FOCUS ARTICLE

Coordinated by Satinder Chopra

Seismic discontinuity attributes and Sobel filtering

Satinder Chopra*, Rajive Kumar[Δ] and Kurt J. Marfurt[†]

*ARCIS SEISMIC SOLUTIONS, CALGARY; [Δ]KUWAIT OIL COMPANY, KUWAIT;
[†]THE UNIVERSITY OF OKLAHOMA, NORMAN

Mapping geologic edges such as faults or channel levees forms a critical component in the interpretation on 3D seismic volumes. While the more prominent features can often be easily visualized, smaller features critical to understanding the structural and depositional environment can be easily overlooked. Careful manual interpretation of such features is both tedious and time consuming. Seismic discontinuity attributes that enhance edges not only accelerate the interpretation process, they also provide a quantitative measure of just how significant a given discontinuity is in relation to others. Since seismic attributes extract all subtle features in the seismic amplitude volume, preconditioning the data to enhance geologic edges and minimize edges due to acquisition and processing is critical to the analysis.

In the present work, we find the application of a Sobel filter to energy-ratio coherence volumes significantly sharpens faults and channel edges of interest. We demonstrate this simple cascaded workflow with examples from Kuwait and Canada, where one of the objectives is to provide improved attributes for subsequent automatic fault plane extraction.

Introduction

The preconditioning of seismic data is essential for the generation of seismic attributes. Its importance has gradually been realized over the last decade and has reached a stage where preconditioning of the data has now become a regular practice. A wide variety of preprocessing steps are run on the seismic data to ensure an effective performance of the discontinuity attributes. These range from suppression of spatial noise (random as well as coherent), through approximating missing data that give rise to acquisition footprint through 5D interpolation, to running structure-oriented edge-preserving filtering (Chopra and Marfurt, 2008, 2013).

Sobel filters are one of many filters that are commonly distributed when you purchase a digital camera. For a flat photograph containing pixels of amplitude a aligned along the x and y axes, the classical Sobel-filtered image, s, is simply

$$s = \left[\left(\frac{\partial a}{\partial x}\right)^2 + \left(\frac{\partial a}{\partial y}\right)^2\right]^{1/2} \tag{1}$$

Unlike a photograph, seismic images have a third dimension. In the presence of structural dip, applying equation (1) to a seismic amplitude time slice would result in strong changes as the wavelet varies laterally from peak to trough, overprinting lateral changes in reflectivity of interest. One way to address this issue is to normalize equation (1) by a measure of the RMS amplitude within the same seismic window. Luo et al. (1996) developed the first such Sobel filter based similarity (or coherence) algorithm. Subsequent Sobel filter based coherence similarity algorithms followed advances in semblance based coherence and are routinely computed along structural dip.

In spite of the "structural leakage" associated with computation without regard to dip, Aqrawi and Boe (2011) show some remarkable images using a simple 3D Sobel filter

$$s = \left[\left(\frac{\partial a}{\partial x}\right)^2 + \left(\frac{\partial a}{\partial y}\right)^2 + \left(\frac{\partial a}{\partial z}\right)^2\right]^{1/2} \tag{2}$$

that is balanced by the amplitude of the data within the analysis window.

Recent interest in structure-oriented filtering has resulted in a reexamination of this basic filter. Rather than "smooth" along dip and azimuth, Al-Dossary and Al-Garni (2013) designed a structure-oriented Sobel filter wherein the derivatives are computed in nine non-orthogonal directions, ξ. The output "edge" attribute is the absolute value of the largest derivative of the nine.

$$s = \underset{\xi}{MAX}\left|\frac{\partial a}{\partial \xi}\right| \tag{3}$$

Unlike Luo et al.'s (1996) Sobel-filter coherence algorithm, equations 1-3 are not normalized by the RMS amplitude of the trace and thus provide a stronger response to an edge cutting a high-amplitude reflector than an edge cutting a low-amplitude reflector.

Application

We apply these attributes on a 3D seismic volume from south-east Kuwait. At the level of faulted and fractured Ratawi shale (~1300 ms), we display time slices through the input seismic amplitude volume (Figure 1a), and the results of the Sobel filter (Figure 1b) and energy-ratio coherence (Figure 1c), both computed from the seismic amplitude volume. Notice that the Sobel filter time slice looks very similar to the

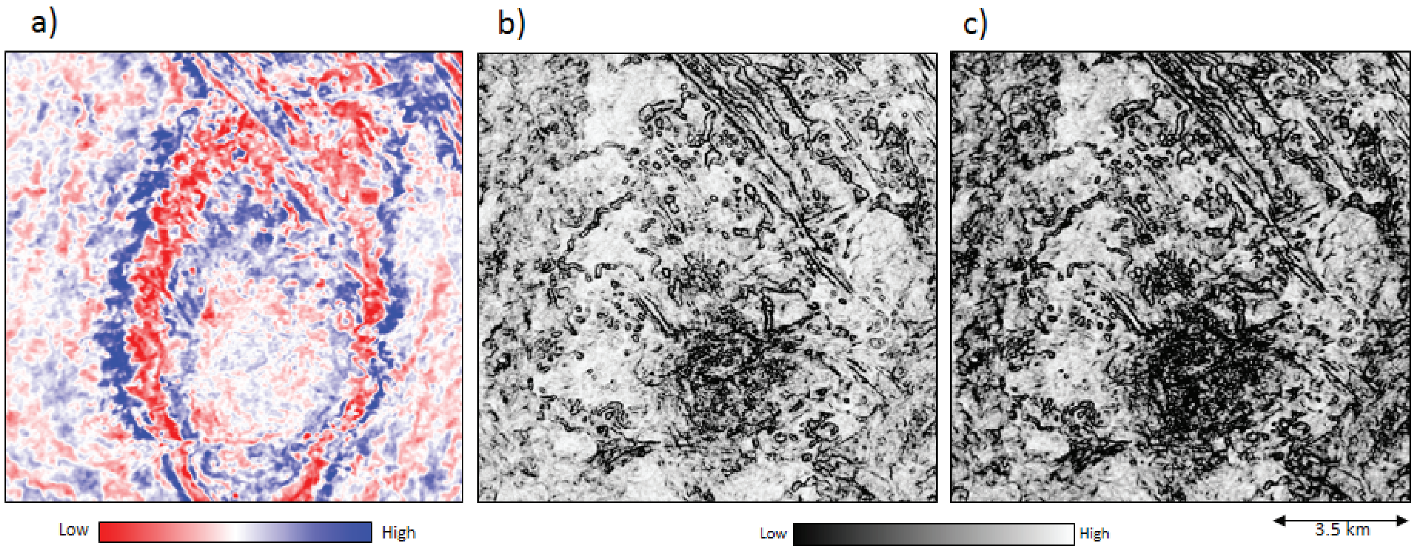

Figure 1. Time slices at *t*=1300 ms through (a) input seismic amplitude, (b) Sobel-filter similarity and (c) energy ratio coherence volumes. The two attribute images are quite similar at this level.

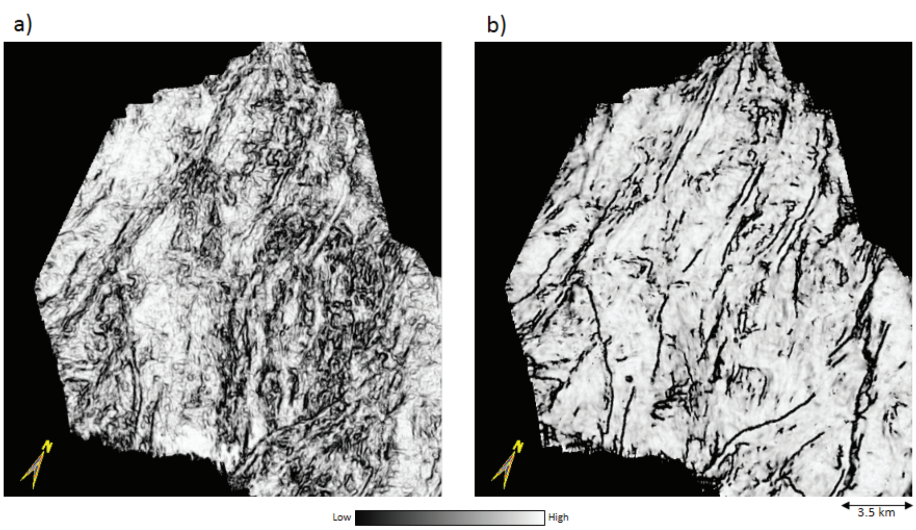

Figure 2. Stratal slices from a horizon picked close to 1200 ms through (a) Sobel filter similarity and (b) energy ratio coherence volumes. These two images are quite different, with the Sobel filter similarity showing more stratigraphic features and the energy ratio coherence providing sharper fault images.

common semblance-based coherence, and shows the faults and large fractures clearly, which are not so clear on the seismic time slice. Barnes (2007) recognized that many of our attributes can often be redundant, such as shown in this Figure. Sobel filter and semblance-based coherence algorithms are sensitive to lateral changes in amplitude *and* waveform. In contrast, energy-ratio coherence is only sensitive to lateral changes in waveform. If our stratigraphic features of interest fall below thin-bed tuning, the waveform no longer changes, such that we see more "features" in Figure 1b. In contrast, the lateral resolution of Figure 1c is somewhat sharper. The differences are clearly seen in Figure 2, a stratal slice through a different survey. Here subtle stratigraphic features appear stronger using the Sobel filter while the larger faults and fractures are much clearer on energy-ratio coherence. In this image, the two attributes are no longer redundant, but complementary.

Ant tracking method is frequently used by interpreters to automatically extract faults from discontinuity attribute volumes. Aqrawi and Boe (2011) demonstrated that the application of ant tracking on Sobel-filter output yielded a better fault interpretation than on a similar fault interpretation carried out on a variance attribute. Having seen the Sobel-filter displays in Figures 1 and 2, this is not surprising. However, given the sharper fault delineation using energy-ratio coherence we expect the ant tracking to work even better on these images.

Cascaded Filters

Since the classical Sobel filter is routinely used in sharpening photographic images, we hypothesize that we can do the same by applying it to edge-sensitive seismic attributes such as coherence. We can achieve this goal by simply cascading the two attribute calculations. First we apply energy-ratio coherence to the original seismic amplitude to obtain good quality fault and channel edges. We then take the output coherence image and use it as input to a Sobel-filter run

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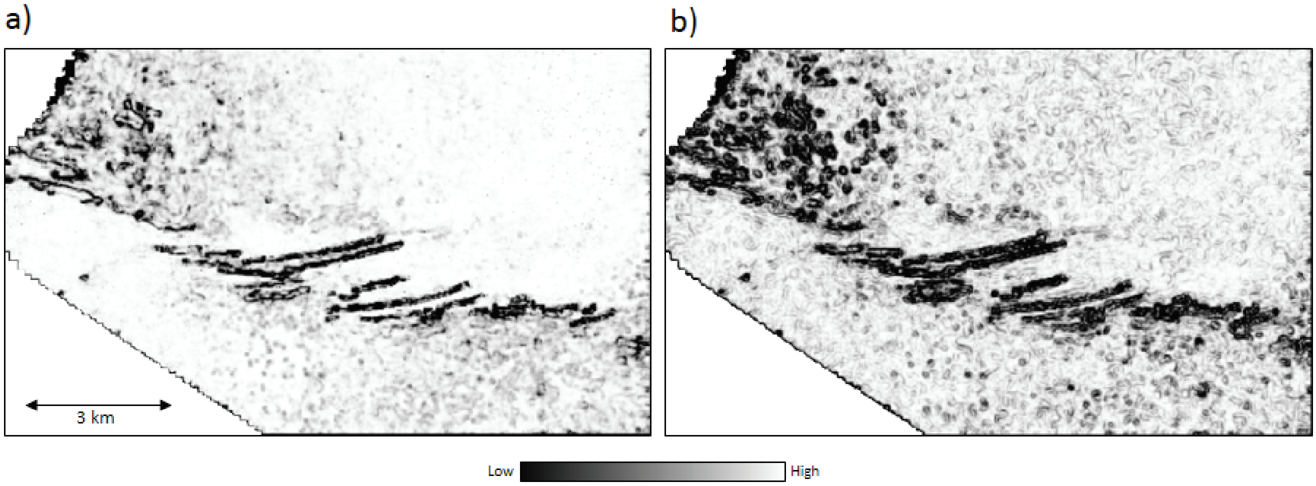

Figure 3. Time slices at *t*=1174 ms through (a) an energy ratio coherence volume computed from the original seismic amplitude and (b) Sobel filter similarity applied to the coherence volume shown in (a). Notice the clarity with which the edges of en echelon faults seen in (a) are seen in (b).

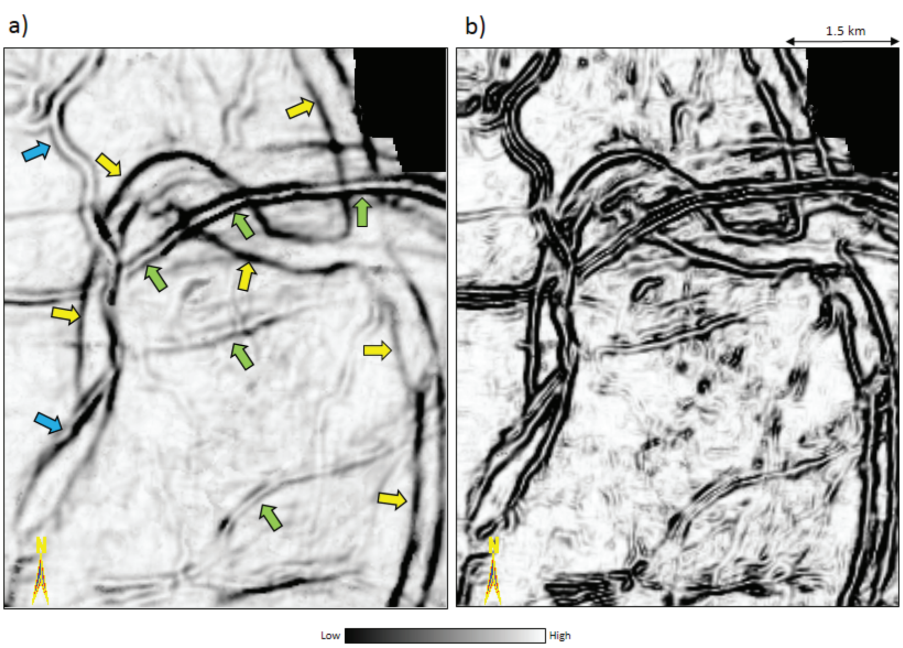

Figure 4. Stratal slices at a level close to a horizon picked at *t*=1020 ms through (a) energy ratio coherence volume computed from the seismic amplitude, and (b) Sobel-filter similarity computed from the coherence volume shown in (a). Notice the clarity with which the edges of channels seen in (a) are seen in (b).

along structural dip, thereby further sharpening any anomalies. This workflow can be used to more rapidly delineate channels, or to automatically detect of faults using modern image processing tools.

The data going into coherence computation are usually preconditioned using structure-oriented filtering, reducing the risk of enhancing aligned noise showing up as edges. In Figure 3 we show a comparison of time slices from a 3D seismic volume from central Alberta. Figure 3a shows a time slice through a coherence volume calculated using the energy ratio algorithm where we see a suite of en echelon faults. As this display is at the level of a coherent reflector, we see high coherence everywhere except at the location of the faults. Figure 3b, shows the result of applying a Sobel- filter to the coherence volume. Notice the overall clarity with which the faults now show up as well as some of the other events around them.

In Figure 4 we show a similar comparison of coherence run on a 3D seismic volume from south central Alberta, Canada but now with the objective of illuminating Mannville channels that traverse the display. In addition to the two main channels indicated with yellow arrows, there are some thin channels indicated by green and blue arrows that crisscross the main channels at many places. In Figure 3b we show the result of applying the Sobel filter to the coherence volume. Notice the crisp definition of the channels on this display. Besides the main channels many of the narrower channels are seen clearly. Invariably, the definition of all the channels on the display is very prominent.

Such convincing displays suggest that the application of the Sobel filter to energy-ratio coherence used in the present exercise should help provide clear definition of many features of interest.

Automatic fault extraction software packages such as ant tracking operate on discontinuity volumes and provide an output volume consisting of fault planes. The quality of the results is dependent to a large extent on the quality of the discontinuity volume used. Needless to mention, a coherence volume with poorly-imaged features may not resolve the fault detail well. We suggest that coherence volumes sharpened by Sobel-filter application will provide improved input to such operations resulting in detailed, accurate fault plane surfaces.

Conclusions

Just as in photographic applications, the Sobel filter provides an excellent means of enhancing edges. Rather than apply the Sobel filter to the original seismic amplitude, we have applied it to coherence, resulting in sharpened images. The application of Sobel filters to coherence volumes enhances discontinuity features such as faults and channels, resulting in crisper, more focused images. We believe such images provide superior input to modern automated fault identification and object extraction software application as well as in visualizing the channel features clearly. Such applications would definitely help with the geologic understanding of the subsurface area of interest. A good and accurate extraction of the fault network system could serve as a useful input for geocellular modeling or for planning of potential drilling targets.

Similar applications with other discontinuity attributes could also be explored.

Acknowledgements

We wish to thank Arcis Seismic Solutions, TGS for encouraging this work and for permission to present these results. The authors extend sincere thanks to the Ministry of Oil, State of Kuwait and the Kuwait Oil Company for granting permission to publish this work.

Satinder Chopra

Biography can be viewed on page 33.

Rajive Kumar

received his MSc degree in Physics from Patna University, Patna, India and M.Phil. degree in Physics from Delhi University, New Delhi, India. He also has M.B.A. degree from IGNOU, New Delhi, India. He joined the Oil and Natural Gas Corporation Limited (ONGC), National Oil Company of India in 1984 and served there till the end of year 2006. In January 2007 he joined Kuwait Oil Company (KOC), Kuwait. Currently, he is a Senior Geophysicist in the Research & Technology Group of KOC. Rajive started his carrier as seismic data processor and has done extensive special seismic data processing for reservoir characterisation. He has carried out a number of integrated projects involving seismic data interpretation, reservoir characterisation, seismic facies analysis and reservoir modelling. Rajive has carried out integrated fracture study and pore pressure study for the Minagish field of Kuwait. He is also experienced in assessing the risk and uncertainty of generated prospects, developing regional play concepts and creating exploration and development strategies. For more than 7 years, Rajive has been working in the Research & Technology Group of KOC, addressing the challenges of imaging, issues of fractured reservoirs, reservoir monitoring, shale gas development, etc. by inducting and managing the appropriate technology solutions. He has an outstanding track record of keeping updated on recent advancements in geophysical methods and technologies and extensively utilizes them in projects under study. He has received several awards at ONGC. He is a member of SEG and SPG, India.

Kurt J. Marfurt

joined the University of Oklahoma in 2007 where he serves as the Frank and Henrietta Schultz Professor of Geophysics within the ConocoPhillips School of Geology and Geophysics. Marfurt's primary research interest is in the development and calibration of new seismic attributes to aid in seismic processing, seismic interpretation, and reservoir characterization. Recent work has focused on applying coherence, spectral decomposition, structure oriented filtering, and volumetric curvature to mapping fractures and karst as well as attributed assisted processing. Marfurt earned a Ph.D. in applied geophysics at Columbia University's Henry Krumb School of Mines in New York in 1978. He worked 20 years in a wide range of research projects at Amoco's Tulsa Research Center after which he joined the University of Houston for 8 years as a Professor of Geophysics and the Director of the Center for Applied Geosciences and Energy (CAGE). He has received best paper (for coherence) best presentation (for seismic modeling) and as a coauthor best poster (for curvature) awards from the SEG and served as instructor of the SEG/EAGE Distinguished Instructor Short Course in 2006 (on seismic attributes). Most recently he received the Honorary Membership award from the SEG. He has been the associate editor for 'Geophysics' for over 18 years and is a member of many professional societies. In addition to teaching and research duties at OU, Marfurt leads short courses on attributes for the SEG and AAPG.