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Generating Watertight Isosurfaces from 3D Seismic Data

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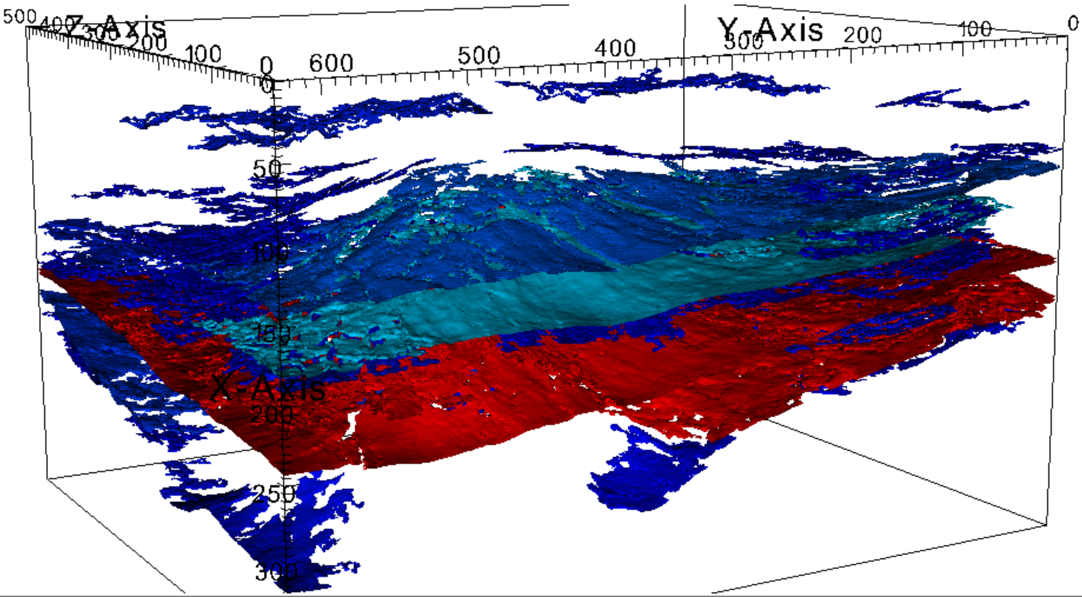

Abstract

Seismic data visualisation and analysis is an area of research interest for a lot of commercial and academic disciplines. It enables the geoscientists to understand structures underneath the earth. It is an important step in building subsurface geological models to identify hydrocarbon reservoirs and running geological simulations. Good quality watertight surface meshes are required for constructing these models for accurate identification and extraction of strata/horizons that contain carbon deposits such as fuel and gas. This research demonstrates extracting watertight geometric surfaces from 3D seismic volumes to improve horizon identification and extraction. Isosurfaces and Fiber Surfaces are proposed for extracting horizons from seismic data. Initial tests with isosurfaces have been conducted and further experiments using fiber furfaces are underway as next direction and discussed in sections 4.5 and 4.6.

Categories and Subject Descriptors (according to ACM CCS): 1.3.3 [Computer Graphics]: Volume Visualisation —Isosurfaces Watertight Meshes Seismic Volumes Seismic Horizon Surface Handles

1. Introduction

3D visualisation has played a vital role in improving the quality of data analysis and the decision making process, especially in medical and engineering fields. Seismic visualization is a method for seismic data interpretation in which a geophysicist can view and conceptualise the subsurface features in three-dimensional space. It is an important step in building subsurface 3D geological models, which are used by geophysicists to identify fossil fuel reservoirs and create seismic simulations. A good seismic interpretation helps to drill oil wells at exact locations avoiding the waste of valuable resources. It is also used in monitoring the underneath the earth changes during gas or oil excavation via seismic simulations.

The earth subsurface consists of layers of various materials; the boundary surface or the interface between two layers is called a

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horizon. These horizons are extremely important for building 3D geological models of the explored area. Horizons have usually fractures in them called faults. These faults affect horizon continuity and identified as discontinuities in horizons and lead to non-uniform meshes as shown in figure 1.

However, identifying and interpreting seismic features and horizons is a nontrivial task because of dense nature and size of the data, presence of noise and the high degree of complexity involved in the manipulation of 3D features. Moreover, obtaining uniform input meshes is also very difficult due to the faults in horizons. Available commercial packages such as Petrel [Sch] for seismic

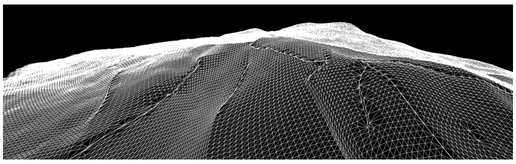


Figure 1: *Non uniform mesh due to faults*

data analysis use conventional seismic interpretation method using 2D seismic maps (images) of 3D volume. In this method user specified data slices are displayed and analysed. The method allows users to specify seeds for horizon location per slice. After seeding, points and locations are extracted and a mesh is created using non-trivial stitching method in which extracted points from slices are stitched using triangles. A limitation is that these geological modelling packages do not generate uniform watertight meshed geometric surfaces. Watertight surfaces are necessary for constructing 3D geological models because the hydrocarbons are trapped in horizons and these horizons must be naturally watertight in order to contain the gas and fuel deposits.

Issues with the commercial packages can be summarised as:

- Seeding or steering is required from a user for horizon propagation algorithms.
- Uniform and watertight meshing is not guaranteed.
- Mesh repairing is required and it usually introduces artefacts in surfaces.
- Scaling is an issue for large datasets.
- A commercial software is not easily extensible.
- Adding tailored functions is costly.

As mentioned earlier, the fault planes introduce discontinuities in the horizons, the issue is that there must be interconnectivity between faults and the horizons in order to interpret a correct physical interaction between a fault plane and the surface to lead to a watertight mesh. Note that building a 3D geological model with non-watertight meshed geometries may produce inaccurate results in seismic simulations because horizons are naturally watertight as discussed above.

The non-watertight surfaces extracted from commercial packages are repaired using intermediate mesh repairing algorithms. Problem with these algorithms is that they may require time intensive manual manipulation procedures and usually introduce artefacts in the surfaces which prevent successful meshing and decrease seismic simulation accuracy.

2. Seismic Technologies

Seismic volume is an image interpretation of the earth, below the surface of the ground. Underground earth has layers of different types of rock, mineral deposits and fluids in between these rocks. Seismic volume shows formation of these underground layers of rocks and fluids.

2.1. Data Acquisition

Seismic data is obtained by setting up lines of sensors across the area of interest and taking measurements along the way at intervals. The data is collected by recording the multiple reflections of acoustic waves sent towards the underground structures as shown in Figure 2.

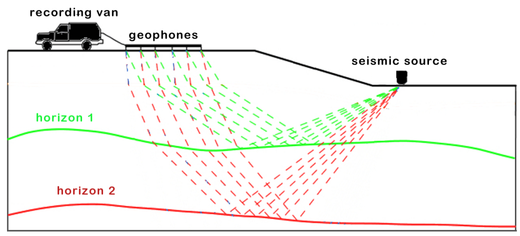


Figure 2: *Seismic Data Acquisition*

This builds up cross-sections of earth in the form of 2D slices similar to CT or MRI data.

2.2. Seismic Gather

A seismic gather is in fact a row of sensors that records the amplitude of reflected acoustic waves at different time intervals. A gather is a volumetric data slice as shown in Figure 3.

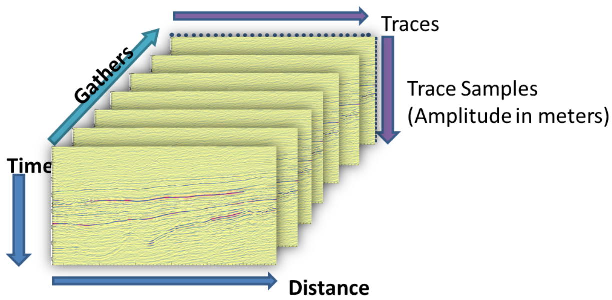


Figure 3: *Seismic volume*

2.3. Seismic Trace

A seismic trace refers to recorded sound wave reflections at different time intervals. These traces are used to fill 3D grids with amplitude values, which eventually become a seismic volume.

3. Literature

In general most work is done in line of conventional interpretation methods using 2D seismic maps and in the volume visualisation methods that produce 3D seismic perspective as discussed in Section 1. The available commercial packages such as Petrel [Sch] are more focused on the similar route..

In the past decade or so, work has been produced in the direction of horizon extraction from seismic volumes [PB05]. Majority of this work is directed at semi-automatic identification for horizons [CLB05]. Semi-automatic methods require an intensive and time consuming user interaction because these algorithms require steering or seed from user for interpreting horizons.

There have been fully automatic voxel based approaches proposed for horizon interpretation as in [BGD*06] [PGT*08] [FP04] [PRB*10], these approaches are based on the propagation algorithms in which after obtaining an initial seed, surface grows through similar adjacent voxels.

Recent work also reports on visualisation and surface extraction from large datasets in order to optimise the computation time and memory issues. Such work is presented in [DJG*08] [GGJ*10] where a small portion of data (called a brick) is loaded in the memory at a time and processed. The problem is that, the surfaces may propagate outside the brick or propagate inside from the adjacent brick. This requires brick tracking and multiple loading and unloading of the same brick, hence, the penalty of the multiple brick transfers from the disk to memory which becomes very costly. Moreover it was not clear that how the surface filtering was applied i.e. extracting a surface of interest (horizon) from multiple surfaces (connected components). In seismic data these may be few hundreds components to few thousands components depends on the size and type of data and geo scientists are only interested in one or few of them. Similarly, no topological analysis of surface genus was reported, as these are important features in seismic analysis because they may appear due to the noise in data or may naturally exists to represent faults in surface as discussed in Section 4.5.

Earlier Kindlmann and Durkin [KD98] showed that material boundaries are parabolic arcs in (f, f') as shown in figure 4. Fiber surfaces [CGT*15] exploited the idea to generate surfaces which are closed and watertight. Figure 5 shows fiber surfaces generated using tooth database. We refer readers to the [CGT*15] paper for further details.

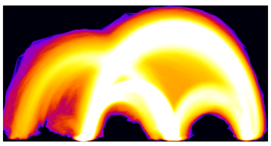


Figure 4: *Continuous scatterplot (tooth database)*

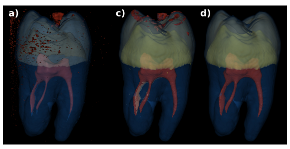


Figure 5: *Fiber Surfaces (tooth database)*

There is no reported work using fiber surfaces in seismic domain because it's a new technique. However to our knowledge there are no commercial solutions that guarantee watertight seismic surfaces and horizon extraction.

4. Current Research

The main goal in this research project is to extract watertight surfaces (horizons) from seismic data. The objectives were to determine which isosurface (iso value) represents a horizon of interest; does the isosurface accurately represents a horizon and how efficiently the horizons are extracted.

The identified tasks to accomplish the research goal are:

- Pre-process raw seismic files.
- Identifying and implementing suitable technique for extracting watertight meshes from seismic data.
- Represent surfaces using appropriate data structures.
- Horizon identification and extraction.
- Ensure watertight meshes.

A data processor was implemented to extract the data of interest i.e. seismic trace samples from raw seismic (SEG-Y) files.

For surface mesh extraction we proposed to apply cubical surface generation method from implicitly represented surfaces in a seismic volume. There are different methods available but we preferred isosurfaces (Marching Cubes (MC)) [WH87]. Recall that the seismic data given to us as sampled rectangular scalar grid i.e. volumetric data, since we are instrusted in boundary surface we therefore consider isosurfaces; extracted with MC. More importantly, a horizon represents a material boundary therefore the amplitude values are consistent across the horizon and suitable to extract if using isosurface. Also, almost all other isosurface methods use MC in one way or the other.

4.1. Experiments

In order to show the applicability of our approach for representing horizons using isosurfaces, we have conducted experiments using real seismic data as shown in table 1.

Dataset details	
Format	Binary
Number of gathers	511
Number of traces per gather	631
Number of samples per trace	376

Table 1: Experimental dataset

The data is an offshore seismic dataset provided by the Department of Earth and Environment at the University of Leeds.

The results showed that the isosurfaces can appropriately represents horizons. Many connected components were generated due to data dimensionality, therefore isosurface filtering (as discussed in Section 4.4) was applied to extract the horizon of interest. Figure 6 shows extracted isosurfaces at 50% and figure 7 shows the surface meshes are uniform, unlike surfaces generated in commercial packages which are non-uniform due to the issues as discussed in Section 1.

4.2. Scaling

The isosurface statistics obtained using the above dataset are shown in table 2.

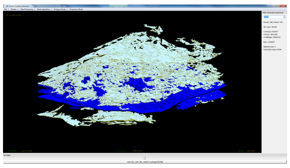


Figure 6: *Isosurfaces 50%*

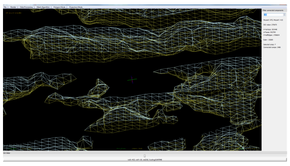


Figure 7: *Uniform mesh*

Isosurface (50%)	
Number of vertices	9M
Number of triangles	18M
Connected components	84K

Table 2: Experimental results statistics

Table 2 clearly shows that computation for large datasets lead to scaling problem using conventional desktop machines and require advanced techniques such as parallel and distributed computing, to handle large data. For parallel and distributed computing, we are using VisIt [CBW*12] on cluster to generate isosurfaces from seismic data. Initial problem with VisIt was that, it does not have a seismic database plugin to process .SEGY [Seg] files. Therefore, a data converter was developed to convert raw seismic files into VisIt understandable VTK format.

4.3. VisIt .SEGY Plugin

We have now developed a VisIt [CBW*12] .SEGY database plugin for processing seismic files. Our plugin can run in serial and on cluster in parallel. We refer reades to [CBW*12] for VisIt's parallel and distributed modes. Once it will be publicly available, a geophysicist can use it to visualise and analyse seismic volumes in VisIt. An example isosurfaces at 50% extracted in VisIt are shown in figure 8.

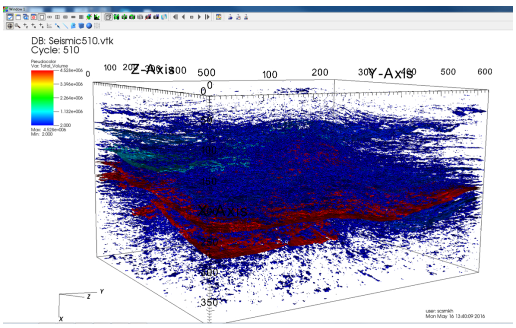
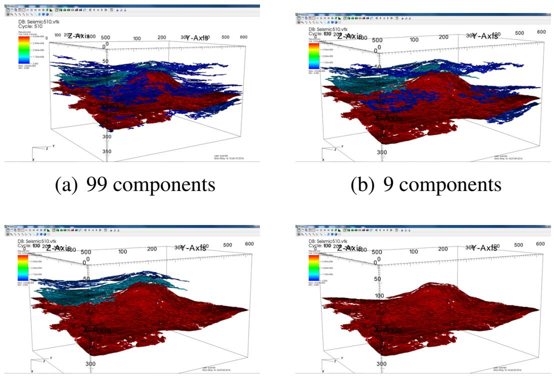


Figure 8: *Isosurface at 50% in VisIt*

4.4. Isosurface Filtering

Figure 8 shows 84K isosurfaces (connected components), mostly non-horizon surfaces. Hence, isosurface volume based filtering was applied to extract the surface of interest. The process is shown in figure 9, filtering from 99 surfaces to 1 surface of interest (horizon). Here the final isosurface is watertight and closed except boundaries due to the data acquisition method.



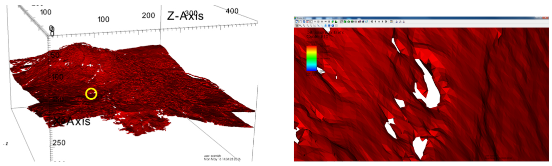
(a) 99 components (b) 9 components

(c) 4 components (d) 1 component

Figure 9: *Isosurface filtering*

4.5. Isosurface Handles

Closely examining the figures, number of holes in the surface can be observed. These holes are actually the surface handles and are closed as shown in figure 10.



(a) Isosurface (b) Handles

Figure 10: *Isosurface handles*

Number and size of these surface handles could increase or decrease by manipulating the iso values. Note that these handles are very important in seismic analysis because they may exists naturally in the data due to some geophysical phenomena such as a fault or appear because of the noise in data.

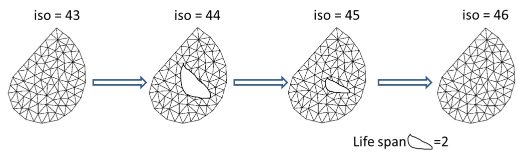


Figure 11: *Surface handle's life span*

Here we are interested in performing topological analysis in order to find the life span of these handles to determine whether these exist naturally in the data or simply appear and disappear by varying iso values.

Figure 11 shows the life span of a handle in an isosurface, which appears at iso=44 and disappear at iso=46. Therefore the life of this handle is 2, which is too short and indicate that this handle is temporary and does not exist in data.

Similar analysis is done by [GDN*07] to show the life span of such handles and determining persistent handles in data.

4.6. Fiber Surfaces

We are extending our research to use fiber surfaces [CGT*15] for extracting horizons. Fiber Surfaces (FS) is fairly a recent concept and can be thought of as an alternative to isosurfaces. FS are generated using bivariate datasets and possess similar properties to isosurfaces which guarantees closed and watertight meshes. We are currently in the process of testing and experimenting FS using different seismic datasets for their suitability for extracting horizons.

5. Conclusions

In this research we have addressed the issues in seismic data interpretation, mainly in extracting the watertight surfaces (horizon). To accomplish this we have proposed and demonstrated that isosurfaces can be generated and extracted to represent seismic horizons. And the extracted horizons are watertight, which is the main goal of this research; to support better 3D geological models and seismic simulations. In order to improve the scalability we have used VisIt on cluster and have developed seismic database plugin for it. We are currently extending the research in two directions, first the isosurface topological analysis to determine natural handles in horizons and secondly experimenting suitability of the fiber surfaces for extracting better horizon surfaces.

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