Attenuation of Residual Multiples and Coherent Noise in the Wavelet Transform Domain

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Introduction

Although generally very powerful, noise and multiple attenuation techniques can often leave remnants in seismic data. For example, noise from extraneous sources such as rigs and other boats can be hard to model and fully remove using standard methods. Similarly, multiple remnants are often present after multiple attenuation when multiples are generated by relatively complex geology, such as rugose water bottoms or salt, and as such do not conform to the assumptions of most multiple attenuation algorithms. These remnants can cause problems in later processing, for example through the generation of migration noise and contamination of AVO analysis etc. and therefore often need to be further attenuated in the processing sequence. As these remnants are often localized and may have high amplitudes compared to the underlying data, they can be relatively easy to identify and can be targeted in a different number of domains. The application of a wavelet transform (wavelet decomposition) on pre-stack data can be used to separate signal from coherent noise in both frequency and time. The noise can then be removed from the data by a variety of noise attenuation methods in the wavelet domain. We show two examples to illustrate the effectiveness of this method: the attenuation of residual multiples and attenuation of boat noise.

Method

The Wavelet Transform (WT) was introduced first by J. Morlet (1982) for analysis of seismic signals as an alternative to the Fourier Transform (FT). The WT is a reversible transform. The main differences between the FT and WT are: (i) Fourier transform is a natural tool for stationary signal analysis, while the wavelet transform is an optimum tool for non-stationary and transient signal analysis, and (ii) the Fourier transform represents signals in time and frequency separately, while the wavelet transform represents signals in time and frequency simultaneously. The FT provides good frequency resolution at the expense of providing no temporal resolution. The WT has variable resolution: higher frequencies are better resolved in time, while low are better resolved in frequency. The WT has found many applications in signal processing and geophysics, in particular: ground roll and random noise attenuation and signal preserving predictive deconvolution. Miao and Cheadle (1998) have shown that filtering in the WT domain can successfully attenuate ground roll, because signal and noise are decomposed into different voices according to their time and frequency features. There are voices with noise only, with little or no noise, and at lower frequency voices, a mixture of coherent noise and signal. This separation forms the basis for successful noise attenuation in the wavelet domain. While experimenting with the WT, we
found that some conventional de-noise techniques produced better results when applied on selected voices in the wavelet transform domain, rather than in time domain. To attenuate residual multiple and coherent noise, de-spiking in WT domain was used. As most of the voices were passed unchanged, processing is limited only to particular time-frequency bands and is very localized, so that primaries are less affected. Two examples illustrate the effectiveness of this process, compared to more traditional techniques.

**Examples**

The first example is from deep water offshore Nigeria (the water bottom reflection is at 3.5s) with complex shale compressions, formed in a dome-like structure (Figure 1). The strong 1st order multiple occurs at 7.6s. 2D SRME was first applied (Figure 2). SRME involves computing a multiple model by convolving the data with itself, followed by an adaptive subtraction of the computed multiple model from the data. Although SRME successfully attenuated most of the multiple, the result suffers from residual energy left in the data, due to 3D effects, that are not modeled by the 2D method. We applied the wavelet transform to the data in common offset planes and reviewed the result for the different voices. When good time-frequency separation between signal and residual multiples for different voices was

![Figure 2. Data after SRME showing some residual multiples.](image1)

![Figure 3. Result in time domain after de-spiking was applied on selected voices in the wavelet domain](image2)
achieved, we selected voices for further processing. Voices with signal only, free from residual multiples, were passed to the inverse transform unchanged. Voices with random noise only were rejected. Other voices (mostly low voices), where residuals have large amplitudes and stood out over the signal, were processed with a sliding window de-spiking. After the reverse wavelet transform, residual multiple energy from the sides of the structure were well attenuated, while the signal was preserved (Figure 3). Figure 4 compares the wavelet domain approach with time and frequency domain methods. The frequency domain technique uses spectral editing in frequency bands within time/space windows. It removes some of the residual multiples without obvious damage to primaries. Simple de-spiking in the time domain suppresses residual multiples better, but this method is potentially more aggressive to primaries. De-spiking in the wavelet transform domain is less aggressive to primaries, while attenuating noise and residual multiples better.

Figure 4. a) residual multiples left after SRME; b) after de-spiking in frequency domain; c) after de-spiking in time domain; d) after de-spiking in WT domain.

Figure 5. Shot gathers with boat noise (left). Same gathers after forward and reverse wavelet transform and de-spiking in wavelet domain (right). Noise is well attenuated.
Another example is the application of processing in the wavelet transform domain for the attenuation of boat noise. Figure 5 shows shot gathers before and after processing. Coherent noise (boat noise) is seen as diffractions and their multiples, which occur randomly as arc shaped events on shot gathers. In the wavelet transform domain it can be observed that noise separates out mainly into low voices (Figure 6). De-spiking for these voices was then used to attenuate the noise.

![Figure 6. Shot gather in the wavelet domain. Boat noise is localised mainly in low voices.](image)

**Conclusions**

The proposed non-standard methodology to attenuate 3D residual multiples and coherent noise in 2D domain involves processing in the wavelet transform domain. The method can provide a solution for structurally complex areas, traditionally a situation that defeats many conventional methods. Diffractions can also be targeted in the shot or other domains, especially if frequency bands of signal and noise do not fully coincide. Because of time-frequency localization, as provided by the WT, the separation of signal and noise is more distinct in different voices. Therefore application of some conventional techniques in a wavelet domain is more successful than in time domain. The advantage of processing in the wavelet domain is that some spectral components of the signal are preserved untouched, and therefore primaries are less affected. Since it represents data using wavelet functions of finite time duration and frequency coverage, the WT provides a convenient domain in which to estimate signals according to their temporal and spectral characteristics simultaneously.

**References**


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