WAVELET BASED VOLUME ATTRIBUTES FOR SEISMIC INTERPRETATION

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Summary

Seismic attribute analysis has gone through a major revolution due to the introduction of three-dimensional seismic imagery. Features of special interest are the local geometry of the seismic signal and its frequency content. We have developed a new kind of wavelet transform that has the ability to both separate approximately the angular information and the polar scale, with only a limited increase in the amount of data.
The directionality of this novel transform is obtained by projection of the wavelet coefficients onto positive and negative frequencies separately. The transformed data results in a complex wavelet transformation with a quasi-quadrature relationship between its real and imaginary parts and with superior directional selectivity. We use this transform for the determination of local orientations of three-dimensional reflectors and for extraction of the local scale in migrated seismic data from the F09 block in the North Sea.

Introduction

Seismic imagery of the earth's subsurface plays a critical role in all aspects of oil and gas exploration and production — from the location of reserves to their appraisal and subsequent monitoring. In oil and gas exploration, seismic cross-sections are scrutinized by interpreters who search for features that indicate possible hydrocarbon reservoirs. Previously, interpreters dealt with large plots of 2D cross sections; they now work on computers with 3D volumes comprising gigabytes of data. Local signal attributes aid the interpretation of seismic data, elucidating its salient characteristics.

Particularly useful attributes are local angle (dip) of a reflector and instantaneous frequency of reflection patterns. Dip representations enable 3D interpretation of *structures* using seismic depth-slices. Channels and faults appear as dip variations, but are often barely visible in amplitude slices. Local frequency is often used as a lithology indicator (1; 2).

Previously, we used the complex steerable pyramid (CSP (3)) to develop attribute representations that provide very accurate angle indications for 2D cross-sections (4; 5). However, the overwhelming redundancy of the pyramid representation prohibits the application to larger 3D seismic volumes because of computational expense.

Other separable wavelet transforms that have less redundancy, such as the discrete wavelet transform (DWT), often have poor directional selectivity.

In this paper we show that we can use the modified discrete wavelet transform as introduced by van Spaendonck and Fernandes (6; 7) for the extraction of volume attributes. The transform employs projection filters derived from the wavelet used in the DWT, to project the energy in each subband onto positive and negative frequencies separately. We call the so obtained modified DWT the *complex discrete wavelet transform* or CDWT. The transform is only slightly oversampled and perfectly reconstructive.

We discuss the extension of the CDWT to three dimensions and show how this transform can be used to extract frequency *and* geometry related attributes. Some preliminary results are shown of the attributes. For that purpose we have used seismic data from the F09 block in the North Sea.

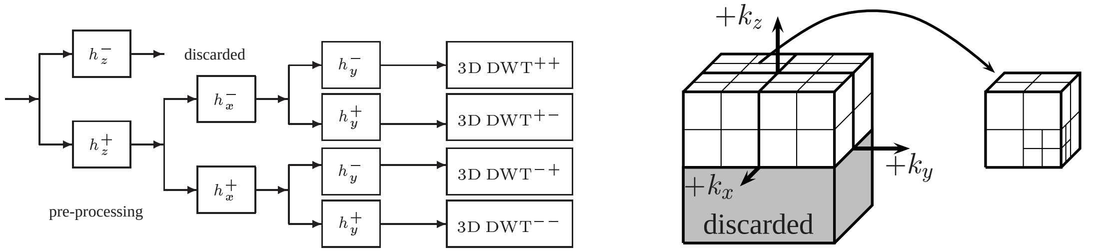

Figure 1: The 3D complex wavelet transform: 3D DWT of projections onto positive and negative spatial frequencies. **Left:** schematic diagram of filtering steps. **Right:** resulting frequency partitioning after projection and 3D DWT.

Complex discrete wavelet transform

The discrete wavelet transform has proven to be useful for signal and image processing. The transform is computationally very efficient and results in a sparse representation for any class of signals. The multiscale structure of the wavelet transform is an attractive feature, because there usually exists an interscale relationship between the scale subbands. These features in combination with the fact that the wavelet transform satisfies the perfect reconstruction condition make this transform a very attractive transform for image or signal processing. It has found its applications in image compression, denoising, network traffic and image classification.

Seismic applications often require the ability to handle complex signals. The Fourier transform belongs to that category of transforms, but has the disadvantages of a global transform and is not as sparse as the discrete wavelet transform. The CDWT is designed for complex signal processing. The projection onto positive and negative frequencies results in a complex representation.

The benefit of the projections is that the envelope of the projection corresponds to the energy in each subband, because of the approximate quadrature relationship that exists between the real and the imaginary part. For more dimensions the additional imaginary part enhances the directional selectivity of the transform. The latter two properties are very beneficial for attribute estimation where the energy in the signal and the directional selectivity both are of vital importance.

An extended background on the development of complex wavelets for signals and images can be found in (6; 7). The structure we use for projection is illustrated in the diagram in Figure 1. A real data volume is projected onto the positive and negative subspaces. The negative z-frequencies can be discarded, because of the symmetry in the Fourier domain of a real input. Subsequently the wavelet transform is applied on each of the resulting complex volumes. The partitioning of the Fourier domain is illustrated in Figure 1. The redundancy of the transform is twice the number dimensions.

Attributes

We now outline a method for developing local angle and dip representations for 3D seismic images using the CDWT as discussed in the previous section. Firstly, we apply the transform to the seismic volume, using a short Daubechies-4 wavelet in each direction.

For dip extraction, we perform three separate reconstructions by considering each angle in isolation. The diagonal features are located in all subbands along the corners of the Fourier volume as indicated by the gray colored subbands in Fig. 2. The vertical features are located in Fourier domain in the subbands adjacent to the $k_x - k_y$ axes. The horizontal features are localized in the upper bands adjacent to the k_z-axis. Each

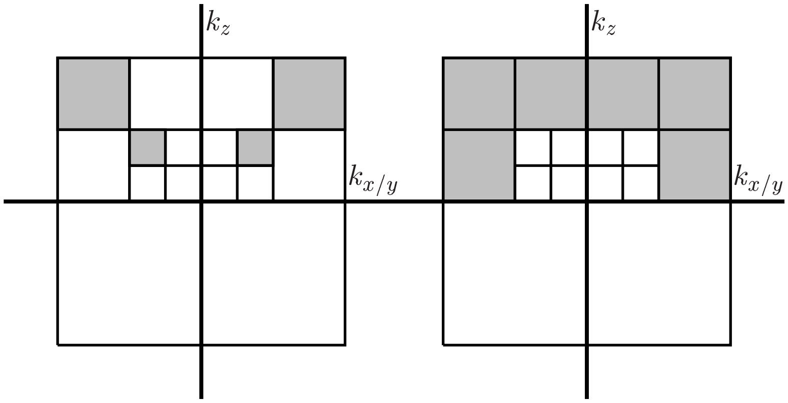

Figure 2: Attribute extraction: **Left:** Subbands used for extraction of diagonal features. **Right:** Subbands used for extraction of finest scale.

reconstructed volume reflects the extent to which the seismic cross-section is oriented in the corresponding direction. We estimate the local dip as the weighted average of the three angles. For the scale extraction, we follow the same procedure as we did for the dip extraction, but now we choose the subbands in a different way. The subbands contributing to scale are radially oriented around the origin as illustrated by gray colored part in the right diagram of Fig. 2, which represents the finest scale. The dataset for illustration of the attributes comprises the F09 block in the Southern North Sea. 3D seismic data was surveyed and time migrated in 1994 by TransCanada. The survey covers 28.2 by 16 km, consisting of 640 in- and 1128 cross-lines with 25 m spacing. Focus of this interpretation is on an enormous delta system, which prograded into the North Sea basin during the Late Cenozoic (8).
We have extracted local dip and scale of a part of this dataset (552-680 ms, 6.2 km×24.8 km). Fig. 3 (a) and (b) illustrate the prograding clinoforms. The local dip in Fig 3 (c) illuminates the reflector that bounds the delta sharply. The internal clinoforms in Fig. 3 (d) show alternating zones of fine and coarse scale, which indicate alternating frequency content of reflections. Furthermore there is a distinct difference between the scale pattern in the (steeply dipping) delta lobe and the subsequent layer.

Acknowledgements

We would like to thank TransCanada for providing the data set. This work was supported by the Dutch Science foundation's NEESDI program, the Rice Consortium for Seismic Interpretation, DARPA, and Texas Instruments.

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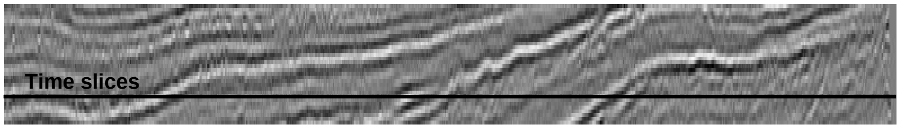
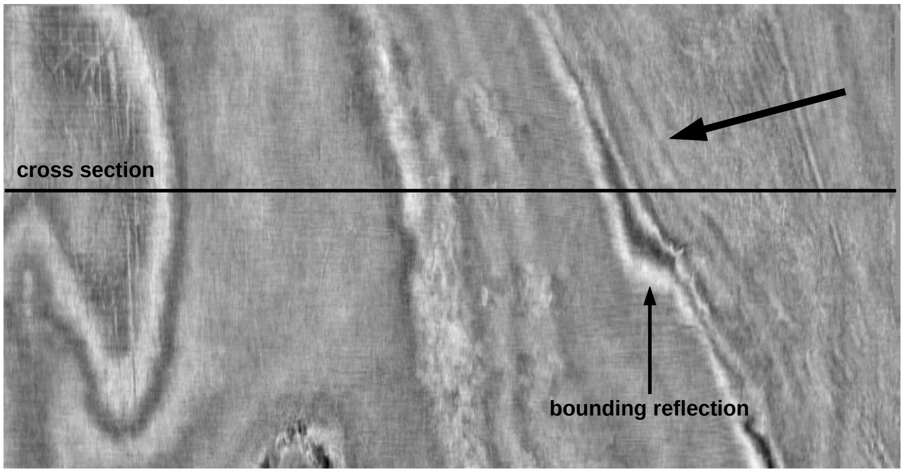
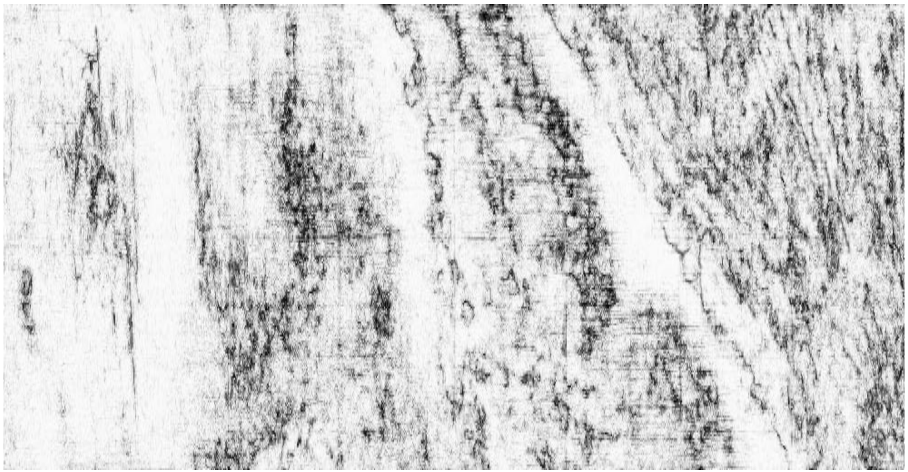


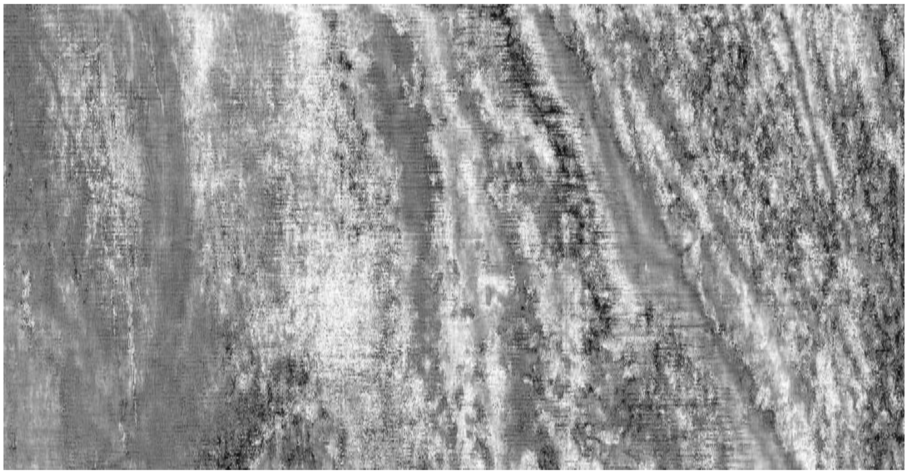
(a) section



(b) amplitude



(c) dip



(d) scale

Figure 3: (a) Seismic section. (b) Seismic amplitude timeslice showing direction of deltaic progradation. (c) Dip attribute (black=vert., white=horz.). (d) Scale attribute (black=fine, white=coarse).