

# SPECTRAL DECOMPOSITION TECHNIQUE BASED ON STFT AND CWT FOR IDENTIFYING THE HYDROCARBON RESERVOIR

## TEKNIK DEKOMPOSISI SPEKTRAL MENGGUNAKAN ALGORITMA STFT DAN CWT UNTUK IDENTIFIKASI RESERVOIR HIDROKARBON

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### ABSTRAK

*Metode dekomposisi spectral merupakan salah satu teknik interpretasi seismik lanjut seperti inversi seismik, analisis amplitud versus offset (AVO) dan atribut seismik yang dapat berperan sebagai indikasi secara langsung keberadaan hidrokarbon dalam kegiatan eksplorasi seismik. Teknik ini menggunakan algoritma transformasi, sehingga sinyal seismik yang berasal dari domain waktu dapat ditransformasikan menjadi beberapa nilai frekuensi tertentu. Terdapat beberapa jenis algoritma yang dapat dipergunakan dalam melakukan dekomposisi sinyal dari domain waktu menjadi domain frekuensi. Beberapa algoritma tersebut diantaranya adalah Short Time Fourier Transform (STFT) dan Continuous Wavelet Transform (CWT). Algoritma STFT adalah metode yang konvensional dan sederhana dalam menghasilkan spektrum waktu-frekuensi, dimana pada algoritma ini menggunakan prinsip transformasi Fourier. Namun demikian algoritma STFT memiliki kelemahan terkait resolusi frekuensi. Dimana resolusi frekuensi akan sangat tergantung pada lebar jendela analisis yang dipilih, semakin kecil jendela analisis maka semakin rendah resolusi frekuensi yang didapatkan. Disisi lain, algoritma CWT dapat mengatasi kelemahan yang dimiliki pada algoritma STFT dalam hal penggunaan lebar jendela analisis. Pada algoritma CWT lebar jendela analisis akan menjadi lebih fleksibel yang bergantung pada karakter dari frekuensi wavelet. Pada penelitian ini, telah dilakukan perbandingan antara dekomposisi spektral berdasarkan algoritma STFT dan CWT dalam aplikasinya pada data sintetik dan data real. Masing masing algoritma memiliki kelebihan dan kekurangan dalam proses dekomposisi sinyal seismik. Lebih lanjut, hasil analisis dari perbandingan kedua algoritma ini dapat dijadikan sebagai referensi dalam pemilihan algoritma yang terbaik pada suatu aplikasi interpretasi seismik. Aplikasi kedua algoritma pada data sintetik menunjukkan bahwa algoritma CWT menghasilkan resolusi frekuensi yang lebih baik jika dibandingkan dengan algoritma STFT. Sedangkan untuk kasus data real aplikasi kedua algoritma menunjukkan kenampakan konten frekuensi dari lintasan seismik sehingga dapat digunakan untuk identifikasi reservoir hidrokarbon yang berasosiasi dengan anomali frekuensi rendah.*

**Kata Kunci:** dekomposisi spektral, STFT, CWT, anomali frekuensi rendah

### ABSTRACT

The spectral decomposition is one of the advanced interpretation techniques such as seismic inversion, amplitude versus offset analysis, and seismic attribute that helpful in direct interpretative approach in seismic exploration. This technique is a transformation algorithm, thus a signal can be transformed into its varying frequency contained in the seismic signal. There are a variety of spectral decomposition algorithms in the decomposing seismic signal from time domain into frequency domain. These algorithms include Short Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT). The STFT algorithm is a conventional and simple technique for computing a time-frequency spectrum, which is based on the application of Fourier transform. However, the STFT algorithm has a problem related to the frequency

resolution. In its implementation, this algorithm is limited by predefined window length. In contrast, the CWT algorithm is believed to be able to overcome the limitation of window length. The CWT threats wavelet at certain window length, which is defined by the characteristics of the wavelet. In this study, the comparison between spectral decomposition technique based on STFT and CWT method was performed, particularly in its application to the synthetic and real data set. Each algorithm has its own advantages and disadvantages in decomposing the seismic signal. Further, this analysis can be used as a reference to select one of two algorithms for the specific application. The synthetic data set application shows that CWT algorithm produces better frequency resolution compared to STFT algorithm. In addition, the real data set application shows that time frequency section of the seismic line provides a spectral feature, which is useful to identify the hydrocarbon reservoir, which is associated with low-frequency shadow zone.

**Keywords:** Spectral Decomposition, STFT, CWT, Low-Frequency Shadow

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## I. INTRODUCTION

Seismic waves in its propagation encounter the lithological change and every time they meet the interface, part of their energy has been attenuated by the sub surface lithological condition. As a consequence, the recorded seismic wave contains the varying frequency, which represents the sub surface geological condition. A different medium will produce different frequency responses. The decomposed seismic waves into their frequencies are the key solution in assessing the reservoir characteristics (Partyka et al. 1999; Johann et al. 2003; Kishore et al. 2006). This analysis is called spectral decomposition analysis. Spectral decomposition has various algorithms for transforming time into the frequency domain. The conventional and simple algorithm, which refers to the Fourier Transformation is the Short Time Fourier Transform (STFT). Its implementation, the STFT algorithm is transforming the series of signal sequentially into a short window. This means that algorithm requires predefined the window length, which is sensitive to the frequency tuning and resolving power in separating the thin layer.

On the other hand, the Continuous Wavelet Transform (CWT) had been broadly used in the signal processing application in the last few decades, (Cohen 1995; Sinha et al. 2005). CWT has a different approach compared to the conventional algorithm. No pre-selecting a window length and fixed time-frequency resolution required in performing the CWT algorithm (Polikar 1996). In addition, CWT algorithm is superior in resolving frequency in short time domain and in contrast situation; resolving time in short frequency domain (Margrave 2001).

The presence of hydrocarbon reservoir is associated with low-frequency shadow zone (Partyka et al. 1999). Attenuation of high-frequency energy in the reservoir itself is a shifting of dominant frequency to lower frequency range (Burnett et al. 2003; Haris, et al. 2008). Attenuation of high-frequency energy indicated that seismic wave energy was absorbed by a typical lithological condition associated with hydrocarbon. This phenomenon is helpful to detect the existence of hydrocarbon (Castagna et al. 2003). High-frequency resolution at low frequencies, produced by the spectral decomposition algorithm would indicate these shadows (Hall and Trouillot 2004). On the other hand, high time resolution for great frequency is able to improve seismic resolution for better stratigraphic interpretation. The spectral decomposition is able to estimate the thickness of reservoir, which is related and indicated by the tuning frequency (Marfurt and Kirlin 2001).

The objective of this paper is to assess the spectral decomposition techniques, which is based on the STFT and the CWT algorithm. The assessment was carried out by applying these two algorithms to the synthetics and real data set. In addition, the comparison between STFT and CWT was focused on their quality in decomposing spectral.

## II. METHODOLOGY

### A. Short Time Fourier Transform Method

The Fourier transform is transforming a signal in time domain  $f(t)$  into the frequency domain. Mathematically the Fourier transform is the multiplication between the seismic wave and a complex cosine of  $e^{-i\omega t}$ , which is stated in equation (1) as follows:

$$f(w) = \langle f(t), e^{iwt} \rangle = \int_{-\infty}^{\infty} f(t) e^{-iwt} dt \quad (1)$$

If the seismic waves are transformed from time into the frequency domain, all of their frequency contents are decomposed into the individual frequency. In STFT method, the single of a seismic wave is segmented to smaller window length (windowing). This approximation can be understood because the seismic wave consists of various frequency reflecting the wave propagation into reflectors. By transforming the segmented signal into the frequency domain, the information of local frequency would be obtained from the signal over the time. This approach is usually called Short Time Fourier Transform (STFT). Time-frequency map, which is produced by this transformation, is called spectrogram. STFT is formulated by multiplication of seismic wave  $f(t)$  with a time-shifted window function  $\phi(t)$ , which is mathematically illustrated in equation (2) as follows:

$$\begin{aligned} STFT(w, \tau) &= \langle f(t), \phi(t - \tau) e^{iwt} \rangle \\ &= \int_{-\infty}^{\infty} f(t) \bar{\phi}(t - \tau) e^{-iwt} dt \end{aligned} \quad (2)$$

where the window function  $\phi$  is centered at time  $t = \tau$ , and  $\tau$  is translation parameter.  $\hat{\phi}$  is the complex conjugate of  $\phi$ .

### B. The Continuous Wavelet Transform Method

Wavelet is a short signal that normally presented the signature or pulse of the seismic source. Conceptually the wavelet is representing the package of seismic wave that propagates pass through the subsurface layer. Thereby understanding the wavelet would be helpful in analyzing the detailed seismic signal in term of the frequency domain.

The new approach to formulate the signal into a short window, which is represented by the wavelet, is the best approach to overcome the problem in the limitation of STFT algorithm due to directly segmenting the signal into a short window. CWT algorithm requires no preselecting window length and it will be substituted by a wavelet function. In its implementation, the CWT algorithm uses dilatation and translation, which is presented by time-scale (scalogram). Mathematically the CWT algorithm is defined as follows (Sinha 2005):

$$\begin{aligned} (\sigma, \tau) &= \langle f(t), \psi(t) \rangle \\ &= \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{\sigma}} \psi^* \left( \frac{t - \tau}{\sigma} \right) dt \end{aligned} \quad (3)$$

Equation (3) consist of  $\sigma$  is scale parameter,  $\tau$  is translation parameter, and  $\psi$  conjugate is a mother wavelet. Translation parameter considers the window location and the shifted window throughout signal. This parameter associated with time information in transformation domain. The high scale has a general view and low scale has detail view (Polikar 1996). The relation of scale parameter with frequency is stated by equation (4):

$$Fa = \frac{Fc}{\sigma \Delta} \quad (4)$$

where  $Fa$  is pseudo frequency associated with scale (Hz).  $Fc$  is the center frequency in wavelet (Hz).  $\sigma$  represents the scale and  $\Delta$  is sampling time.

Time-frequency map can be produced by equation (5) (Sinha et al. 2005):

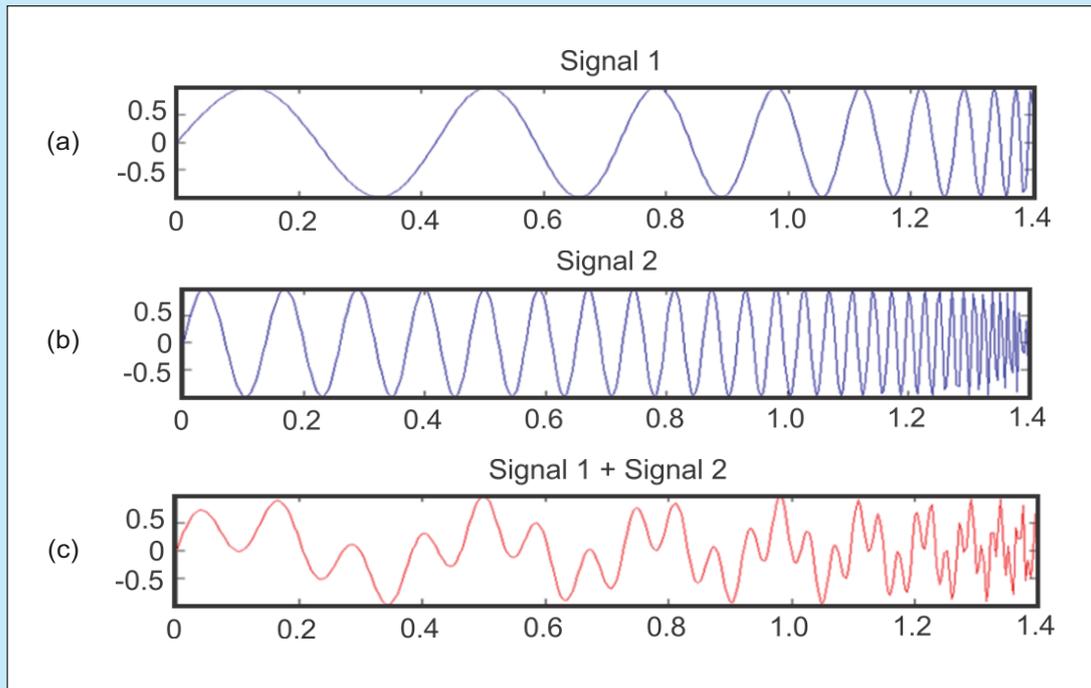
$$\hat{f}(\omega, t) = \frac{1}{C_\phi} \int_{-\infty}^{\infty} F_W(\sigma, \tau) \hat{\phi}(\sigma, \omega) e^{-\omega t} \frac{d\sigma}{\sigma^{3/2}} \quad (5)$$

## III. RESULTS AND DISCUSSION

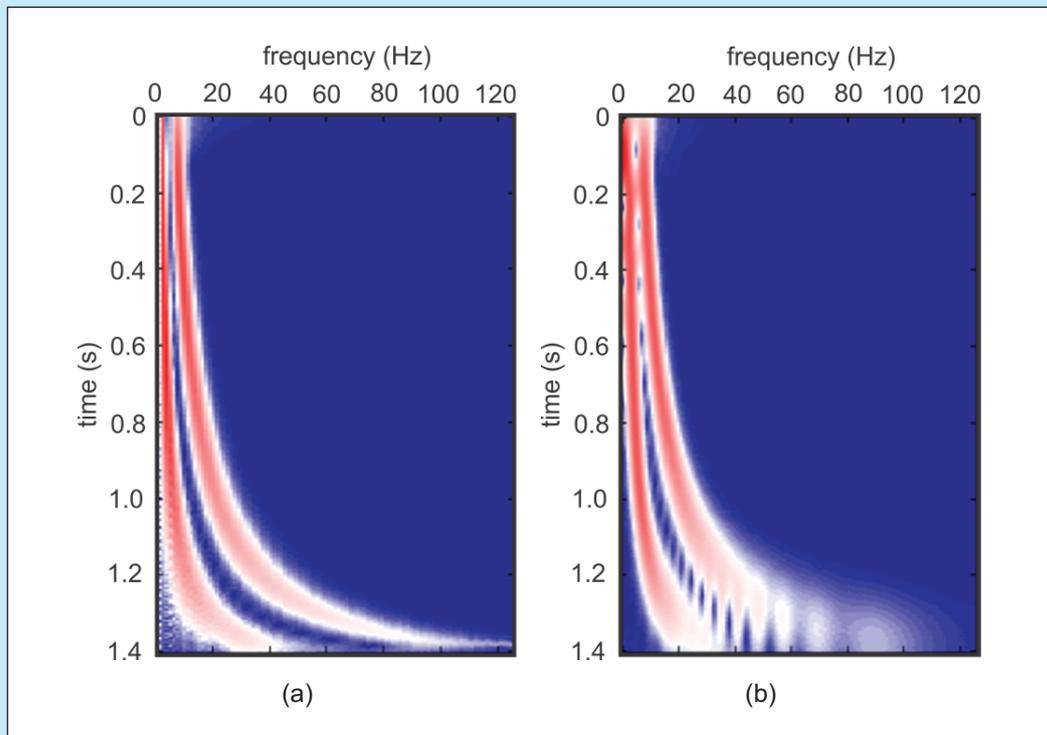
### A. Application of Spectral Decomposition to Synthetic Data

Prior to applying these two algorithms to real data set, the synthetic data set is applied to assess the robustness and stability of the algorithm. This assessment is very important because the original frequency content is already known. Therefore the decomposed spectral must be containing the similar frequency to the original signal.

In this paper, the synthetic data set was generated by designing the special signal that contains various frequencies as superposition from two different signals. The first signal is shown in Figure 1a. This Figure shows a chirp hyperbolic signal that contains the frequency content from 2 to 50 Hz. The second signal is the chirp hyperbolic signal with frequency content from 2 to 125 Hz, which is shown in Figure 1b. The synthetic data set, which is used for testing these two algorithms, is the result of the superposition of two chirp hyperbolic signals. The superposition of two chirp hyperbolic signals is shown in Figure 1c.



**Figure 1**  
Chirp hyperbolic signal with frequency range from 2 to 50 Hz (a), frequency range from 7 to 125 Hz (b), and superposition of two chirp hyperbolic signals (c).



**Figure 2**  
Time-frequency section, which is decomposed by STFT (a) and CWT (b).

The chirp hyperbolic signal is a non-stationary signal that has frequency varying with respect to time. The chirp signal is defined by using equation (6).

$$y = \sin(a \cdot \log(1 - kt)) \quad (6)$$

$$a = \frac{2\pi \cdot f1}{k} \quad (7)$$

$$k = \frac{(f2 - f1)}{(f2 \cdot tend)} \quad (8)$$

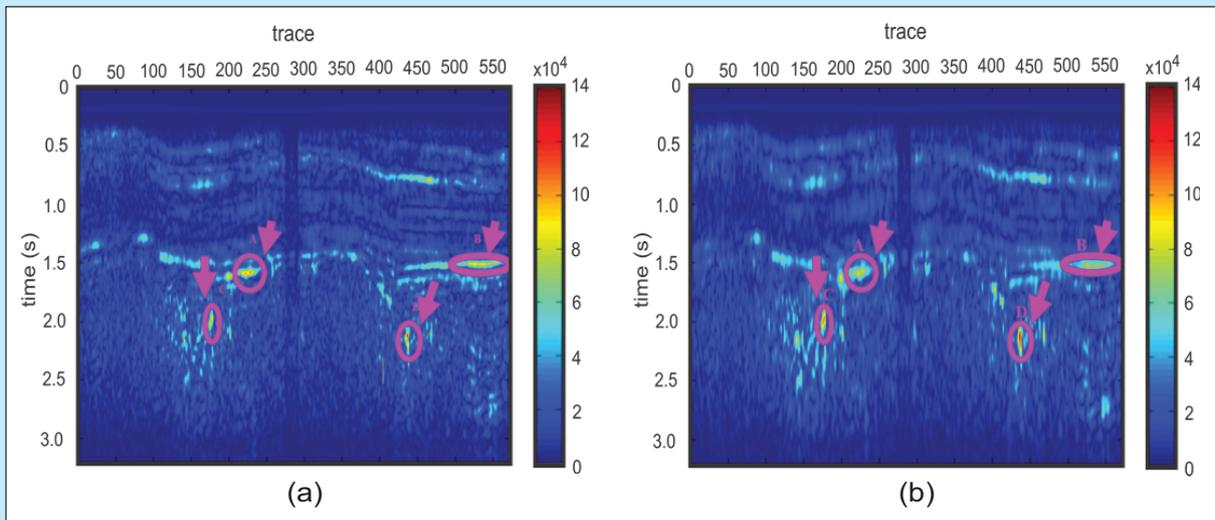
f1 represents the initial frequency(Hz), f2 is final

frequency (Hz) and t related to the time signal.  $t_{end}$  is the final time.

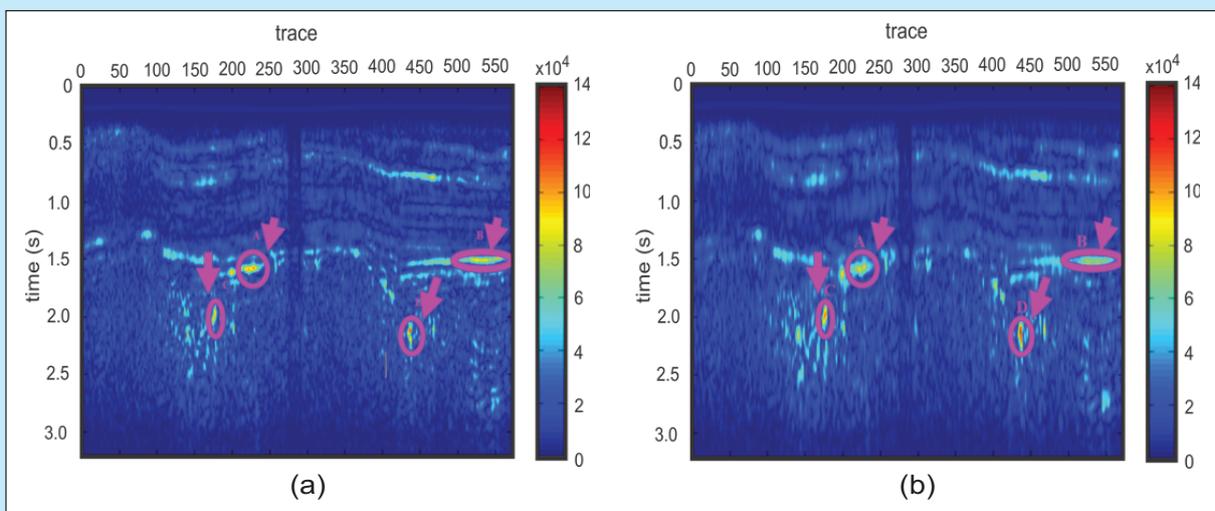
The decomposed spectral of the synthetic data set by these two algorithms are shown in Figure 2. The assessment to these two algorithms shows that STFT produces poor frequency resolution in high frequency, which is shown in Figure 2a. In contrast, CWT provides better frequency resolution compared to the STFT as shown in Figure 2b.

### B. Application of Spectral Decomposition to Real Data

After having validation of these two algorithms to the synthetic data set, the spectral decomposition was applied to the real data set. Further, this



**Figure 3**  
Decomposed spectral for individual frequency of 20 Hz, which are produced by CWT (a), and STFT (b).



**Figure 4**  
Decomposed spectral for individual frequency of 40 Hz, which are produced by CWT (a), and STFT (b).

application is intended to characterize the reservoir and subsurface rocks response in frequency domain. Figure 3a shows the result of STFT algorithm with 100 ms window length for the individual frequency of 20 Hz. The individual frequency of seismic section at 20 Hz, which is slightly below frequency dominant (25 Hz), shows low-frequency anomalies (purple circle). The STFT product for the high-frequency spectrum (40 Hz) is shown in Figure 4a. The image shows the decreasing of high spectrum amplitude, particularly the event pointed by a circle. It is caused by the energy absorption related the hydrocarbon presence.

In addition, the decomposed spectral of CWT algorithm is shown in Figure 3b for the individual frequency of 20 Hz. For the high-frequency spectrum of 40 Hz is shown in figure 4b. The image shows low-frequency shadow zone anomaly that is indicated by a purple circle. The analysis of low-frequency shadow zone exhibits the anomaly, where in the individual frequency of 40 Hz, the indicated event by a purple circle disappears. These anomalies are associated with the hydrocarbon.

In general, these two algorithms show that the STFT algorithm provides low resolution spectral, which is indicated by the thicker anomalies, blurred event, and tuning effect excessively when shifting to higher individual frequency. In contrast, the CWT algorithm produces better resolution compared to the STFT, which is indicated by the thinner anomalies, more focus event, and slightly the tuning effect.

#### IV. CONCLUSIONS

The application of spectral decomposition technique was successfully applied to the synthetic and real data set. In its application time-frequency analysis is useful in identifying and delineating the hydrocarbon reservoir distribution. Refer to two assessed algorithms, STFT provides poor frequency resolution at high frequency. In contrast, the CWT produces high-frequency resolution at high frequency.

In general, these two algorithms properly decomposed the real seismic data set into its frequency content. The analysis shows that STFT also provides less resolution of frequency anomalies, which are indicated by thicker feature compared to the decomposed spectral from CWT algorithm. In addition, the tuning effect excessively occurs in the STFT when shifting to the higher individual frequency. However, the distribution of low-

frequency anomalies can be clearly observed on both of decomposed spectral.

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#### REFERENCES

- Burnett, M.D., Castagna, J.P., Méndez-Hernández, E., Rodríguez, G.Z., García, L.F., Vázquez, J.T.M., Ailéz, M.T. & Villaseñor, R.V.**, 2003, 'Application of spectral decomposition to gas basins in Mexico' *The Leading Edge* vol. 22 no.11, pp. 1130-1134.
- Castagna, J.P., Sun, S. & Siegfried, R.W.**, 2003, 'Instantaneous spectral analysis: Detection of low-frequency shadows associated with hydrocarbons' *The leading edge* vol. 22 no.2, pp. 120-127.
- Cohen, L.**, 1995, *Time-frequency analysis*: Prentice Hall, Inc.
- Hall, M. & Trouillot, E.**, 2004, 'Predicting stratigraphy with spectral decomposition' *Proceedings of CSEG National Convention, Landmark Graphics*, Calgary, Canada, pp. 1-3.
- Haris, A., Suabdi, I.N., Erwinsyah, Adriansyah, Nurhasan, A., Khair, A. & Kainama, I.A.**, 2008, 'Low-Frequency Shadow Zone Analysis Based on CWT Spectral Decomposition: Case Study of South Sumatra Basin' *Proceedings of IPA, 32<sup>nd</sup> Annual Convention & Exhibition*, Jakarta, Indonesia, May 2008, pp. IPA08-G-070.
- Johann, P., Ragagnin, G., & Spínola, M.**, 2003, 'Spectral decomposition reveals geological hidden features in the amplitude maps from a deep water reservoir in the campos basin' *In SEG Technical Program Expanded Abstracts 2003*, pp. 1740-1743.
- Kishore, M., Sharma, S., Kumar, B. & Srivastava, A.**, 2006, 'An approach to net thickness estimation using spectral decomposition' *Geohorizons* vol. 11, pp. 58-61.
- Marfurt, K.J. & Kirlin, R.L.**, 2001, 'Narrow-band spectral analysis and thin-bed tuning' *Geophysics*, vol. 66 no. 4, pp. 1274-1283.
- Margrave, G.F.**, 2001, 'Numerical Methods of Exploration Seismology with Algorithms in MATLAB' *The University of Calgary, Canada*.
- Partyka, G., Gridley, J. & Lopez, L.**, 1999, 'Interpretational applications of spectral decomposition

in reservoir characterization' The Leading Edge, vol. 18 no. 3, pp. 353-360.

**Polikar, R.**, 1996, 'The wavelet tutorial part iii' IOWA State University, USA.

**Sinha, S., Routh, P.S., Anno, P.D. & Castagna, J.P.**, 2005, 'Spectral decomposition of seismic data with continuous-wavelet transform' Geophysics, vol. 70 no. 6, pp. P19-P25.