High resolution seismic data analysis by Wavelet Transform and Matching Pursuit Decomposition

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Wavelet analysis is a rapidly developing area of mathematical and application-oriented research in many disciplines of science and engineering including geophysics. The wavelet transform (WT) is a localized transform in both time (space) and frequency (wavenumber) (Daubechies, 1990), and this property can be advantageously used to extract information from a signal that is not possible to unravel with conventional Fourier or even windowed Fourier analysis. The wavelet multiresolution representation also provides an extra dimension to visualize and analyze a signal. There are various types of wavelets, orthogonal, biorthogonal or non-orthogonal, that can be chosen for wavelet analysis. Among them the compactly supported Morlet wavelet is one of the most useful for seismic data analysis. Since this wavelet is complex, it enables one to extract information about the amplitude and phase of the signal being analyzed. The wavelet modulus is helpful in analyzing signals in time and frequency simultaneously, while the wavelet phase is useful in locating discontinuities and identifying fractures, layering and also the fractal nature of data. With the information of wavelet variance, or spectrum, one can identify at what WT voices coherent events of interest are best expressed and perform detailed analysis at those voices.

To improve the resolution of the wavelet transform in the high frequency range, several wavelet related techniques have been developed in recent years, which include Wavelet Packet Decomposition and Matching Pursuit Decomposition (MPD) (Mallat and Zhang, 1993). The Wavelet Packet Decomposition is better suited for data processing purposes, while Matching Pursuit Decomposition is an excellent tool for time-frequency analysis. Instead of using only one wavelet family generated by dyadic dilation and shift of the mother wavelet, the MPD algorithm decomposes a signal based on a wavelet dictionary, which is a large collection of wavelets covering the full ranges of time, frequency, scale, and phase indexes at the highest resolution supported by the data. Based on a residual regression method, it finds a best matched wavelet to represent each component of a signal. Thus it provides a high resolution tool for time-frequency representation of a signal. A synthetic data example is shown in this paper (Fig. 1a, b, c) to demonstrate the capability of MPD method for high resolution time-frequency analysis. It shows that an instantaneous spectrum of the data, that is a spectrum varying with time, can be derived by the MPD algorithm.

In part, interpretation requires the extraction of information from seismic data to help deduce subsurface structural, stratigraphic and lithologic features. One way of obtaining such information is through the visualization of seismic attributes. Many diagnostic seismic attributes have been developed over the last two decades, with a trend toward higher resolution techniques. A recent example is the use of spectral decomposition for creating monofrequency slices for 3D volumes based on short time windowing (Gridley and Partyka, 1997). The wavelet transform and matching pursuit decomposition are two new technologies which have shown good potential for enhancing seismic attribute analysis in a related manner. Localization is the key property which offers higher resolution power over conventional methods. The joint time-frequency analysis capability of the WT enables both methods to avoid windowing artifacts. Visualizing data in the WT domain following the non-orthogonal Morlet wavelet transform reveals structural features sensitive to specific wavelengths that may not be as visible at the dominant frequency of the conventional broadband data. Useful hydrocarbon indicators, such as fluid filling and absorption, permeability, and porosity are all closely connected with subtle changes in spectral content over short temporal windows associated with reservoir thickness. In this paper we have derived several new seismic attributes from MPD and WT methods to explore the subtle changes in seismic data and to help characterize reservoir related properties. Figure 2 shows an example of WT attribute analysis on a migrated section

Estimation of attenuation, or Q, from seismic reflection data is commonly performed using a spectral ratio method (Jacobson, 1987). This technique uses the ratio of the amplitude spectrum of the know unattenuated source function with the amplitude spectrum of the attenuated amplitude spectrum. After taking the natural logarithm of the spectral ratio, a slope of this ratio against frequency yields the attenuation, and geometrical spreading etc. is assumed to be independent of frequency, as seen in the following formula:

$$In \frac{A_m}{A_1} = (\gamma_1 - \gamma_m)vtf + In \frac{G_m}{G_1}$$

where v is velocity, t is travel time, f is frequency, $\alpha(f) = \gamma f$ is the attenuation at f, G represents geometrical spreading, and the left hand side of the equation is the spectral ratio. However, a difficulty inherent in the conventional method is error in estimation of amplitude spectra from any finite segment of data (White, 1992). In this paper we also develop a method to estimate attenuation by using the Wigner distribution of MPD spectra, or WT modulus spectra. It naturally avoids selection of a gate length in estimation of amplitude spectra, and provides potentially higher accuracy for Q function estimates.

References

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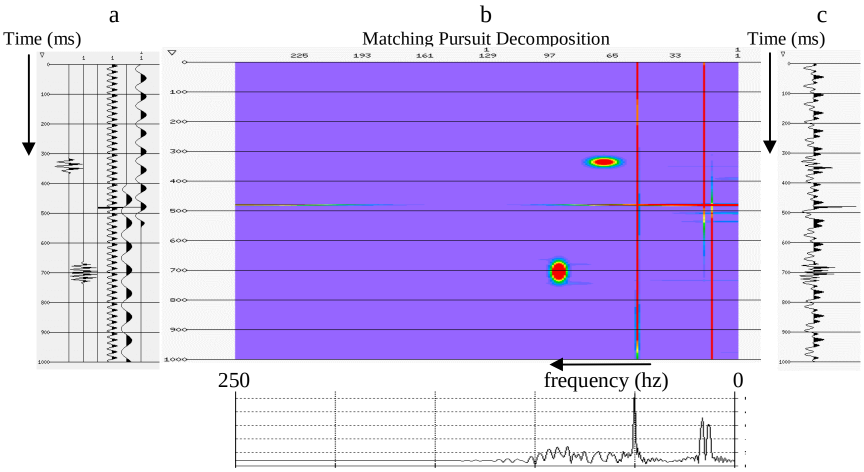
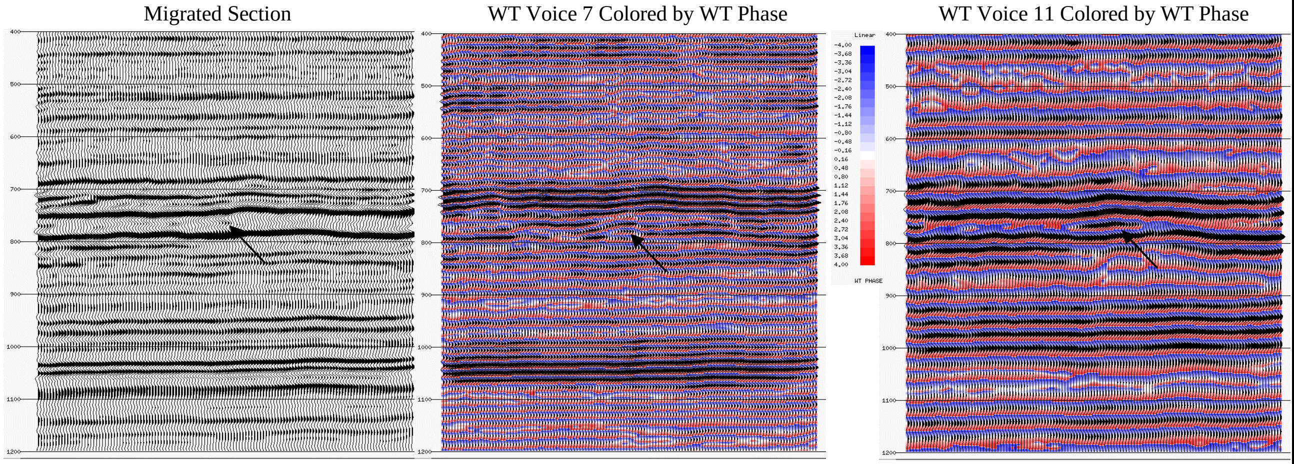


Figure 1: Time-frequency representation by Matching Pursuit Decomposition. a. Different components of signals, b. MPD spectrum of the signal in c compared with its Fourier spectrum, c. the synthetic signal created by all the components of signal in a.



(a) (b) (c)

Figure 2. Wavelet attribute analysis on a migrated seismic section. (a) The original migrated section, (b) WT decomposition at voice 7 colored by WT phase attribute, (c) WT decomposition at voice 11 colored by WT phase attribute. Arrows in (a), (b) and (c) highlight an interesting feature in the section.