Generalized spectral decomposition

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Summary

Spectral decomposition (SD) has been used for a variety of applications including layer thickness determination, stratigraphic visualization and direct hydrocarbon detection (Sinha et al., 2005; Xiao-dong et al., 2011). The main purpose of this attribute is to enable the interpreter to see amplitudes tuned to specific frequencies. Generalized spectral decomposition (GSD) tool allows mapping of thin beds and identification of subtle stratigraphic features (Marfurt and Kirlin, 2001; Partyka etal., 1999). SD refers to any method that produces a continuous time-frequency analysis of a seismic trace. Thus, isolated frequency components are output for each time sample of the seismic trace. Because the seismic wavelets contain a wide spectrum of frequencies, spectral notches or peak frequencies can be used to indicate extremely thin beds, like the thinning-out part of channels. GSD gives the interpreter the flexibility of designing the wavelet to be correlated with the geological feature to be identified (Manral, S., Aarre, V., Hoff, G., d`Hamonville P. T. 2015). The figures presented are from the Poseidon 3D Marine Surface Seismic Survey within Browse Basin Offshore Western Australia.

Introduction

There exist several SD methods with their own advantages and limitations; Exponential Pursuit Decomposition (EDP), Matching Pursuit Decomposition (MPD), Discrete Fourier Transform (DFT), Continuous Wavelet Transform (CWT) and Maximum Entropy Method (MEM) are among them. The most common methods used in the industry are Short-Window Discrete Fourier Transform (SWDFT) and CWT. Because of limitations with SWDFT and CWT within the time- and frequency resolution, GSD gives greater control of both vertical and frequency resolution.

Theory and method

A method for decomposing a signal includes receiving sampled data. A wavelet is built using the sampled data that includes a plurality of samples. The wavelet includes a number of oscillations per sampling unit, and a length of the wavelet corresponds to the number of oscillations. The wavelet is time-shifted. The wavelet is then scaled such that the samples proximate to one or both ends of the wavelet decay toward zero. The wavelet is also scaled such that an amplitude at a peak frequency of the wavelet, when transformed into a Fourier domain, is substantially unity (Victor Aarre and Edo Hoekstra, 2014).

$$\boxed{w(t) = c * w_c(t)}$$

$$w_c(t) = g(f, n, t) * \cos(2\pi f t + \varphi)$$

$$c = \frac{1}{MAX\left(AMP\left(FT(w_c)\right)\right)}$$

t	: Sample time (in seconds)
w	: scaled filter wavelet
w_c	: raw (un-scaled) filter wavelet
g	: Window function
f	: Frequency (Hertz)
n	: Number of oscillations
FT	: Fourier Transform
φ	: Phase shift (in radians)

Figure 1: Mathematical formula of the Convolutional model used for the Spectral Decomposition.

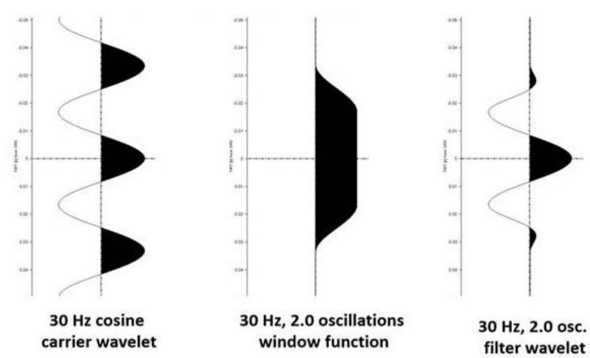

Figure 2: The theory behind spectral decomposition. To the left is a sample with multiple wavelets, in the middle is a time-shifted wavelet which is scaled and implied with band-pass filter, the result is shown to the right when the wavelet is Fourier Transformed.

Generalized spectral decomposition

The GSD method contains five elements, as shown in figure 3, most of them optional. The key step, which is mandatory, is flexible design of a wavelet which we will use for the filtering/decomposition of the input seismic. The second step is to optionally remove all negative correlations. The third step is to optionally distribute the positive part of the correlation function over a window defined by a fraction of the desired center frequency. The fourth step is to optionally do a convolution of the wavelet in step one instead of a correlation, effectively turning the method into a band-pass filter. Finally, the fifth step is to use the wavelet generated in step 1 to do a pseudo Fourier decomposition (Manral, S., Aarre, V., Hoff, G., d`Hamonville P. T. 2015).

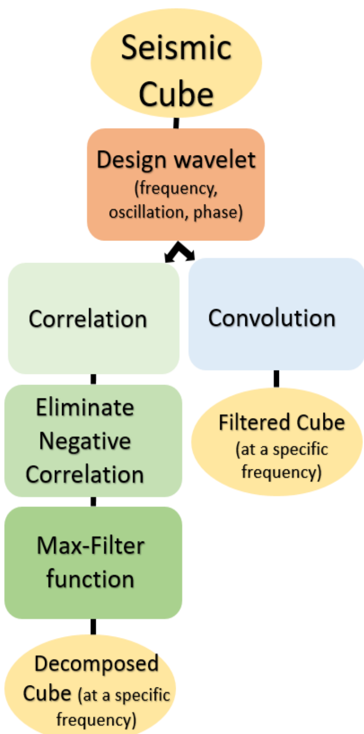

Figure 3: Schemtaic showing the Generalized Spectral Decomposition (GSD) methodology.

Results and discussion

GSD has multiple advantages. It is a virtual attribute, so the interpreter can easily and very intuitively scan through all frequencies ranges to find the tuning thickness. The technique is fast and works well on big 3D seismic surveys. It also uses much shorter window lengths compared to CWT. Along a time-slice intersection, the difference between GSD and SWDFT are not tremendous, as shown in figure 6. To make a fair comparison, the window lengths need to be similar. The benefit on the other hand, is that GSD is moveable towards much shorter window lengths. SWDFT is not efficient for window sizes below 32 samples. The layers in GSD are more separated compared to the SWDFT method, as shown in figure 5, because GSD is parameterized to focus on the presence of a positive-negative interface combination. The SWFT method is unable to discriminate between positive-negative sequences, unless the phase spectrum is also included in the analysis.

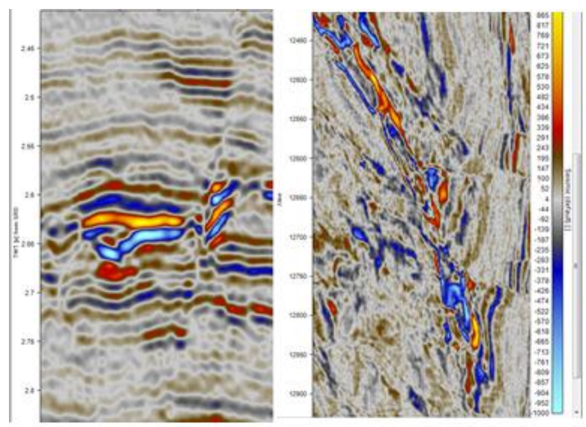

Figure 4: Input seismic. Left image shows a sedimentary channel characterized by a strong reflector defining the top of the channel, and a trailing reflector with opposite polarity, but similar amplitude. the distance between top and bottom is 35 milliseconds, and the resonancy frequency for the channel embedded between the two interfaces will hence be 1000 / 2 *35 ms = 14 Hz. This means that the wavelet shape which will correlate best with this channel body will be a wavelet kernel with central frequency of 14 Hz, and a phase of +90 degrees. Right image shows the same data, but displayed along a timeslice intersection.

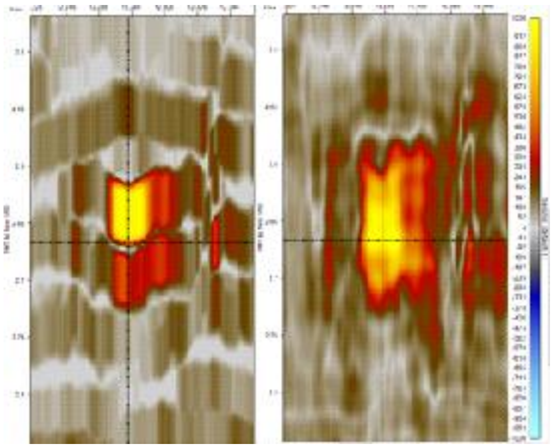

Figure 5: Left shows the results from the new method (using 14 Hz corner frequency, +90 degree phase shift, 2 cycles/140 millisecond wavelength). Right shows the results from SWTF method (14 Hz center frequency, 128 ms/32 samples window length, the shortest window length practically possible with this method). It shows more well-separated layer responses with the new method to the left.

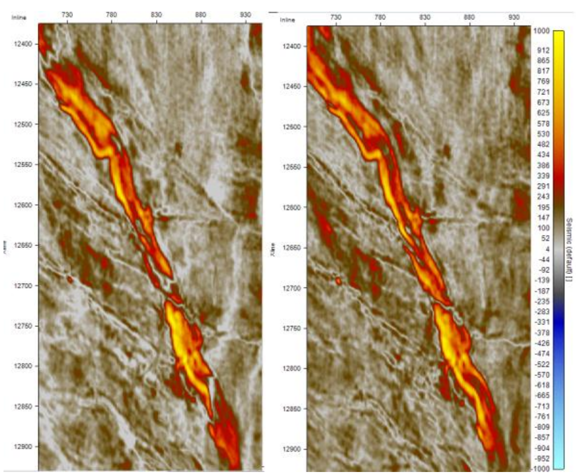

Figure 6: Less energy in the shown in the left with the GSD approach, when compared to the SWDFT result to the right. This is due to better focusing on the positive-negative interface sequence. In order to a fair comparison, almost equal window lengths are used, resulting in no huge uplift with the new method.

The data input in figure 7 and figure 8 are from the Poseidon 3D Marine Surface Seismic Survey within Browse Basin Offshore Western Australia. These are examples of channel-like features in the basin which help to accurately interpret the architectural elements in such systems. It is crucial to make this interpretation available as it reduces the risk in exploration and development in environments such as deep-marine and fluvial-deltaic reservoirs.

The major structural features identified in this area extensional faulting which defines the elements of the potential Jurassic and Triassic petroleum systems in the Caswell sub-basin. Numerous channel-like features are identified in some of the formations in Cretaceous where the dominant lithology is marine shale, with minor sand development towards the base.

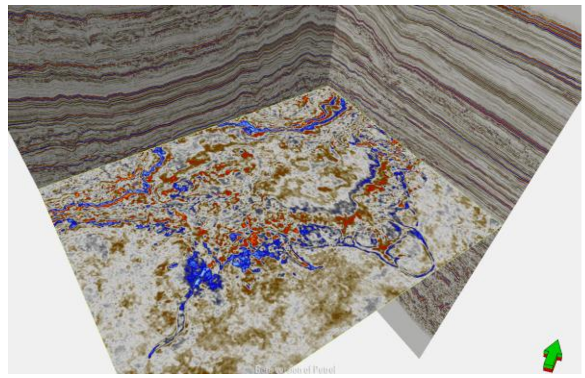

Figure 7: Input horizontal seismic time-slice from the Poseidon 3D Marine Surface Seismic Survey within Browse Basin Offshore Western Australia. This image is captured around 2600 ms. Channel-like features are seen, but not too clearly.

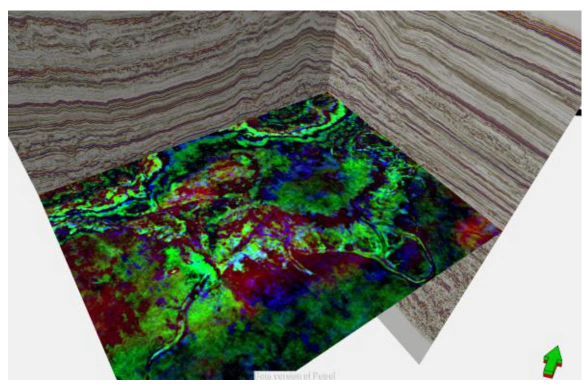

Figure 8: Same image as figure 5, but with GSD implied. The results are showing more of the channel-like features. It is now easier to map the channels and therefore make a characterization of the geology within the basin investigated.

Conclusion

The new method described here enables the interpreter to flexibility of designing the wavelet to be correlated with the geological feature to be identified. An advantage is the shorter window length that can be applied compared to the CWT method. Another advantage is that GSD allows differentiating the negative-positive and the positive-negative interfaces associated with sand channel features, which was shortcoming in the existing SWDFT method. The results are promising in terms of identification and thickness determination of the channel bodies. It also proves to be a fast technique, even when applied to large 3D seismic surveys (as compared to other existing commercial spectral decomposition techniques available in the industry). The GSD helps the interpreter to easily map channel-like and sedimentary features and reduce the risk in exploration and development.

Acknowledgements

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