3D Seismic Volume Rendering

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Abstract

Volume Visualization has become a very useful tool for modern seismic interpretation. The main purpose of this technique is to obtain an overview of structural and stratigraphic features. Most of the currently available software for 3D seismic visualization employs the same rendering equations used in traditional medical imaging. However, the nature of seismic data demands a specialized implementation of the rendering pipeline. Traditional medical methods are designed to visualize isovalue contours that represent boundary surfaces within three-dimensional sampled scalar fields. In this context, the use of local gradient information to estimate surface normal at each voxel, during shading calculations, is a reasonable approach. This technique yields excellent results for mathematical functions and medical data. In 3D seismic data, however, the illumination of structural and stratigraphic features cannot be obtained with simple isovalue contour and gradient estimations. In this paper, we discuss the necessary modifications to the shading and classification steps of traditional algorithms. Our method combines 3D seismic data with a derived seismic attribute to better adapt the display of seismic events. The paper also presents results for both synthetic and real seismic data to validate our proposal.

Introduction

The display of shaded iso-surfaces is the most natural approach to visualize three-dimensional sampled scalar fields, or volume data for short. A technique to render iso-surfaces from volume data is to firstly extract a polygonal approximation of the surface that can be rendered using standard algorithms. This technique is known as surface extraction (Lorensen *et al*, 1987). Another technique, known as direct volume rendering (DVR), is to define transfer functions, which assign color and opacity to each voxel value; all voxels are shaded and then composed in the viewing direction to form the final image (Levoy, 1990; Lacroute *et al*, 1994; Meissner *et al*, 1999).

In modern seismic interpretation, these techniques have been employed as basic tools to view structural and stratigraphic features from 3D seismic data. Direct volume rendering is particularly interesting for previewing seismic datasets. Using DVR the user can interactively manipulate the transfer function to control the iso-surface displayed. There are, however, important differences between seismic and medical data. In a previous paper (Gerhardt *et al*, 2001) we have discussed that seismic horizons are not iso-surfaces and proposed the use of two-dimensional transfer functions to properly map the geometry of seismic structures. Other researchers have also discussed the problem and proposed similar solutions (Kniss, 2001).

Given that seismic horizons are not iso-surfaces, the shading equations used in classical volume rendering algorithms are also incorrect. Shading is an important attribute for the correct visualization of a three-dimensional seismic structure. Without shading our spatial perception is seriously challenged.

The present paper proposes the necessary modifications in direct volume rendering algorithms to perform correct shading calculations at seismic horizons. In the next two sections we attempt to briefly discuss the nature of seismic data emphasizing the need for an approach that is not based in iso-surface assumptions and justifying our proposal for 2D transfer functions. In the two subsequent sections we discuss the shading equation and focus in a proper estimation of the seismic horizon normal. Finally examples are shown to validate our discussion and the proposed solution.

3D seismic data

The seismic data acquisition process is based on the seismic reflection phenomena. Disturbances created by seismic energy sources propagate through the earth. At interfaces between geological layers, part of the energy is refracted and part is reflected and then measured along time at surface receivers (Robinson *et al*, 1980). Deeper reflectors have greater arrival times. This process is repeated, until the survey area is covered, and all the data is grouped and processed. Considering that all undesirable effects are eliminated in the processing phase, the resulting data to be interpreted is a 3D regular sampled scalar function.

$$X(t, x, y) \in \Re \tag{1}$$

In (1) x and y are spatial variables and t is commonly time. There are methods in seismic processing that convert the time axis into depth. Given a spatial position (x0, y0), the one-dimensional time-dependant function X(t, x0, y0) is called a seismic trace. The value at each sample, called seismic amplitude, is proportional to the

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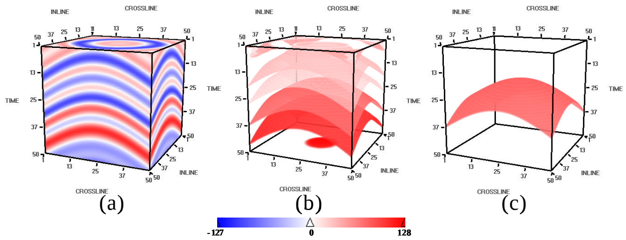
amount of energy reflected at the interface, which is a function of the difference of acoustic impedance between the adjacent geological layers. An important task in seismic interpretation consists in identifying a seismic horizon, following peaks (or troughs or zero-crossings) along neighboring traces. Despite the existence of some situations where horizons so calculated fail to locate reflectors, this is a good way to identify reflector attitude. Due to lateral geological variations, the seismic amplitude along a horizon is not necessarily an iso-surface of the amplitude data.

Classification

As mentioned in the previous section, the amplitude value may vary along the seismic horizon. It induces us to use a range of values instead of a single value in order to isolate a horizon. But as was discussed in (Gerhardt *et al*, 2001), the oscillatory nature of the seismic data raises: we cannot distinguish a horizon with intermediate amplitude values from one with higher amplitude values by just selecting amplitude intervals. This is due to the fact that there are samples with intermediate amplitude values surrounding the horizon with higher amplitudes.

To overcome this problem we apply a two-dimensional transfer function depending on amplitude and instantaneous phase values. The instantaneous phase is a quantity computed from the seismic amplitude, trace by trace, which is the best indicator of lateral continuity. If we set opacity equal to one for samples with instantaneous phase near zero and equal to zero otherwise, we display only samples at peaks of amplitude values. We can now use amplitude values to distinguish the horizons. Figure 1(a) shows a synthetic seismic data that was obtained repeating and shifting a real seismic trace to form a dome. Figure 1(b) shows the data classified using the two-dimensional transfer function described above. Figures 1(c) shows a distinguished horizon with intermediate amplitude values.



(a) (b) (c)

Figure 1: (a) Synthetic dome; (b) Classified peaks; (c) Classified seismic horizon.

Discussion

Local Illumination models approximate the interaction between light and a point laying on a surface. One of the most used local illumination model is the Phong model (Hadwiger *et al*, 2002).

$$I_{Phong} = I_{ambient} + I_{diffuse} + I_{specular} \qquad (2)$$

$$I_{ambient} = k_a (\text{constant}) \qquad (3)$$

$$I_{diffuse} = I_p k_d < \vec{l}, \vec{n} > \qquad (4)$$

$$I_{specular} = I_p k_s < \vec{r}, \vec{n} >^n \qquad (5)$$

The evaluation of reflected light intensity at a point, using the Phong model, depends on the surface normal at that point. Within the context where the classified surface is an iso-surface, using the gradient of the scalar field is a reasonable approach and yields excellent results. But we have at least two problems computing normal vectors for seismic data this way. First, in the case of a horizon with amplitude variation, the gradient turns in order to have a component along the horizon, providing wrong orientation information. Second, by defining a horizon by the peaks or troughs, the time derivative tends to zero near the horizon, which leads to poor orientation information. This occurs even if the horizon is an iso-surface.

Surface normal estimation

As we mentioned in past sections, the features of interest, as seismic horizons, are not iso-surfaces of amplitude values. Instantaneous phase values, calculated at each trace of the seismic 3D data, are 0^o at peaks and 180^o at troughs. We have used this fact at the classification step to isolate seismic horizons. We now propose to use the gradient of the instantaneous phase volume to estimate the local surface normal at each sample of the seismic volume.

The instantaneous phase gradient can be evaluated by first calculating the analytical signal to each trace. Given a seismic volume as in equation (1) we set

$$Y(t,x,y) = h(t) * X(t,x,y) \qquad (6)$$

$$Z = X + iY \qquad (7)$$

Y is the volume of Hilbert transforms of all traces in X and the complex volume Z are the analytical traces of X (Barnes, 1996), and h(t) here denotes the kernel of the Hilbert transform in time. The arguments of complex numbers in Z are

$$q(t,x,y) = \arg(Z(t,x,y)) = \tan^{-1}\left(\frac{Y(t,x,y)}{X(t,x,y)}\right) \qquad (8)$$

the instantaneous phase values. Finally we estimate the normal vector at seismic horizon surfaces using the gradient of the instantaneous phase 3D scalar field.

$$\vec{n} \cong \nabla q(t,x,y) \qquad (9)$$

Results

As can be seen in Figures 2 and 3, we have induced a radial amplitude variation to the same synthetic data shown at the Classification section. Figure 2(a) shows gradient vectors of seismic amplitude volume displayed as RGB values. In order to visualize the normal vector field we employed a color scheme that uses RGB values to represent vector coordinates. Specifically, $(B, R, G) = (v_t, v_x, v_y)$. Note that there is a spurious pattern at the image due to lateral variation of amplitude. Figure 2(b) shows gradient vectors of instantaneous phase volume evaluated using equation (9). Note the continuity of the image.

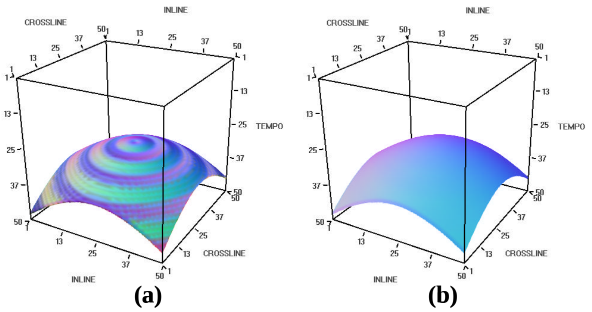


Figure 2: Normal vector visualization: (a) Gradient of amplitude components, (b) Gradient of instantaneous phase components.

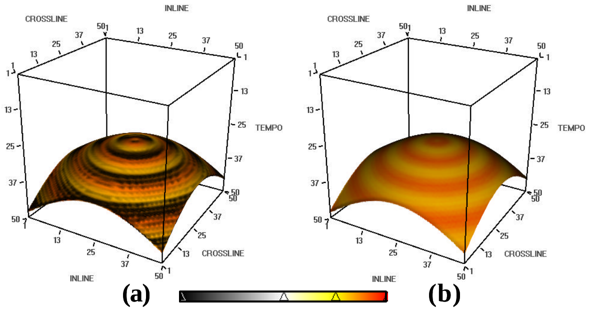


Figure 3: Amplitude visualization with illumination: (a) Traditional method, (b) Our method.

Figure 3 compares the images obtained by illuminating the data using: (a) traditional normal estimation; and (b) the proposed method. The vector field obtained by the gradient of seismic amplitudes is not normal to the horizon, while the gradient of instantaneous phase is.

Figure 4 shows a seismic horizon from a real 3D seismic dataset acquired at the Campos Basin, Brazil. We used a two-dimensional transfer function that assigns a constant cyan color and sets opacity to one only for voxels with instantaneous phase value near zero and intermediate to high amplitude values. The choice of a constant color is in order to better evaluate the shading step. In Figure 4(a) we evaluate only the ambient component of equation (2), in 4(b) only the diffuse component is calculated using our method and in 4c the traditional approach is used.

The target seismic horizon of Figure 5 is the seafloor of an offshore real data acquired at Campos Basin, Brazil. In this picture we defined a transfer function that assigns yellow to intermediate seismic amplitude values and red to high seismic amplitude values. With this color scheme we verify changes in amplitude values along the seismic horizon. Figure 5(a) was rendered using a traditional one-dimensional transfer function with opacity set to one for all amplitude values; the upper portion of the volume is white (near zero amplitude) due to water. Figure 5(b) was rendering considering only the first component of equation (3) (ambient light); Figure 5(c) was rendered considering only diffuse component of equation (3) and using our method of normal vector estimation using gradient of instantaneous phase attribute. Figure 5(d) the same as 5(c) but using the traditional approach of gradient estimation.

These pictures were rendered using a 3D texture-based volume rendering algorithm using NVIDIA's OpenGL extensions to implement two-dimensional transfer function and pixel shading engine to perform shading calculations (Hadwiger *et al*, 2002).

Conclusion

Since some interesting features such as seismic horizons are not iso-surfaces, the nature of seismic data volumes demands modifications in the direct volume rendering pipeline. In order to distinguish the horizons we used a two-dimensional transfer function depending on amplitude

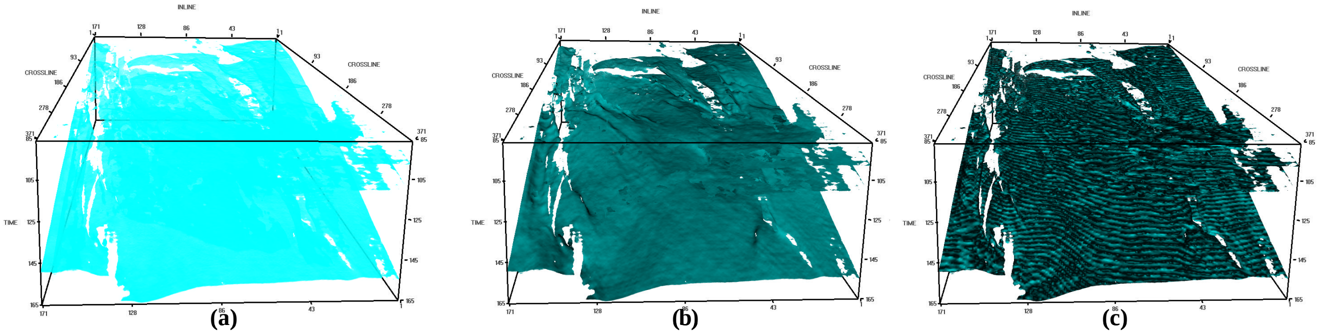
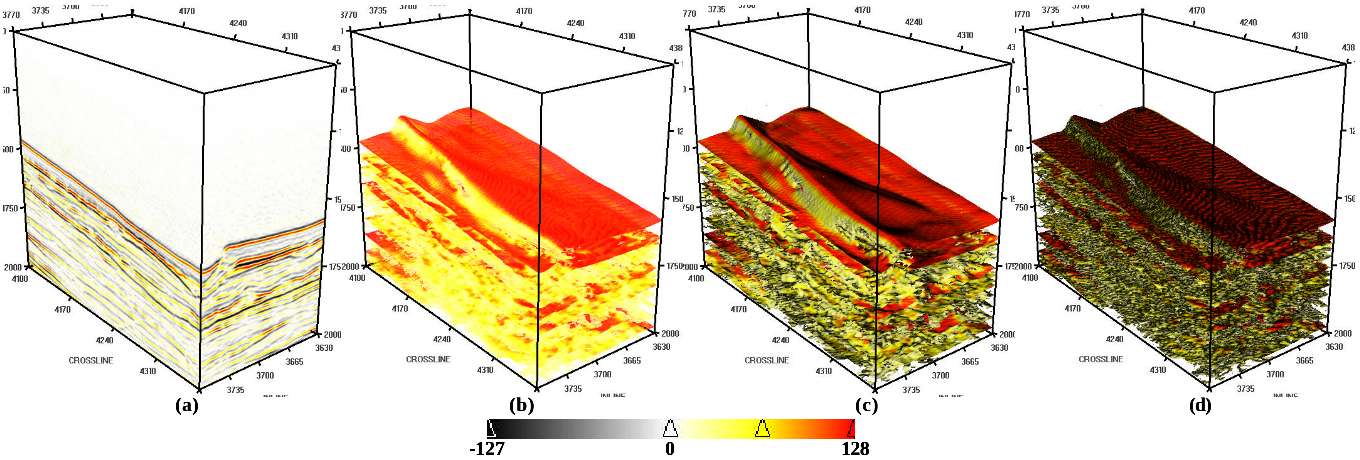


Figure 4: Real seismic data: (a) Ambient light;(b) our method; (c) traditional approach.

and instantaneous phase value. The use of the gradient of the instantaneous phase to estimate the local surface normal, instead of gradient of amplitudes, has yielded good results for both synthetic and real seismic data.

There is an approach that combines reflection dip and azimuth attributes through the Phong model. This technique produces the Shaded relief seismic attribute, which is viewed as time slices or attribute maps (Barnes, 2002). The main difference between this technique and our approach is that Shaded relief is just a derived dataset from the original seismic data, and is not used in volume rendering pipeline.



(a) (b) (c) (d)

Figure 5: Real offshore data: (a) one-dimensional transfer function; (b) Ambient light; (c) our method; (d) traditional approach.

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