Application of Fractal, Hough and Hilbert-Huang Transform in Seismic Reflection Prospecting

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ABSTRACT : Seismic attributes and supervised and unsupervised neural networks have become increasingly popular in recent years in the realm of quantitative interpretation for hydrocarbon exploration. The main emphasis is on the qualitative and quantitative measurement of stratigraphic and lithologic effects on seismic signatures. We used the concept of fractals for the identification of seismic reflectors with special emphasis to thin bed delineation, which are generally overlooked during standard data processing. A new fractal analysis scheme is applied on both the synthetic and real field seismic data. The fractal dimensions of the three seismic attributes, amplitude, phase, and instantaneous frequency have been analyzed. A change in fractal dimension is found to occur whenever there is a reflection. The resolution in the delineation of reflectors, however, varies depending on the attribute we are considering and the method of fractal dimension estimation we have used. The fractal analysis is performed on both the noise free and noisy synthetic data to establish the noise tolerance limit for both the "divider method" and the "Hurst method". It is then tested with different peak frequency of the source wavelet to establish the criteria for using the "divider method" and the "Hurst method". The "divider method" is found to be suitable for high peak frequency of the source wavelets (> 25 Hz), while the "Hurst method" is best suited for low peak frequency source wavelets (< 25 Hz). Finally, when applied to the digitally processed and migrated field seismic data, it could even delineate the reflectors which otherwise went undetected on the migrated time section. The intensive computational complexity, storage requirement, recognition of envelopes with parametric equations have rendered the standard Hough Transform inferior to the intellectual mechanism of human's visual recognition. We proposed a Modified Generalized Hough Transform that implements parametric equation of a straight line to establish relationship among various samples lying on a seismic reflector. It performs thresholding, demarcation of interfaces in each window, establishment of continuity of interfaces from one window to another and mid-point smoothing. Based on its application on a zero-offset synthetic seismogram and a migrated CDP section, the algorithm is found to be sensitive to the choice of window length. A time window of six samples or less with an equal degree of scrolling seems to be best suited for pattern recognition using this technique. However, a trade-off is necessary between the window length and the amount of overlap to obtain better reflection continuity. The technique has been applied on the seismic attributes namely, amplitude, frequency and phase to determine if there are more reflectors present and also to validate the results obtained from the raw seismic traces. High-resolution studies also necessitate the quantification of the seismic signals in time and frequency domain. Moreover, these signals being nonlinear and non-stationary, a nonlinear and non-stationary signal analysis tool has to be used to localize events in both the time and frequency domain. Hilbert-Huang Transform is such a high-resolution tool we have used in the present study. The Hilbert Amplitude Spectrum obtained from this transform shows a much greater temporal and spatial resolution compared to the spectra obtained from Short Time Fourier Transform and Wavelet Transform. Frequency slices obtained from this analysis show the reflector continuity at its characteristic dominant frequency. Empirical Mode Decomposition (EMD) can be used as a tool for elimination of ground-roll as we tested on a set of common shot gathers. It is superior in performance compared to the current methods for elimination of ground-roll, namely frequency filtering and f-k filtering. Moreover, the IMFs obtained from EMD can substitute their mother seismic traces for forming better seismic section displays. These displays combine the functionalities of both the instantaneous amplitude and phase and thus would prove to be very handy in seismic interpretation.

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