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Structure Oriented Signal Enhancement (SOSE)

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SUMMARY

Most existing signal enhancement and random noise removal algorithms take no account of structure, and so tend to smear coherent events across faults and harm steeply dipping events.

A new noise suppression technique is presented here which uses 3D structure tensors, calculated from stacks or offset panels, to detect event edges and applies anisotropic diffusion filtering between those edges, to enhance signal at the expense of noise.

Using both synthetic and real data, we have demonstrated the capability of this technique to remove noise as effectively as existing methods whilst also preserving signal and honouring truncations (faults, etc).

We propose how this fast and flexible technique can be used not only on seismic reflection data as an aid to interpretation, speeding up automated horizon picking, but also on other attribute volumes, for example as a robust method of helping build initial velocity models that honour structure.

Key words: Signal enhancement, semblance, seismic image, fault preserving.

INTRODUCTION

Structure Oriented Signal Enhancement (SOSE) is a noise suppression tool based on the work of David Hale (2009). It is a two step process, composed of first calculating structure tensors, and hence a 3D semblance, and secondly solving the anisotropic diffusion equation for these tensors to derive an anisotropic smoothing filter.

Semblance creation

Calculating structural semblance is key to any structurally oriented smoother. Regular methods for calculating this semblance are based on semblance scanning, where multiple orientations are tested for semblance and orientation derived from the direction in which the maximum semblance is obtained. This scheme is general implemented in 2D along 2 orthogonal directions in order to derive a 3D field, and is limited to the radius over which a given structure appears locally planar. Semblance scanning involves a large number of computations, and can be computationally costly.

An alternative to planar semblance scanning is to compute structure tensors (Fehmers and Höcker, 2003) at every sample, which allow for curvi-planar structures to be estimated. Structure tensors are simply smoothed outer products of image gradients. The eigenvalues of these tensors give us a measure of isotropy, linearity, and planarity for that specific sample, as well as the direction of the features that we discovered.

These tensors are calculated in a one-hit 3D fashion making them not only able to handle more geologically realistic reflector shapes, but also able to be sensitive to directionality seen in the third dimension (time/depth slices), not sampled by traditional semblance scanning. Subtle stratigraphic features, as well as small faults are often not well sampled when viewed in inline and crossline directions separately, but with a structure tensor calculated in 3D, there is no such directional bias.

Anisotropic diffusion filtering

Once the structure tensors have been identified and the semblance derived, these could be used to smooth the data using any smoothing scheme However, now that we have information about the curvilinear nature of the events, we do not have to restrict ourselves to smoothing schemes designed around the lengths inherent in a locally planar assumption.

In order to maximise the use of the information present in the structure tensors we use a solution of the anisotropic diffusion equation shown below to calculate a diffusion operator at each image point (Fehmers and Höcker, 2003and Hale 2009).

$$g(\mathbf{x}) - \alpha\, \boldsymbol{\nabla} \cdot \mathbf{D}(\mathbf{x})\, \boldsymbol{\nabla}\, g(\mathbf{x}) = f(\mathbf{x}).$$

Where f(x) represents the input image, and g(x) the output smoothed image. D(x) is the smoothing tensor field, and the term α has been spun out from the tensor field to give the user a series of parameters to use to control the degree of smoothing, and relative weightings of different aspects of the tensor field.

This equation is solved using finite-difference approximations to obtain a sparse symmetric positive-semidefinite system of equations that we may solve efficiently using conjugate-gradient iterations.

METHOD AND RESULTS

To show a controlled use of the algorithm, we have produced a synthetic section containing a dipping structure (Figure 1)

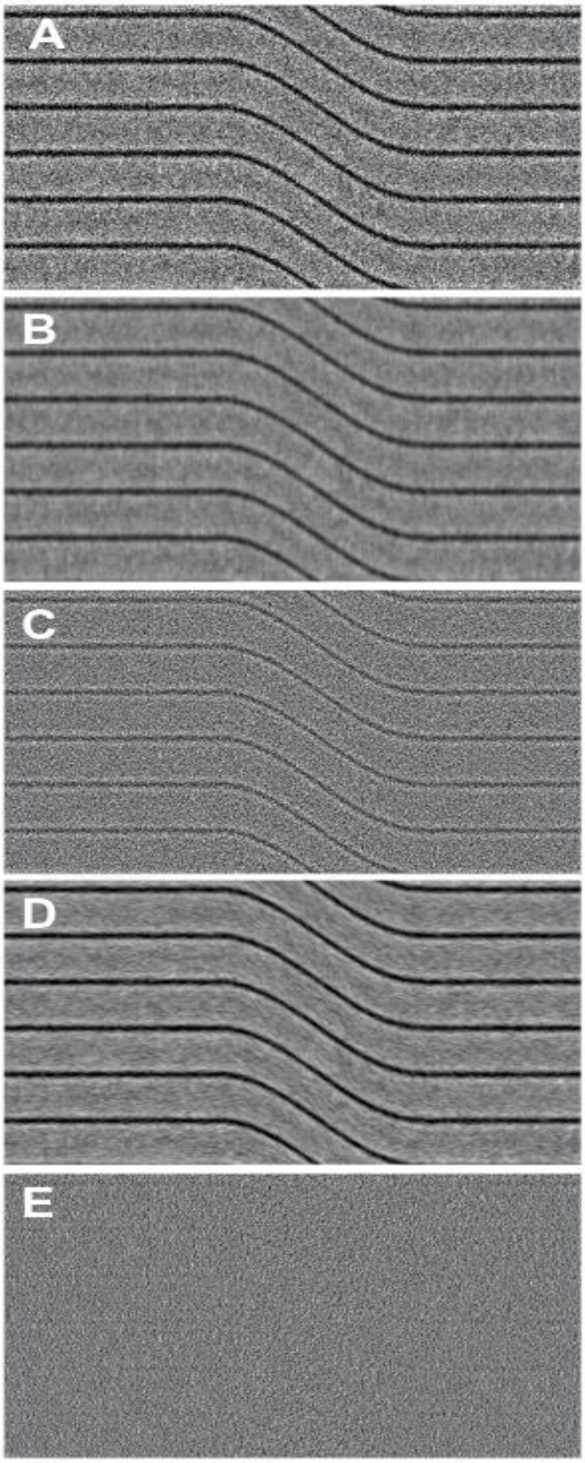

Figure 1. A synthetic example of dipping structure showing simple smoothing vs SOSE structural enhancement

(A) Synthetic structure with added noise,

(B) Result using a simple smoother ,

(C) Difference between A and B,

(D) Result using SOSE,

(E) Difference plot between A and D

Note the lack of primary structure in the difference plot from SOSE

Random noise was then added to the section and smoothing performed on the data using both a conventional smoother, and Structure Oriented Signal Enhancement (SOSE). Difference plots showing what is removed from the section are also shown (figures 1c and 1e). While a similar level of noise is removed using both methods, the simple smoothing also removes significant primary, and leaves the image looking blurred, whereas the SOSE result leaves the primary almost entirely intact.

Figure 2 shows images before and after the SOSE process on some data examples from the Taranaki Basin in New Zealand, courtesy of Loyz Energy. The structural continuity and ease of interpretation is much enhanced with the application of SOSE, especially in the thrusted region towards the top of the image, and the noise level in the deeper part of the section is also much reduced.

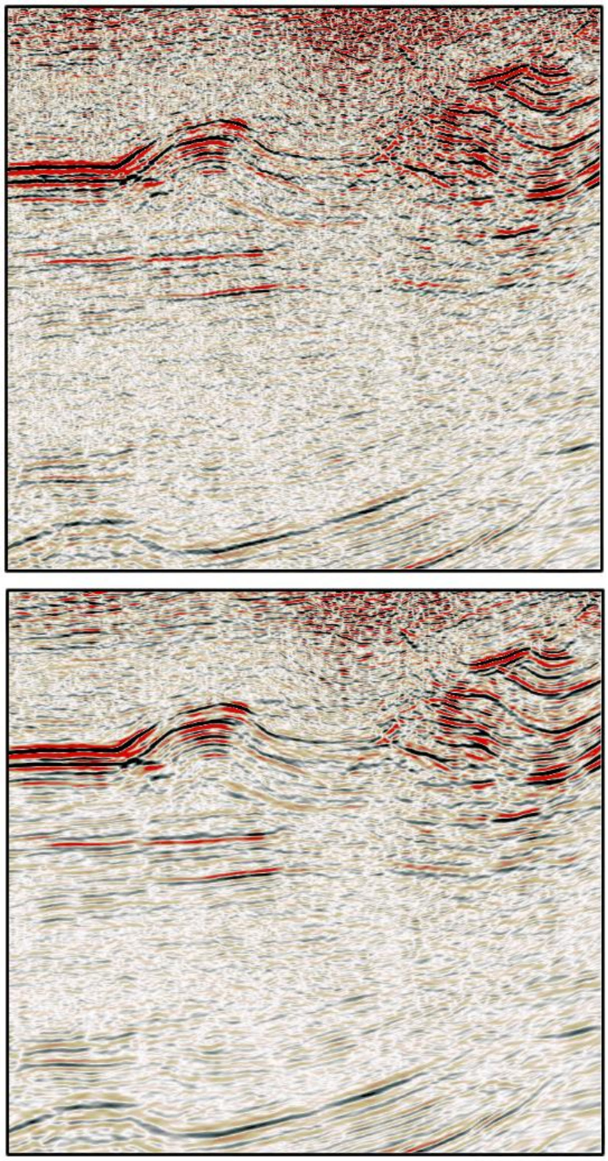

Figure 2. Stack showing above the input to the process, and below the SOSE result (Image Courtesy of Loyz Energy)

The use of SOSE is not limited to use on post-stack data. It can be applied in any number of required dimensions, although most practical applications involve 3. There is also no requirement for the diffusion filtering to be performed on the same data volume that the structural tensors are calculated on. This allows for a full offset stack to be used for calculating the tensors, but applying the diffusion. filters pre-stack on offset planes, in order to reduce the possibility of introducing inconsistencies across offsets.

By varying the degree of smoothing with frequency, SOSE can also be used to help enhance bandwidth.

Figure 3 shows the effects of a stack driven offset plane SOSE as seen on gathers.

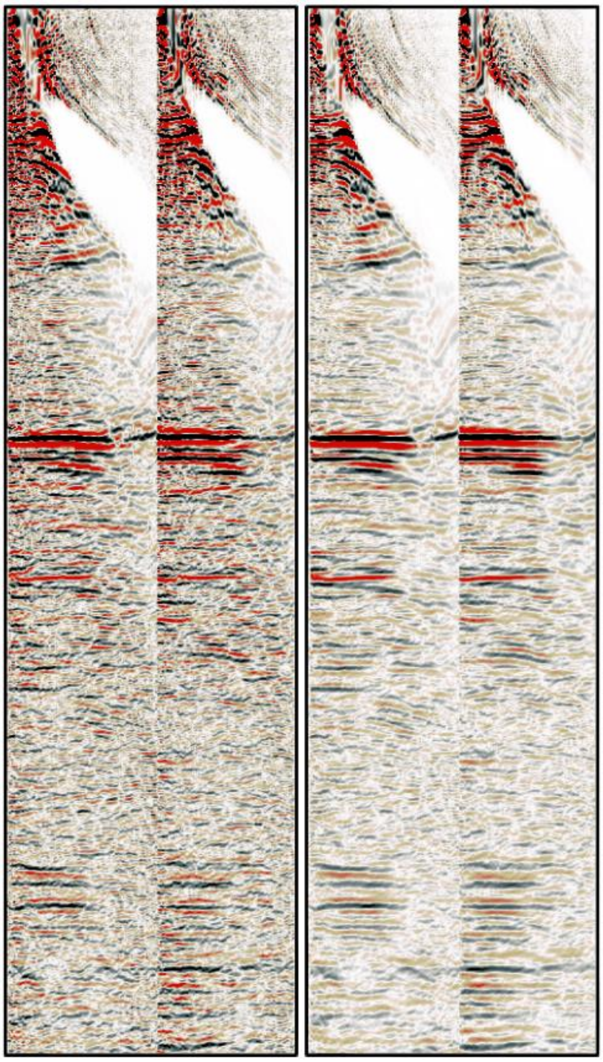

Figure 3. Gathers showing the input data on the left, and on the right the result of SOSE performed on offset planes (Image Courtesy of Loyz Energy)

If gather volumes are used as input, then the SOSE process will create datasets better suited to the auto-picking of residual move-out, and hence forms a new addition to the toolbox of depth imagers.

The tensors created can even be used to smooth other attributes, aside from seismic amplitudes. For example, slightly different parametrisation of the diffusion operators can enable the process to be used to guide velocity smoothing such that a structurally meaningful velocity model can be derived very quickly from a stack and a few well profiles, without the need for a time intensive first pass of manual velocity picking based on gather move-out. Figure 4 shows an example of this process performed using a synthetic dataset containing both structure and a fault. Using a single velocity function (on right hand side of the image), a structurally consistent velocity field is created that honours both the fault and the structure closely.

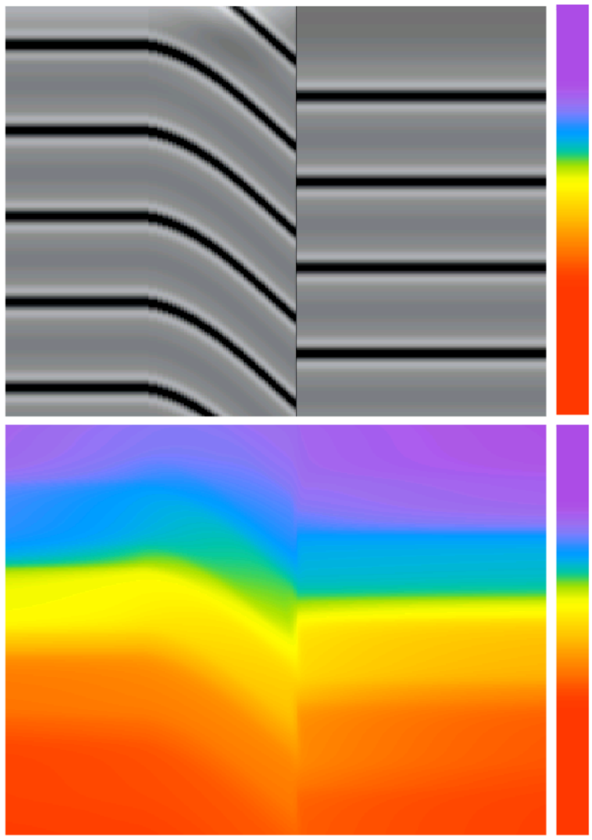

Figure 4. Above, the synthetic stack used to derive the structural tensors. Beside the stack is the single velocity function used to generate the lower image, which is the result of the SOSE process parameterised to create an initial velocity model from sparse information.

While the results of SOSE can sometimes be very impressive, it should be remembered that it is an enhancement tool only, and cannot produce something from nothing. A good and experienced interpreter could likely obtain the same interpreted horizons from the input data as they would from the SOSE data, however the advantage is that interpreting those horizons should be much quicker and easier. To demonstrate this, a real world 3D stack volume of a thousand or so square kilometres was used, both with and without SOSE. These stacks were loaded into a widely available 3rd party interpretation program with a 3D auto-tracker. A mid-to-deep level horizon was chosen, which suffered from residual noise, migration swing related noise and was cut by several faults. Using the input stack that had been enhanced using SOSE, the horizon could be tracked using only 3 seed points, and a total cpu time for propagation of 214 seconds. In contrast, tracking the same event on the input stack required an additional 5 seed points to be picked, and took a total of 893 seconds of cpu time to propagate. With a propagation time of 3.5 minutes, compared to 15, and less manual intervention, it can be seen that using a stack treated with SOSE can speed up interpretation times significantly

On stack data with reduced noise content, interpreters can create maps faster, and with added confidence. When presenting these maps, along with the seismic to managers, or other decision makers, there is much less need for a new person to "get their eye in" before understanding the map and the data.

CONCLUSIONS

SOSE provides a new method for signal enhancement and noise attenuation that avoids many of the pitfalls of algorithms designed for the same purpose. The 3D structure tensor derivation allows for a smoothing scheme to be applied more accurately due to, firstly its ability to identify curved surfaces correctly, and secondly its ability to identify structure only apparent on time/depth slices.

The smoothing is able to adapt seamlessly to variations in the orientation and coherence of the image features. This gives automatic smoothing that is aware of reflector dip, and stops at faults.

The potential of this method for the enhancement of gathers, and other attributes is only just touched on here, but the applications of this method could be as diverse as the imaginations of the people who choose to use it.

As both an aid to interpretation, and a velocity model building tool, structurally oriented signal enhancement can help to speed up the seismic cycle.

ACKNOWLEDGMENTS

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