Wavelet-based volume attributes.

Rutger L.C. van Spaendonck, F.C.A. Fernandes[†]*, J.T.Fokkema*
Applied Earth Sciences, Delft University of Technology, Delft, Netherlands
[†]*Department of Electrical and Computer Engineering, Rice University, Houston, TX, USA*

SUMMARY

Attributes for seismic signal analysis have gone through a major revolution due to the introduction of three-dimensional seismic imagery. Formerly, frequency and phase were features of interest, now also the geometry of reflectors in the volume have become of great importance. We have developed a new type of wavelet transform that has the ability to both separate angular information and polar frequency information. We call this transform the complex wavelet transform.
The directionality of this novel transform is obtained by projection of wavelet coefficients onto positive and negative frequencies separately. The resulting wavelet transform has a quasi-quadrature relationship between its real and imaginary part and has superior directional information. We use the transform to determine the geometry of reflectors in the seismic volume and to extract local polar frequencies (scales). The method is illustrated with a simple model and subsequently applied to 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 (polar) 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 (Taner et al., 1979; Steeghs, 1999).

Previously, we used the complex steerable pyramid (Simoncelli et al., 1992) to develop attribute representations that provide very accurate angle indications for 2D cross-sections (Hindriks et al., 2000; van Spaendonck et al., 2000a). However, the overwhelming redundancy of the pyramid representation prohibits the application to larger 3D seismic volumes because of computational expense.

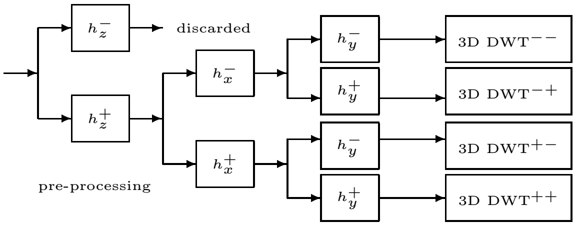

Figure 1: Complex discrete wavelet transform: preprocessing before DWT.

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 a modified discrete wavelet transform as introduced by van Spaendonck and Fernandes (van Spaendonck et al., 2000b; Fernandes et al., 2000) 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 for the extraction of frequency *and* geometry related attributes. We illustrate the concept of the attributes with a simple zero-offset convolution model. Subsequently we show some preliminary results of the attributes on migrated seismic data. For that purpose we have used seismic data from the F09 block in the North Sea near the Netherlands.

Complex 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 multi-scale structure of the wavelet transform is an attractive feature, because usually the scale-subbands have a strong relationship. It is for these reasons that the wavelet transform is extremely well-suited for compression purposes. Other applications of wavelet transforms in image processing have been found in denoising, network traffic and image classification.

Seismic applications however, often require the ability

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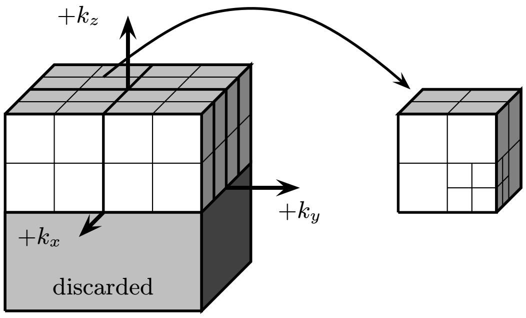


Figure 2: The resulting frequency partitioning of the 3D complex discrete wavelet transform.

to handle complex signals. the DWT lacks this specific property. The Fourier transform on the other hand belongs to a category of transforms that has the ability to handle complex signals, but this transform has the drawbacks of a global transform and is not as sparse as the discrete wavelet transform.

The CDWT is designed for processing of complex signals. The projection onto positive and negative frequencies results in a complex representation.

The benefit of the projection is that the envelope of the projected signal corresponds to the energy of that signal, because of the quadrature relationship that exists between the real and the imaginary part. For more dimensions the additional imaginary part can be used to enhance the discrimination of directional information of the transform. The latter two properties are very beneficial for volume 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 (van Spaendonck et al., 2000b; Fernandes et al., 2000). The structure we use for projection is illustrated in the diagram in Figure 1. A seismic 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 2. The redundancy of the transform is only twice the number dimensions.

Attributes

The complex wavelet transform splits a signal in terms of its scale and the geometry of reflections. Since the information in the transform is hard to interpret, we describe the transform by two attributes extracted from the transform. The attributes are the local dip as an indication for the geometry of the reflector, and the instantaneous scale.

local dip

We now outline a method for developing local 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 Daubechies-8 wavelet for the wavelet transform and a Daubechies-32 wavelet for the projection (longer wavelets generally correspond to a better approximation of Hardy space).

We perform 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. 3. 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 reconstructed volume reflects the extent to which the seismic cross-section is oriented in the corresponding direction. We can estimate the local dip as the weighted average of the three angles. Sometimes we want to study the dip in a direction of preference to obtain more angles (because we can now disitinguish positive and negative dips). Automatically this means that we have to treat the volume along the crossline and the inlne direction separately. Optionally we can recombine both attributes to a dip and an azimuth.

To illustrate the latter attribute we have created a simple synthetic seismic example. The model that we have used to illustrate the attribute, is the model given in Fig. 4 (a). A single reflector that consists of a little channel, a fan and a fault through the fan. We have convolved the model in the vertical direction with a fifty sample ricker wavelet. After the convolution we have downsampled the data by four (in the z-direction). In Fig. mod (b) we show a time-slice that cuts through part of the fan and through the fault. At the same depth we have cut the resulting dip-attribute volume. The result is shown in Fig. 4 (c). We have removed information outside the range of the data. Dark values indicate steep positive dips, white values indicate steep negative dips. The ramp dips in the direction orthogonal to the direction in which we measure the dip and hence appears to have zero dip. The fan changes from negative dips on one side to positive dips on the other side. As a discon-

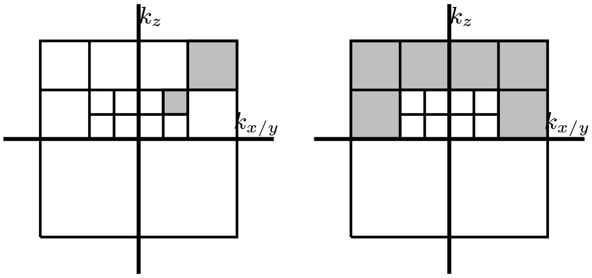


Figure 3: Attribute extraction: **Left:** Subbands used for extraction of diagonal positive features. **Right:** Subbands used for extraction of finest scale.

tinuity, the fault appears very clearly.

Instantaneous scale

For the extraction of instantaneous scale, we follow the same procedure as we did for the extraction of the local dip, but now we choose the subbands in a different way. The subbands contributing to the instantaneous scale are radially oriented around the origin as illustrated by gray colored part in the right diagram of Fig. 3, which represents the finest scale.

Seismic data from the F09 block, North Sea

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 the edge of a salt dome.

We have extracted local dip and scale of a part of this dataset (940-1200 ms, 6.2 km×24.8 km). Fig. 5 (a) shows a section through the amplitude data to give an indication of the structures. The time-slices are located at the depth of the black line in the section. In Fig. 5 (b), the amplitude time-slice is shown. the black line here indicates the localization of the cross-section in (a). Fig. 5 (c) shows the dip in the cross-line direction. The steep positive dipping events are indicated with light gray values, the steeply negative dipping events by dark gray values. Fig 5 (d) indicates the instantaneous scale. Dark values here indicate fine layering (scale) and the white values indicate coarser layering. From the sections we can observe that dip and scale together add a lot of extra information to the amplitude time slice. especially in the right region of the slices we can distinguish a lot of variation in dip and scale, whereas the amplitude hardly shows any variation. As we would expect, neither the dip nor the scale responds to the higher amplitudes at the edge of the salt dome. The little circle in the lower right of the amplitude slice, shows up on both , the dip and the scale slice.

Fernandes, F. C. A., van Spaendonck, R., Coates, M., and Burrus, C. S., 2000, Directional complex-wavelet processing: SPIE, Proceedings of SPIE 2000, 61–61.

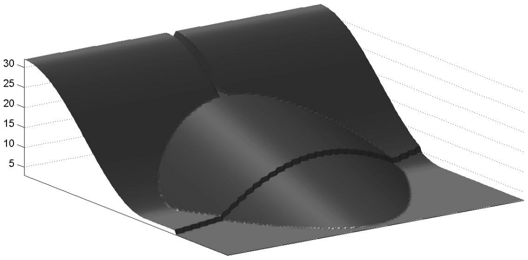
Hindriks, F., van Spaendonck, R. L. C., Drijkoningen, G., and Fokkema, J. T., 2000, Directional scale analysis for three-dimensional seismic data: EAGE, Extended Abstracts, A–02.

Simoncelli, E., Freeman, W., Adelson, E., and Heeger, D., 1992, Shiftable multi-scale transforms: IEEE trans. Inform Theory, **38**, 587–607.

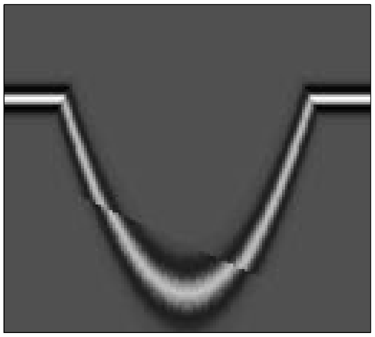
Steeghs, T., 1999, Fast computation of the sliding-window radon transform applied to 3-d seismic attribute extraction: SEG, Ann. Mtg. Abstracts, 1146–1149.

Taner, M. T., Koehler, F., and Sheriff, R. E., 1979, Complex seismic trace analysis: Geophysics, **44**, no. 06, 1041–1063.

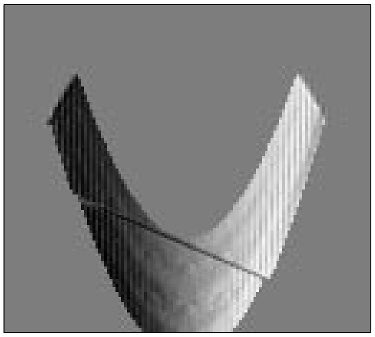
van Spaendonck, R., Hindriks, F., Fernandes, F., and Drijkoningen, G., 2000a, Three-dimensional attributes for seismic interpretation: Soc. Expl. Geoph., Ann. Mtg. Abstracts, 2059–2062.



(a) model



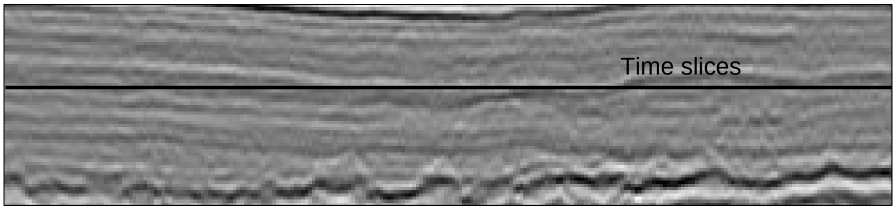
(b) amplitude



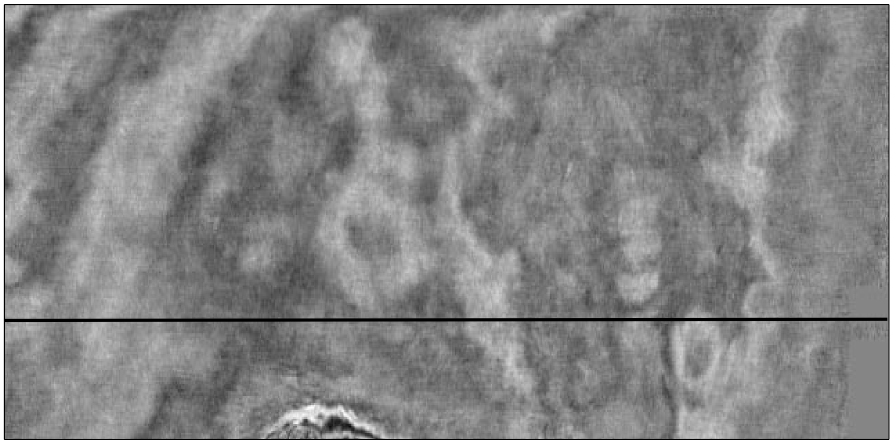
(c) dip

Figure 4: (a) Model for synthetic data. (b) Seismic amplitude time-slice. (c) Dip attribute in x-line (black=negative dips, white=positive dips).

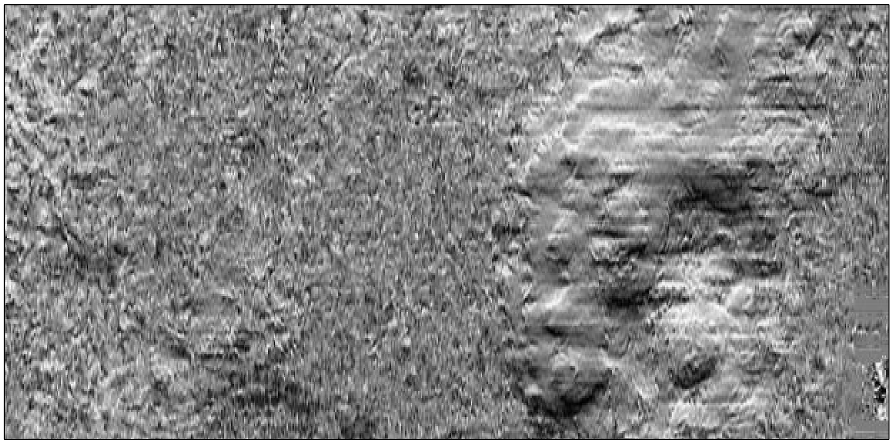
van Spaendonck, R., Fernandes, F. C. A., Coates, M., and Burrus, C. S., 2000b, Non-redundant, directionally selective, complex wavelets: Int. Conf. Image Processing, IEEE, Extended Abstracts II, 379–382.



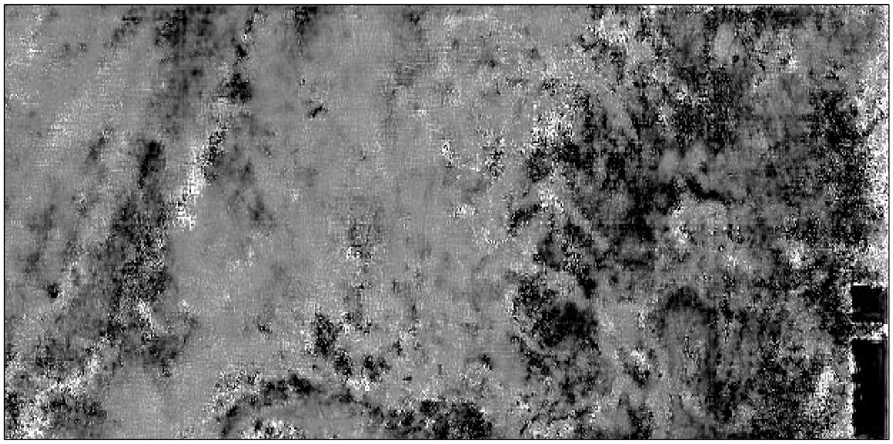
(a) section



(b) amplitude



(c) dip



(d) scale

Figure 5: (a) Seismic section. (b) Seismic amplitude timeslice. (c) Dip attribute (black=negative dips, white=positive dips.). (d) Scale attribute (black=fine, white=coarse).