Ground roll attenuation using 2D Wavelet transform

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Abstract

Ground roll is in a list of several coherent noises in land seismic aquisition, producing records with low-frequency and high amplitude that can hide almost entirely near-surface events. Hence, a variety of processing techniques, such as the Fourier transform, uses the frequency filtering techniques to supress this persistent noise. As an alternative to them, the Wavelet transform provides a signal analysis in time and frequency domain, giving better resolution and analysis of the entire input data. This article presents a case study with a real shot-gather and ground roll supression using the Wavelet transform in two dimensions and the analysis of this technique.

Introduction

The signals received by geophones, both in on-shore surveys, as in ocean bottom cable (OBC), have a quantity and variety of noise greater than in surveys using hydrophones. Among these noises, surface waves are extremely common sources of unwanted events in seismic records. The ground roll, composed of dispersive Rayleigh wave, but with variant frequency and velocity (Deighan and Watts, 1997), almost completely mask near surface records and blur deep reflections, generating, an event of great dipping, and high amplitude. Problems with this particular type of noise are so common that specific survey geometrys were designed to suppress it in land seismic surveys, however the implementation of such geometrys increase the time and operating cost and do not guarantee that the procedure is successful.

In this way, a divertsity of filtering techniques to eliminate the effects of the ground roll are implemented in seismic data processing. Among them, the filtering tools, like the f-k, are widely used, resulting in a process that affects all the seismic trace. However, aiming at a more incisive methodology, that affects only the noisy areas of the data, analysis techniques of certain intervals in time, like the windowed Fourier transform, used for example in Nawab and Quatieri (1988), are also implemented. Even such, this filtering techniques have limitations in an incisive ground roll noise suppression, as in the problem of frequency resolution versus the selected size of the window. In this way, new techniques are being presented and studied, such as the Wavelet transform, used in cases such as Matos et al. (2002), Goudarzi and Ali Riahi (2012) and Deighan and Watts (1997).

Thus, the objective of this article is to present a brief analysis of the 2D Wavelet transform filtering technique and a case study applied to a real shot-gather.

Wavelet Transform

The Wavelet transform analyses the signals in the time and frequency domain, without major losses in low and high frequencies resolution, thus enabling the data filtering without great loss of relevant information.

For a better understanding of the filtering technique, the formulation for the 1D continuous Wavelet transform is first presented, given by the *kernel* wavelet, wavelet of input, scaled, translated and convoluted with the analyzed signal, thus creating coefficients as a function of the scale used and position/time. The **Equation 1** shows the formula for the wavelet coefficients.

$$C(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t)\ \psi\left(\frac{t-b}{a}\right)\ dt \tag{1}$$

Where a and b are the scale and translation parameters, respectively, $f(t)$ the signal being analyzed and $\psi(t)$ the wavelet used for signal analysis - the *kernel* wavelet. Each value of a the wavelet is scaled by a factor $1/a$ and moved by a b factor, creating the wavelet coefficients, similar to a signal decomposition process using band-pass filtering with successive frequency bands. It also should be noted that the coefficients are directly dependent on the "mother" wavelet, with the need for analysis of which would be the best wavelet for the signal analysis.

The **Figure 1** and **Figure 2** presents the result of the 1D continuous Wavelet transform of a sinusoidal signal with an abrupt variation of frequency and its scale panel, respectively. It may be noted that in t =1000 ms, moment that the analyzed signal change its content of high frequency to low frequency, the panel presents a change in the lower scales, corresponding to the high-frequency. When $t <$ 1000 ms, the variation at low scales is easily recognizable, indicating the presence of high frequency on the respective signal area, when $t >$ 1000 ms this variation is smoothed, almost not notable and with low intensity, demonstrating the lack of high frequency content in the respective signal portion.

In its discrete form, the Wavelet transform works in a different way, instead of scale the kernel wavelet and later convolve with the input signal, the discrete Wavelet transform is implemented using a quadrature mirror filter (QMF), that is, a set of two filters, a high-pass and a low-pass (Chakraborty and Okaya, 1995). The **Equation 2** presents the mathematical formulation for the discrete Wavelet transform.

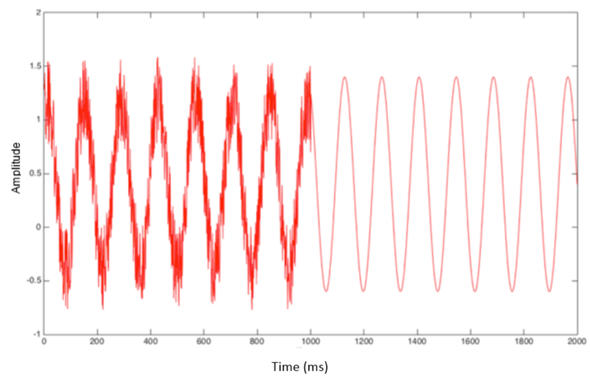

Figure 1: 1D sinusoidal analyzed as example.

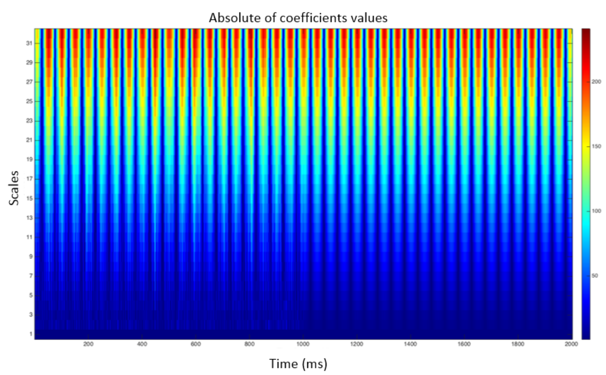

Figure 2: Respective Wavelete transform panel.

$$C(p,n) = \int_{-\infty}^{+\infty} f(t)\; 2^{-\frac{p}{2}}\; \psi(2^{-p}\, t - n)\; dt \tag{2}$$

Where p and n are the coefficients of approximation and detail respectively, which are complex numbers. It can be noted that for a big value for p, $\psi(2^{-p}\, t - n)$ becomes a compressed version of $\psi(t-n)$. In the same way, for a small value for p the term becomes an extended version. This property allows both high and low frequencies in the input signal be recognized by the technique.

The implementation of the Wavelet transform is not unique. Several methodologies can be used to implement this thechnique, for example Mallat and Zhang (1993) and Daubechies (1988). Each one differs from the other in questions of mathematical properties, constraints, and wavelets used in the process.

The case of the 2D Wavelet transform also does not escape of the variable forms of implementations. In this case, the common factor between most of them is the simplest form to represent the *kernel* wavelet, from the multiplication of each base for the respective dimension. The **Equation 3** shows base wavelet in a case of a signal with a time, t, and space dimension, x, in the case of a 2D seismic signal.

$$\psi_{aa'bb'}(t,x) \;=\; \psi_{ab}(t)\; \psi_{a'b'}(x) \tag{3}$$

However, as pointed out by Cohen and Chen (1993), this type of base has the downside of mixing scales a and a'. The same author presents the alternative form, with a base using three wavelets for each level of a. The **Equations 4, 5** and **6** present this new base.

$$\psi^{H}_{abb'}(t,x) \;=\; \psi_{ab}(t)\; \phi_{ab'}(x) \tag{4}$$
$$\psi^{V}_{abb'}(t,x) \;=\; \phi_{ab}(t)\; \psi_{ab'}(x) \tag{5}$$
$$\psi^{D}_{abb'}(t,x) \;=\; \psi_{ab}(t)\; \psi_{ab'}(x) \tag{6}$$

In this way, the average scale function of level j, also called approximation coefficient, for each level a, is given by the **Equation 7**.

$$\phi_{abb'}(t,x) \;=\; \phi_{ab}(t)\; \phi_{ab'}(x) \tag{7}$$

The **Figure 3** presents, graphically, the result of the implementation method of the Wavelet transform for each level a. The example is in 3 levels, forming four panels per level as indicated by the equations presented above.

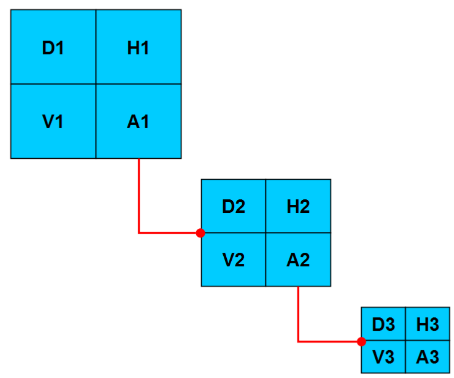

Figure 3: Graphical representation of the Cohen and Chen (1993) method for the 2D Wavelet transform.

The panels with the letter **A** refer to the coefficients of approximation - average coefficients for each level of decomposition - the panels with letter **H** refer to the detail coefficients with emphasis on horizontal events, panels with the letter **V** refer to the detail coefficients with emphasis on vertical events and the panels with the letter **D** refer to the detail coefficients with emphasis on diagonal events

In this way, events with different dips or relative positions in the data, for example the ground roll, can be more easily filtered giving focus on respective coefficients, vertical, diagonal or horizontal.

Methodology

For the 2D Wavelet filtering a real shot-gather was used, **Figure 4**, derived from the Yilmaz (2001) test data library. The **Figure 5** presents its respective frequency spectrum.

For the implementation of the filtering algorithm the Matlab programming language was used. In the process, the 6.8

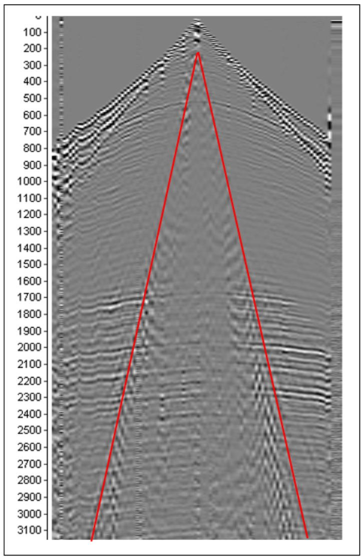

Figure 4: Shot-gather used for the 2D Wavelet transform implementation, ground roll area in red.

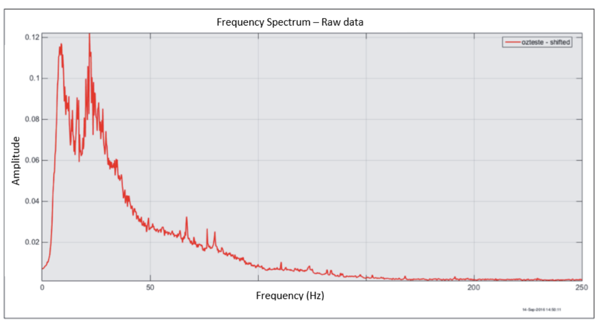

Figure 5: Frequency spectrum of the raw shot-gather.

Biorthogonal wavelet was used due to partial symmetry of the given data and its orthogonal feature, preventing the highlights of errors present in the initial data for processing, having greater chance of numerical stability (Deighan and Watts, 1997). In addition, was given focus on vertical coefficients generated by the Wavelet transform, due to the ground roll dipping, being the region to be filtered.

Results

Thus, the Wavelet transform was applied in the raw data, **Figura 4**, in 3 levels, since it has been found that from the fourth level the resolution loss in the coefficients view were very high, allowing the possibility of filtering in undue areas of the data, impairing the end result. The **Figure 6** presents the vertical coefficient of 1 level, where, in red, is demarcated the area used for filtering.

After filtering the coefficients, was performed the inverse Wavelet transform from every detail and approximation coefficients, generating the filtered data. The **Figures 7** and **8** present the filtered seismogram and its frequency spectrum, respectively.

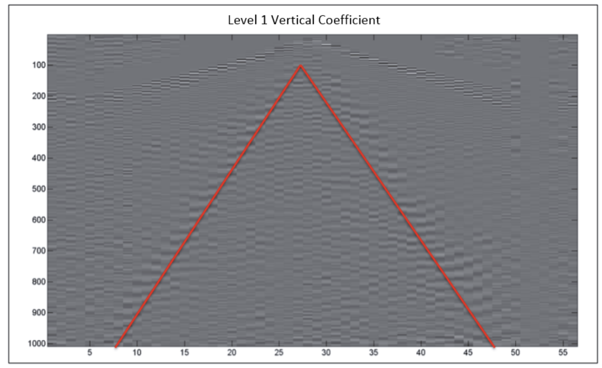

Figure 6: Vertical coefficients of level 1 of the raw data, filtering area in red.

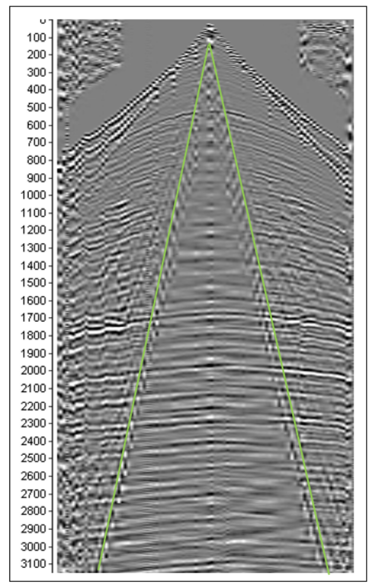

Figure 7: Filtered data, green area demarking the previously region of ground roll presence.

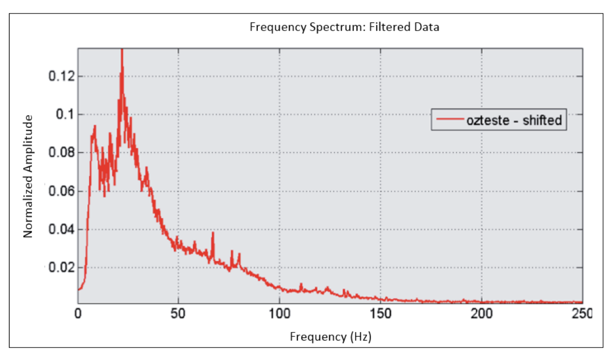

Figure 8: Frequency spectrum of the filtered data.

Thus, it may be noted that where there was a strong presence of the ground roll, see **Figura 4**, now has the clearest presence of possible reflectors consistent with records outside the delimited area. In addition, the filtering technique is efficient in regions also outside the noise cone, where reflectors were highlighted and the seismogram in a whole became clearer. However, it is worth mentioning that there was a generation of noisy records on the top corners of the seismogram and still the existence of residual noise referring to the *ground roll*.

Recalling the attention to the reduced seismogram frequency spectrum, it may be noted that the low frequency portion, between 5 and 25 Hz, had lost amplitude, see **Figure 5**, and can be expected to be on the ground roll low-frequency package, since the same is for the low frequencies. Meanwhile, the portions pertaining to the highest frequencies and others remained similar to the raw data spectrum, showing how the process just modified the region of the noise.

Another factor that can be used to analyze the result acquired is the magnitude of errors that the process has generated. In this case, the percentage error was 4.94 % and the PSNR error, peak to noise ratio was 80 dB. These two measures can be considered satisfactory, since the first error was low and the second factor, used to measure the quality of an image reconstruction and its noise, is considered an excellent value. Thus, it can be understood that the result obtained was satisfactory.

Conclusion

The Wavelet transform is an excellent technique for filtering and signal analysis, both 1D, as 2D, possessing a satisfying result in filtering ground roll in seismic data, obstacle present in land and OBC surveys, which may interfere negatively on data quality, future interpretations or noise-sensitive algorithms.

Such inference may be considered because of the representativeness of the signal in the time and frequency domain, without resolution loss due to the windowing techniques, as in the case of windowed Fourier transform, enabling noise suppression more incisively, as was observed, with the minimum loss of relevant information contained in the data.

It is worth mentioning that such results and methodology were applied in academic project of scientific research at Universidade Federal Fluminense. In this way, the project is still under development, where possibly optimized results may arise.

Acknowledgments

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