perform the processing, using SeisSpace developed by Landmark Gaphics Corporation. And the free Seismic Unix (SU) processing package was developed and is freely distributed by the School of Mines Center for Wave Phenomena (CWP).

Empirical Mode Decomposition

Historic

Unlike some traditional methods, such as Wavelets, Fourier and Orthogonal Empirical Functions - EOF, the DME is an intuitive, direct and adaptive method, and its decomposition bases are derived from the original data, and can be used in non -linear and non-stationary without losing the physical and mathematical character. The great incentive to use the method is that we can determine its instantaneous frequency, since the data contains different intrinsic modes of oscillation.

As the decomposition is of the adaptive type, it becomes possible to represent complex and non-stationary signals through a summation of functions in an intrinsic way (IMF). In this way, the DME method works dash by decomposing the wide frequency bands into several strokes with narrow frequency bands, which are the IMFs.

Intrinsic Mode Function (IMF)

An Intrinsic Mode Function (IMF) is a symmetric function in which it represents a mode of oscillation of the die. In this way an instantaneous frequency (Amorim, 2015) is defined. Since an IMF is oscillatory in nature, it may exhibit variations of amplitude and frequency over time. It must satisfy two conditions:

1) The number of zeros and extremes are equal to or different from one.

2) For any point, the sum of the mean value between the maximum and minimum points is equal to zero.

These conditions aim to restrict and prove the need for IMFs to be symmetrical with respect to the media and that no fluctuations in the instantaneous frequency occur.

Therefore, an IMF is generated by the decomposition of a f function, generating finite functions with amplitude and phase components (Vatchev, 2002), represented in equation 1

$$\Psi(t) = r(t)sen\theta(t) \qquad (1)$$

Where r represents the amplitude and $theta$ the phase of the function.

It has the premise that in the time-space domain (t-x), the sum of the generated IMFs of the decomposition, plus the resulting noise, is the initial signal. This is explained by the fact that IMF's present different frequency modes, where the first IMFs have the highest frequencies, while the last IMFs have the lowest frequencies.

In this way, it is necessary to perform an analysis around the noise to be attenuated, to preserve the frequencies of interest and to subtract the appropriate IMF from the original data.

Application of Empirical Mode Decomposition

The decomposition method in empirical modes, when applied in an initial seismic trait, calculates the extremes, that is, the maximum and minimum points. These points are interpolated by generating the maximum and minimum envelopes, defined by $esup(t)$ and $einf(t)$, respectively (SÁ, 2013).

The figures 1 and 2 describe such steps:

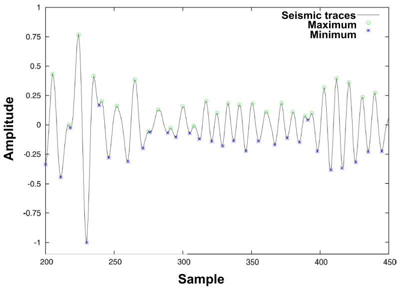

Figure 1: Seismic traces with their mapped ends (modified from (Ferreira, 2010)).

Given these values, we calculate the mean envelope defined by the mean of the maximum and minimum envelopes described in the equation 2. Look at the Figure 3.

$$m_1(t) = \frac{[e_{sup(t)} - e_{inf(t)}]}{2} \qquad (2)$$

Knowing the theoretical conditions for the existence of an IMF, we can gauge that a first candidate for the IMF will be the difference between the input seismic data $x(t)$ and the average $m1(t)$ according to the equation 3.

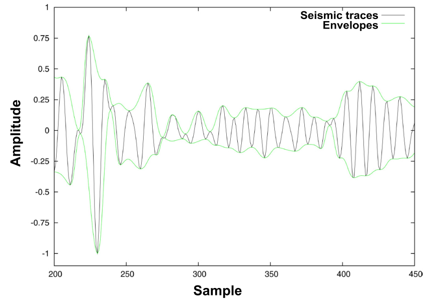

Figure 2: Seismic Trace Envelopes (modified from (Ferreira, 2010)).

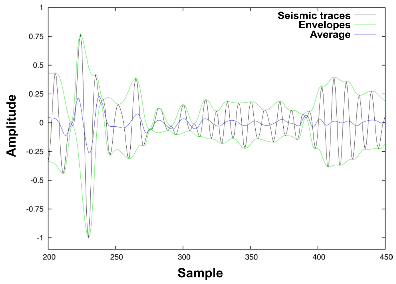

Figure 3: Average envelopes of the seismic trace (modified from (Ferreira, 2010)).

$$X(t) - m_1(t) = h_1(t). \qquad (3)$$

From the equation 3, we have $h1(t)$ defined as the first candidate for the IMF. In this case, we have that the previous signal, $h1(t)$, constitutes the new input data of the process of obtaining the new IMFs.

$$h_1(t) - m_{11}(t) = h_{11}(t). \qquad (4)$$

$$c_1(t) = h_{1k}(t) \qquad (5)$$

In addition, the new term, $m11(t)$, refers to the new average of the envelopes, defined in the first step and $h11(t)$ becomes the new candidate for the IMF according to the equation 4. This process will be repeated until the input signal becomes an IMF (equation 5).

In the first IMF $c1(t)$ we will remove it from the original signal $x(t)$ resulting in the residue $r1(t)$, the equation 6.

$$x(t) - c_1(t) = r_1(t), \qquad (6)$$

However, this process must have an end. That is, to limit the size of the standard deviation, which will be calculated after two consecutive separation processes (equation 7). Generally, these values vary according to the proposed problem. This limit is reached when you have the desired number of IMFs, or when the output data is smaller than the initial value at which you can no longer extract any IMF.

$$SD = \sum_{t=0}^{M} \left[\frac{|h_{1(k-1)}(t) - h_{1k}(t)|^2}{h^2_{1(k-1)}(t)} \right], \tag{7}$$

Thus, the sum of all the IMFs with the residue constitutes the original data, as seen in the equation 8. This allows us to analyze several IMF panels in order to keep only the relevant frequency bands in the final data.

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t), \tag{8}$$

The lower the value of this standard deviation, the greater the number of iterations for the separation of IMF's. Although generating a more accurate result, it generates a higher computational cost. In contrast, very low values of standard deviation may generate an opposite result than expected, that is, removal may occur not only from noise but also from signal bands.

The great purpose of using the DME method is that it preserves the physical and mathematical aspects, since it is applied directly to the die. Therefore, this method does not use predefined bases, such as sines and cosines in the case of Fourier and a mother wavelet in the case of Wavelet Transform.

Spectral Balance

The method that was used is the most common form of spectral balancing. We can analyze the steps used through the flowchart of Figure 4. Initially the data is converted from the time domain $x(t)$, to the frequency domain, through the Fourier transform 1D. Then the data is separated into frequency bands where each of the original traits is decomposed into several traces with different frequency contents. Such a division is performed as defined above by the band-pass filtering. The inverse Fourier transform is performed in order to return the data to the time domain. After this step, an Automatic Gain Control (AGC) gain function is applied to each of the decomposed strokes. The user can choose the number of bands of this filter. In the present work, seven frequency bands were chosen. After the equalization, the balanced trait is obtained by the sum of the traits decomposed in each frequency band.

Empirical Mode Decomposition and Spectral Balance

After the theoretical knowledge about the method of Empirical Modes Decomposition (DME), we can conclude that, this method works trace-to-dash by decomposing the wide frequency bands into several strokes with narrower frequency bands, called IMFs.

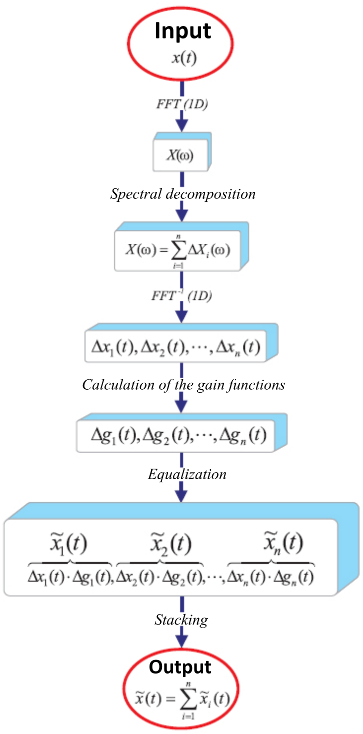

Figure 4: Flowchart used to apply the Spectral Balance (modified from (Silva, 2004))

However, what makes this method different from the frequency filter is that each IMF overlaps the frequency content of previous IMFs. It can be applied in the time-space domains (t-x). Due to this fact, the DME method has a great approximation to the principles of Spectral Balancing. Since this performs the filtering from the choice of polygons that also overlap.

Therefore, the application of Spectral Balancing to DME data will balance such frequencies in order to achieve high resolution to the seismic data. For this purpose, the bandwidth of the frequency spectrum must be increased.

Numerical Results

For the attenuation of ground roll one must choose the best frequencies that fit this objective. It is known that ground rool has characteristics of low frequency and high amplitude, it is recommended that, according to theory, the first extracted IMFs have higher frequency content, while the latter a lower content. Therefore, our filtering will perform the sum of the first IMFs and the exclusion of the last two, resulting in a significant noise removal.

Some tests were carried out in order to identify the best number of FMIs for ground roll attenuation. The results then presented in the shooting domain with their respective frequency spectra.

The sections of the seismic section stacked in the figures 7, 8 e 9 confirm the results obtained in the field of shooting.

The seismic session stacked with four IMFs presented a good preservation and enhancement of the reflections

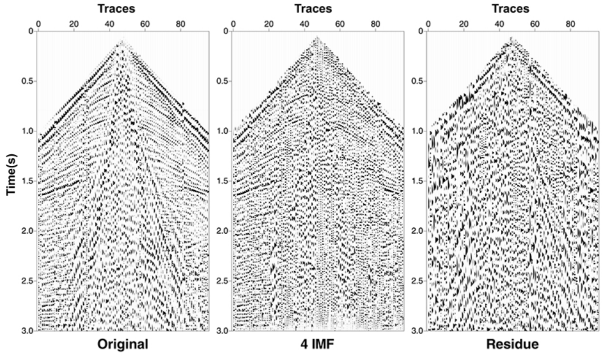

Figure 5: Seismogram of shot 111 of the original data, filtered with the sum of the first four balanced IMFs and the residue.

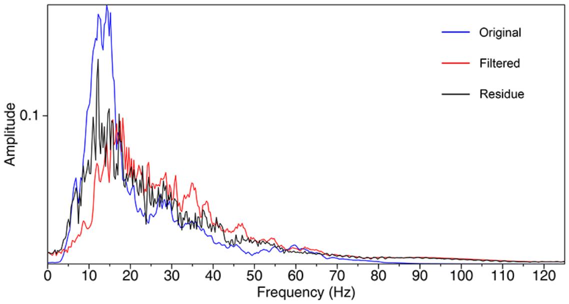

Figure 6: Frequency spectrum of the filtered data with the sum of the first four IMFs, the original data and the residual.

that were previously masked by ground roll. Besides a remarkable increase in the continuity of the reflections when compared to the seismic session stacked of the original data. It is also observed the attenuation of the linear events, referring to the ground roll.

Conclusions

It was proposed the application of the Spectral Balancing method combined with the DME technique. Such a combination provided a good alternative in filtering linear events and improving signal-to-noise ratio. In addition, there were significant improvements in the continuities and the resolution of the reflections, when we got the data stacked.

The results show the efficiency of the filtering for a seismogram with strong noise, where the possible reflections were not affected and the means that were subtracted from the data do not deviate from the speed defined as noise. The method, besides the ease of application, allows a flexibility of construction of the filters, with adoption of different percentages of attenuation. Therefore, it is concluded that the seismic sections filtered with the combination of such methods generated reflectors susceptible to geological interpretation.

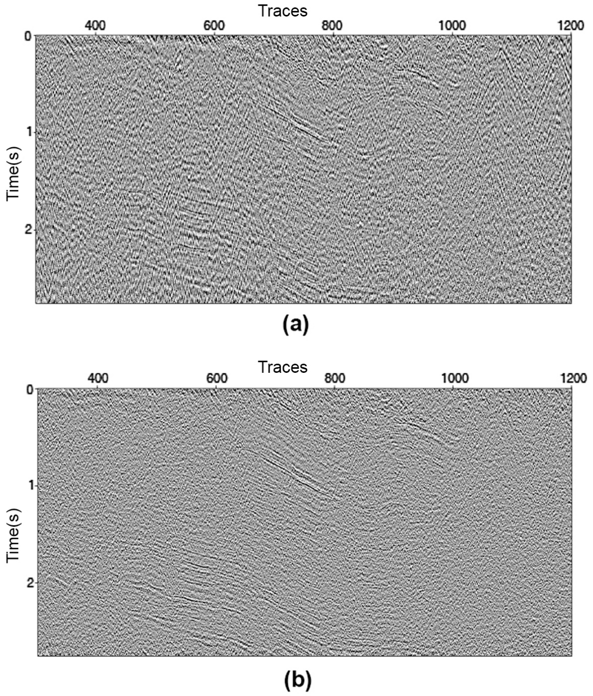

Figure 7: Excerpt of the stacked section of the original data in (a) and of the filtered data with the DME method combined with Spectral Balancing in (b).

Acknowledgements

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References

Amorim, F. Z., 2015, Atenuação de ruídos coerentes utilizando decomposição em modos empíricos: Master's thesis, Universidade Federal do Rio Grande do Norte.

Ferreira, L. E. S., 2010, Aplicação do método de decomposição em modos empíricos na atenuação do ruído de rolamento em dados sísmicos.: PhD thesis, Dissertação de mestrado, Universidade Federal da Bahia, Salvador, Bahia, Brasil.

SÁ, A. J., 2013, Aplicações do método de decomposição em modos empíricos no processamento de dados sísmicos marítimos.

Silva, M. G. d., 2004, Processamento de dados sísmicos da bacia do tacutu: Dissert. de mestrado, Universidade Federal da Bahia, Salvador, Brasil.

Vatchev, V., 2002, The analysis of the empirical mode decomposition method: USC, November, **20**.

Yilmaz, Ö., 2001, Seismic data analysis: Processing, inversion, and interpretation of seismic data: Society of exploration geophysicists.

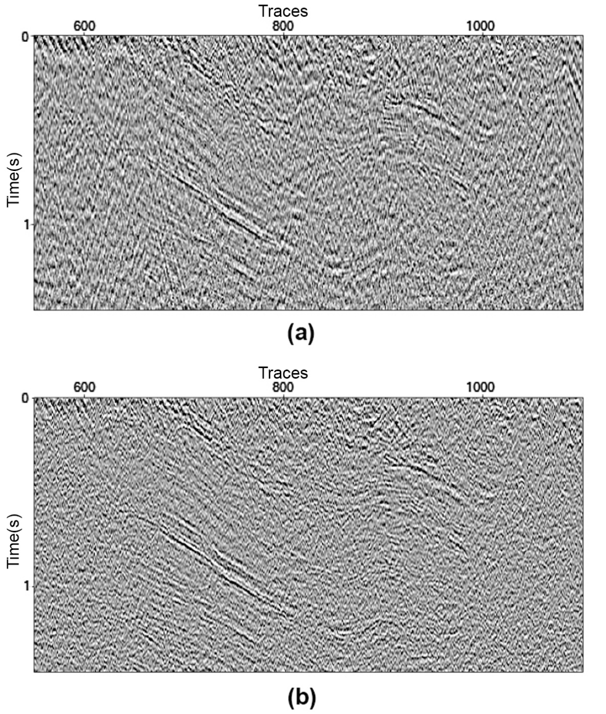

Figure 8: Excerpt of the stacked section of the original data in (a) and of the filtered data with the DME method combined with Spectral Balancing in (b).

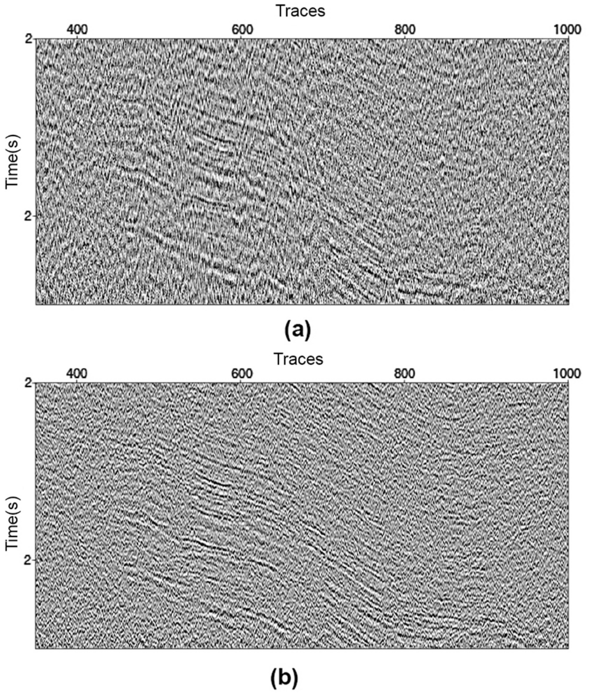

Figure 9: Excerpt of the stacked section of the original data in (a) and of the filtered data with the DME method combined with Spectral Balancing in (b).