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Wavelet Transform Teager-Kaiser Energy – A Seismic Attribute Applied to Reveal Geological Features

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SUMMARY

A new method to estimate the instantaneous seismic traces energy is presented here. We propose to use the Teager-Kaiser energy associated with wavelet transform to generate a joint time-frequency representation, which can be used as a nonlinear energy tracking of the seismic waves. The method was applied to detect important geological marks and reservoir zones on synthetic seismic traces from well logs. It was also applied to wedge models and has shown effective to detect thin beds.

Introduction

Usually, we are not concerned with the total energy of a wave but rather with the energy in the vicinity of the point we observe it (Sheriff and Geldart, 1995). The main way used to estimate the energy of any kind of signal is squaring their amplitude samples. But this way we don't take care of the time-frequency behaviour of them. Following this idea, Kaiser (1990) has shown that the instantaneous energy of the signals can be estimated taking into account the neighbourhoods of each time sample amplitude.
We have shown in this work that the seismic waves energy are directly associated with the physical model used by Kaiser (1990) and, consequently, his result can be directly used with seismic signals. We have also extended this fact using wavelet transform to obtain a joint time-frequency representation which we have applied to detect and to track the main seismic events in seismic traces. The results were used to detect geological markers and reservoir zones on synthetic seismic traces from well logs and to characterize thin beds when applied to synthesized wedge models.

The Teager-Kaiser energy

One way to estimate the total energy associated with the motion of the medium as the seismic wave passes through it is by calculating the energy per unit volume which is called the energy density. The energy density can be expressed by the Equation (1) and is proportional to the first power of the density of the medium, ρ, and to the second power of the frequency, ω (in radians) or f, and amplitude, A, of the wave (Sheriff and Geldart, 1995, pg58).

$$\mathrm{E} = \frac{1}{2}\rho\omega^2 \mathrm{A}^2 = 2\pi^2 \rho f^2 \mathrm{A}^2 \qquad [1]$$

Using an analogue mass-spring physical model, Kaiser (1990) has proved that the energy of a discrete time signal can be estimated by:

$$\mathrm{E} = \frac{1}{2} m\omega^2 \mathrm{A}^2 \cong x^2[n] - x[n+1] - x[n-1], \qquad [2]$$

where m is the mass of the object suspended by a spring and x[n] are the samples of the discrete time signal. This expression, called as the Teager-Kaiser (TK) energy, is usually referred as a nonlinear energy-tracking signal operator (Hamila et al., 1999). It was also proved by Hamila et al. (1999) that the TK energy of complex signals can be simply obtained by the sum of the TK energy of the real part and of the TK energy of the imaginary part.
The original TK energy algorithm when it is expressed by Equation (2) is not effective when applied to signals which have multi frequency components such as the seismic traces. Then, as suggested by the Kaiser results (1990), the signal should be band pass filtered before calculating the TK energy.
Comparing Equations 1 and 2, it should be clearly observed that, despite of the terms density for seismic waves and mass for mass-spring model, the expressions are exactly the same and the TK energy expression as presented by Kaiser (1990) can also be directly applied to estimate the instantaneous energy of the seismic waves.

The Wavelet Transform TK Energy - WaveTeK

It is well known that the wavelet transform can be interpreted as a joint time-frequency representation, where the frequencies are associated with the mother wavelet dilation/compression and can also be implemented through a band pass filters bank (Mallat, 1999). Following this idea, we propose to implement the TK energy along each scale, or each band pass filter, after calculating the Wavelet transform. This way the Wavelet Transform

Teager-Kaiser Energy, or the WaveTeKE, is calculated after the signal being band pass filtered.

The Figure 1 shows schematically the WaveTeKE algorithm applied to a real seismic trace using the real Morlet wavelet. Figure 1a shows the acoustic impedance of a Campos Basin offshore Brazil well producer log and its geological markers and the Figure 1b shows the correspondent synthetic seismic trace. Comparing Figures 1b, 1c and 1e it can be easily observed the WaveTeKE capability to track the time-frequency energy locating the main seismic events in the trace. Specifically in this example, it should be observed at Figure 1e the detection of the three main geological marks from a typical Campos Basin well log (around 1.46 s, 1.7 s and 1.86s). Particularly, the WaveTeKE around 1.86 seconds is associated to a reservoir turbidite system of an important Campos Basin oil field.

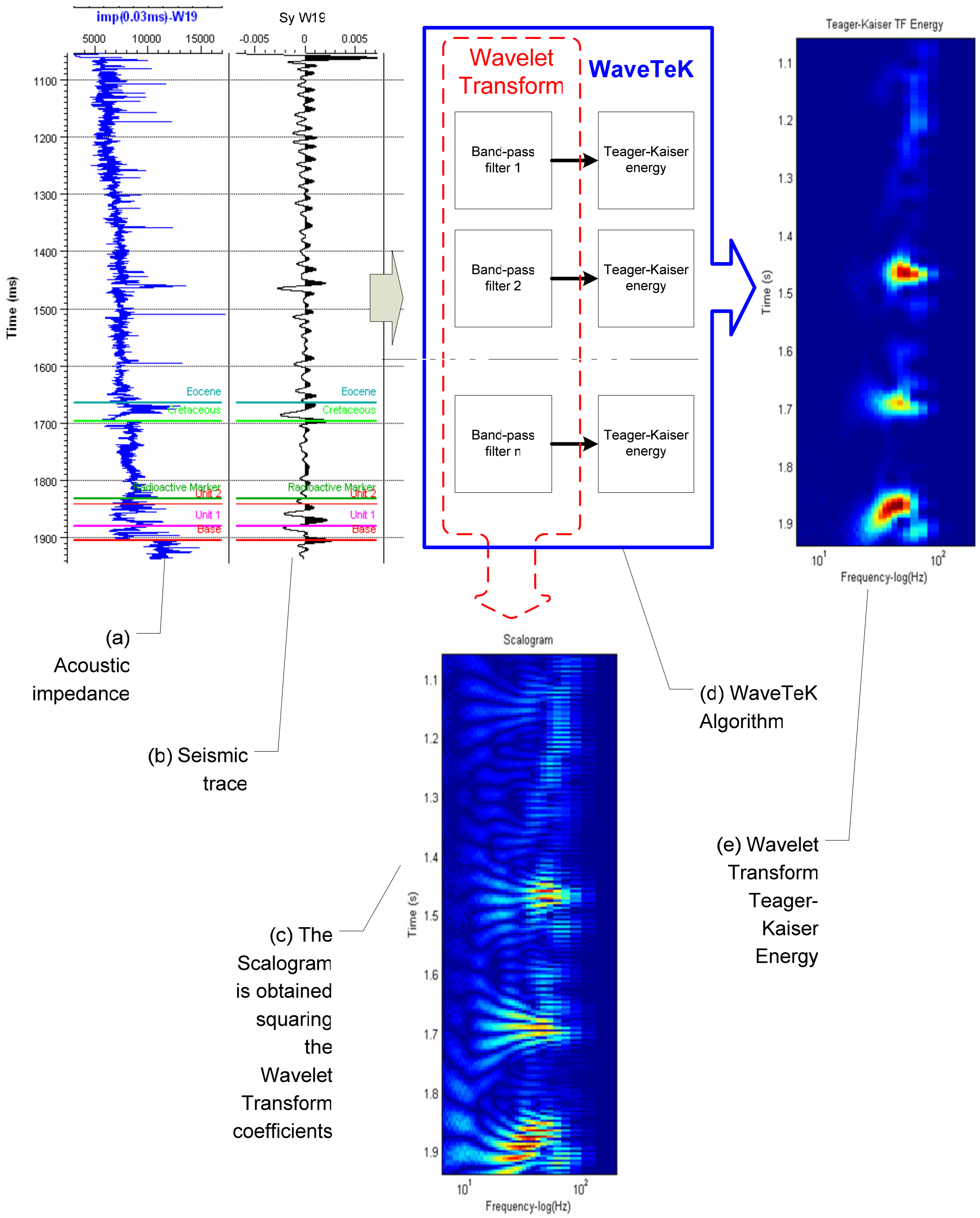
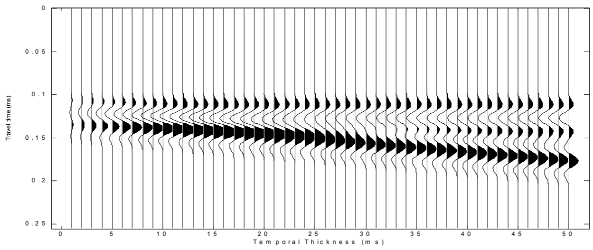


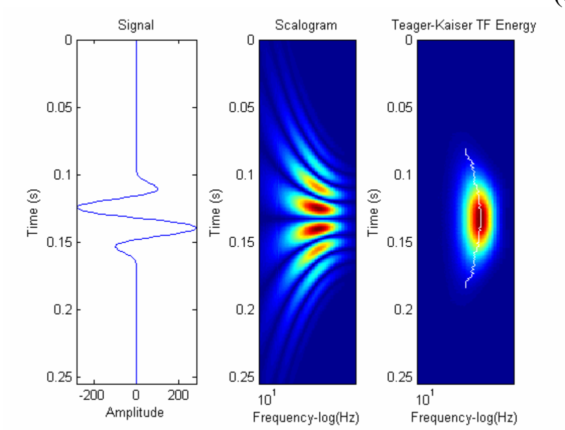
Figure 1: The WaveTekE algorithm: a) Acoustic impedance; b) Synthetic seismic trace; c) The wavelet transform scalogram; d) WT as a filter bank followed by the Teager-Kaiser Energy estimator; e) The WaveTeKE result.

Applying the WaveTeKE Energy to detect thin beds

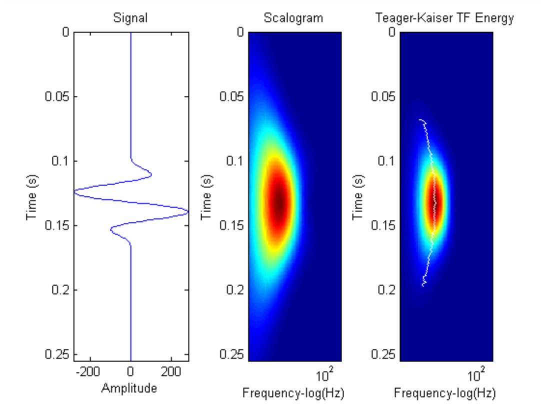
It was showed that the maximum instantaneous frequencies and their associated amplitudes can be related to the thin beds detection (Matos and Osório, 2005), (Matos et al., 2005) and (Liu and Marfurt, 2006). Following this idea we have applied the WaveTeKE time-frequency representation to a synthesized seismic traces wedge model using the Morlet and the complex Morlet wavelets. Specifically, the Figure 2a shows a classical wedge filtered model (Partyka et al., 1999), the Figures 2b1 and 2c1 show the modelled seismic trace with 10 ms temporal thickness, the Figures 2b2 and 2c2 show the Scalogram obtained from the continuous wavelet transform. The CWT has been applied to the seismic traces using the real Morlet and the complex Morlet wavelets, respectively. The Figures 2b3 and 2c3 show the WaveTeKE energy obtained and the white lines in these Figures show the maximum instantaneous frequency. It should be observed the WaveTeKE capability to locate the time-frequency energy of the seismic event. It should also be observed that the maximum instantaneous frequencies detected for each case were almost the same, despite of the different wavelets used.



(a)



(b)



(c)

Figure 2: a) Filtered wedge model; b) The seismic trace with 10 ms temporal thickness, the WT scalogram obtained using the real Morlet wavelet and the WaveTeK; c) The seismic trace with 10 ms temporal thickness, the WT scalogram obtained using the complex Morlet wavelet and the WaveTeK.

As suggested by Matos et al.(2005) the maximum frequencies and their associated amplitudes of each seismic trace were extracted using the WaveTeKE and plotted at Figure 3b and 3c, respectively, where it can be easily visualized the localization of the thin bed phenomena. These results also suggest the extraction of time interval seismic attributes from these data, which were obtained as the maximum of the frequencies and amplitudes for each trace on Figures 3b and 3c and are plotted in Figure 3d as a function of the wedge model time thickness. Figure 3d confirms the expectation of the thin bed high frequency contents.

Conclusions

In this paper we have shown how to obtain a joint time-frequency representation using the Teager-Kaiser energy associated with the wavelet transform. It was also discussed the effectiveness of the WaveTeKE to detect and to track important seismic events. The results obtained with synthesized seismic traces show the WaveTeKE potential use as an exploratory tool to detect energy associated with important geological marks and potential exploratory leads. It also has shown, when the technique was applied to characterize thin beds using wedge models, that WaveTeKE is very promissory and its robustness suggests that changes in the analysing window could have little influence in it.

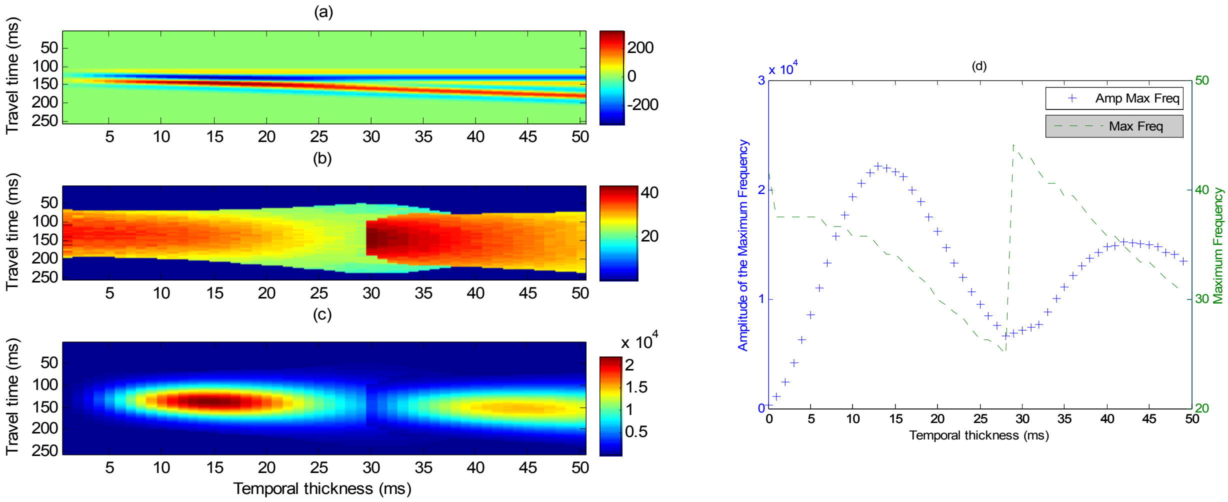


Figure 3: a) Filtered wedge model; b) The maximum instantaneous frequency versus temporal thickness; c) The amplitude of the maximum instantaneous frequency obtained through the ridge WaveTeK versus temporal thickness; d) Time interval seismic attributes: the Maximum Instantaneous frequency and the associated maximum amplitude versus temporal thickness.

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