

Revealing geological features through seismic attributes extracted from the wavelet transform Teager-Kaiser energy

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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 real seismic data and has shown effective to reveal important geological features.

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 behavior of them. Following this idea, Kaiser (1990) has shown that the instantaneous energy of the signals can be estimated taking into account the neighborhoods 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 reveal important geological features when applied to real seismic data.

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, p. 58).

$$E = \frac{1}{2} \rho \omega^2 A^2 = 2\pi^2 \rho f^2 A^2 \quad (1)$$

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

$$E = \frac{1}{2} m \omega^2 A^2 \cong x^2[n] - x[n+1]x[n-1] \quad (2)$$

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 Continuous Wavelet Transform (CWT). This way the Wavelet Transform Teager-Kaiser Energy, the WaveTeKE, is calculated after the signal being band pass filtered.

Revealing geological features through seismic attributes extracted from the WaveTeKE

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 in 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.

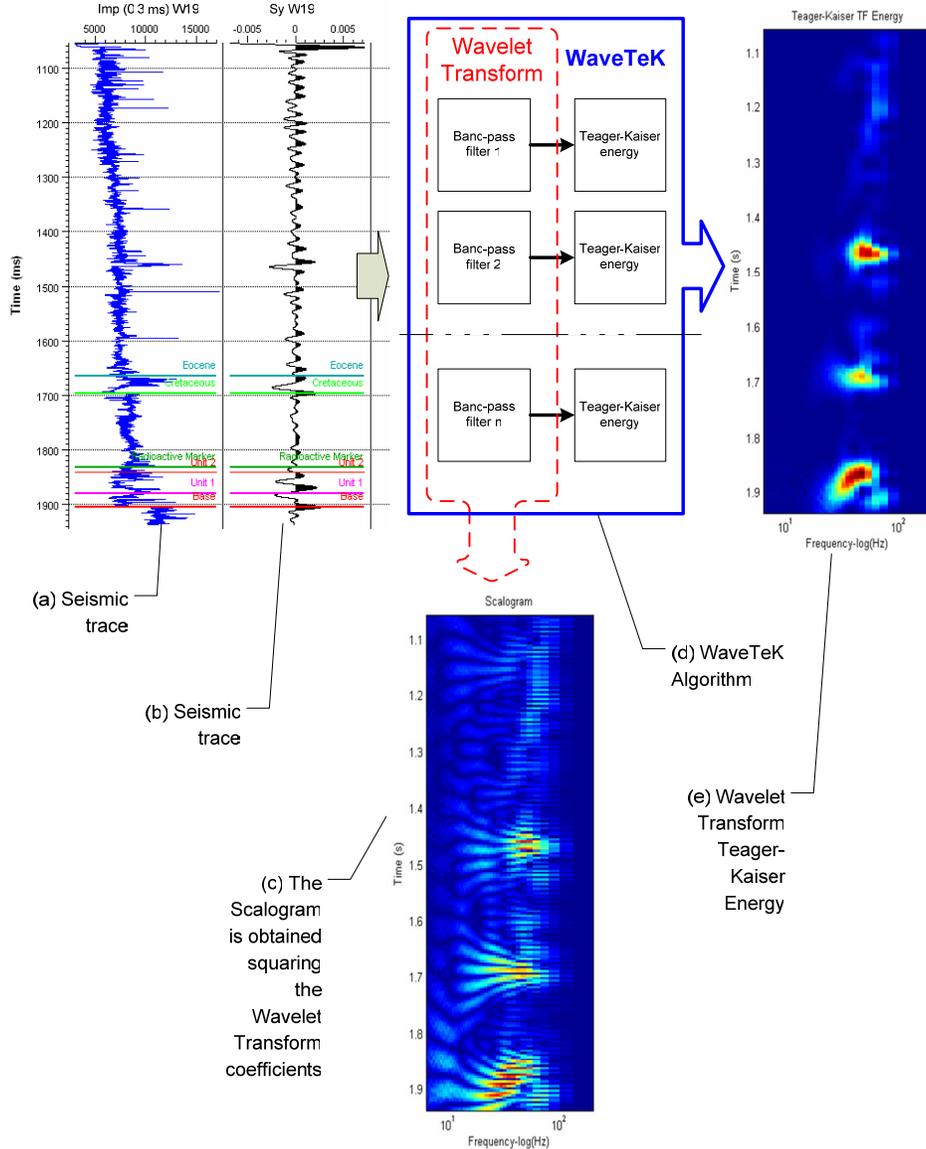


Figure 1: The WaveTeKE algorithm: a) Acoustic impedance; b) Synthetic seismic trace; c) The wavelet transform scalogram obtained squaring the CWT coefficients and using the real Morlet wavelet; d) WT as a filter bank followed by the Teager-Kaiser Energy estimator; e) The WaveTeKE result. The colours close to blue represent positive values close to zero of the coefficients, while colours close to red represent the highest positive values.

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Applying the WaveTeKE to reveal geological features on seismic data

To verify the effectiveness of the algorithm, the WaveTeKE was applied to real seismic data. Specifically, we have chosen the closest seismic trace to the well used in the Figure 1 example. Figure 2a shows the seismic trace and Figures 2b and 2c show the CWT scalogram using the real Morlet wavelet and the WaveTeKE, respectively. It can be easily verified in Figure 2c that the reservoir area was detected around 2.6 s, with the same dominant frequency of the Figure 1e, approximately 30 Hz.

In Figure 3b, the scalogram of the same seismic trace, shown in Figure 2a, has been obtained using a complex Morlet wavelet. The corresponding WaveTeKE is shown in Figure 3c and it is very similar to the one at Figure 2c, with the same dominant frequency of approximately 30 Hz around 2.6 s. It should be observed the WaveTeKE capability to locate the time-frequency energy of the seismic event. It should also be observed that the instantaneous energy detected for each case were almost the same, despite of the different wavelets used.

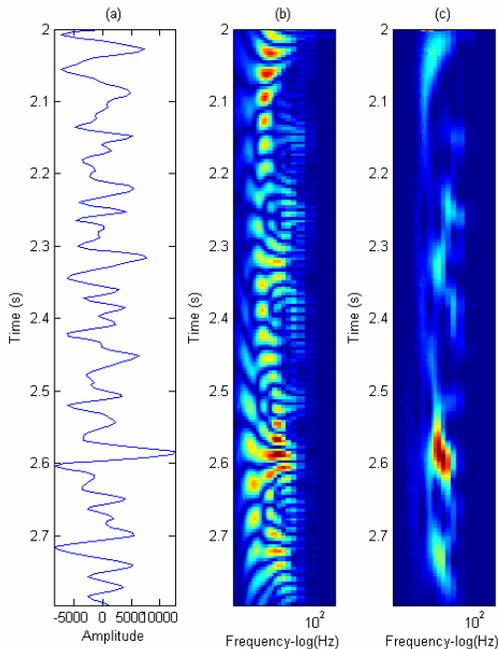


Figure 2: a) Seismic trace close to the well; b) The scalogram using the real Morlet wavelet; c) The WaveTeKE. The colours close to blue represent positive values close to zero of the coefficients, while colours close to red represent the highest positive values.

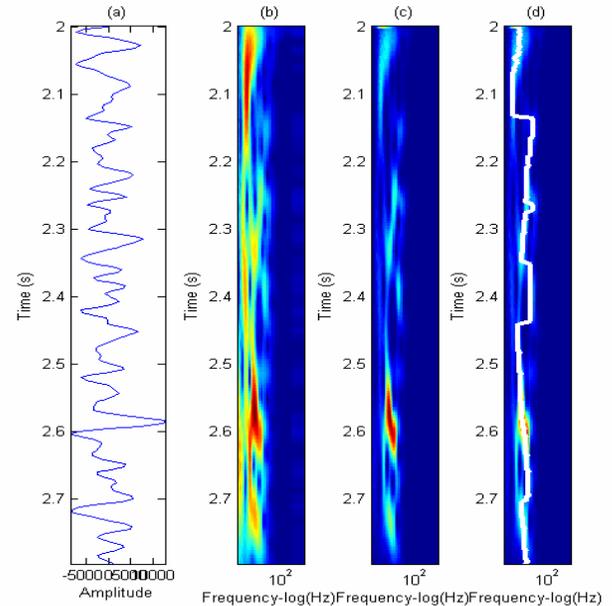


Figure 3: a) Seismic trace close to the well; b) The scalogram using the complex Morlet wavelet; c) The WaveTeKE; d) The WaveTeKE and the white line represents the maximum instantaneous frequency. The colours close to blue represent positive values close to zero of the coefficients, while colours close to red represent the highest positive values.

It was shown 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, 2007). Following these ideas the WaveTeKE time-frequency representation had been applied to a synthesized seismic traces wedge model and was shown effective to detect thin beds (Matos et al., 2007).

Therefore, as illustrated in Figures 1e, 2c and 3c the dominant instantaneous frequency or the maximum instantaneous frequency extracted from the WaveTeKE can also be used as an instantaneous seismic attribute and, specifically, the Figure 3d shows that the WaveTeKE and its associated maximum instantaneous frequency represented by a thick white line can also be used to reveal important seismic features from real data.

Then, as suggested by Matos et al. (2005), the amplitudes associated to the maximum frequencies of each seismic trace were extracted using the WaveTeKE from two seismic 2D lines close to the well used in Figure 1. The

Revealing geological features through seismic attributes extracted from the WaveTeKE

resulted attributes are plotted in Figure 4, where it can be easily detected the reservoir area. Specifically, as a reference, in both Figures 4a and 4b a white dotted line represents the base of the reservoir and a vertical black dashed line locates the closest trace to the well used in the first example. These lines confirm the seismic events detection capability of the proposed algorithm.

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 real

seismic data 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 that WaveTeKE is very promissory and its robustness suggests that changes in the analyzing window could have little influence in it.

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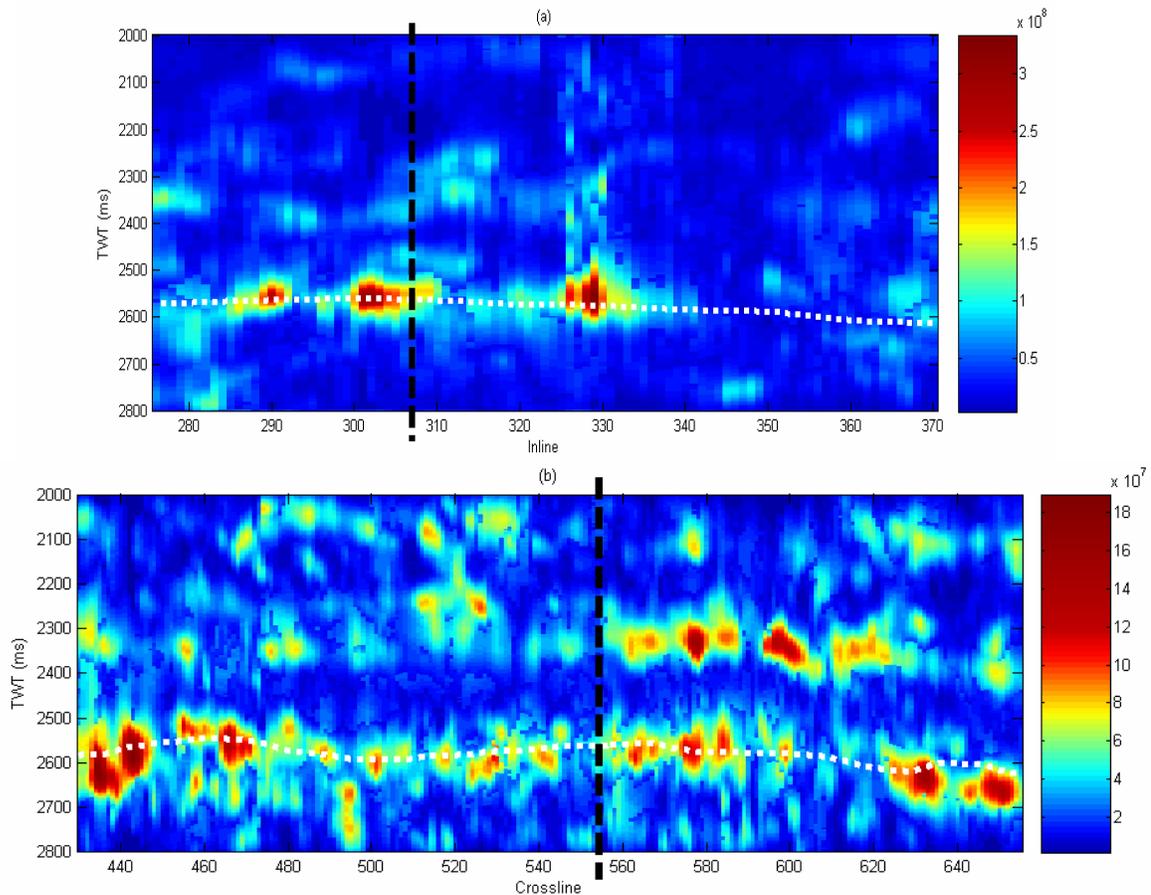


Figure 4: a) The amplitude of the maximum instantaneous frequency obtained through the ridge of the WaveTeKE applied to a 2D seismic line; b) The amplitude of the maximum instantaneous frequency obtained through the ridge of the WaveTeKE applied to a 2D seismic line; The vertical black dashed line illustrates the location of the well used in Figure 1 and the white dotted lines are the base of the reservoir horizon interpretation.

EDITED REFERENCES

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