

Research on 3D Visualization Method of Seismic Data

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Abstract

3D visualization is an important link in seismic data processing and interpretation, and the development of the microcomputer system of 3d visualization software for seismic data is very necessary. This paper uses MFC (Microsoft Programming Interface) and VTK (Visualization Toolkit) building three-dimensional scene, realizing the 3d seismic data field Visualization display system and determining the projection window according to characteristics of the seismic data field which is a regular three-dimensional spatial data field. In this paper, we apply the 3d visualization technology to the field of seismic data processing, use the improved light projected volume rendering method to directly render 3d seismic data and displaying the 3d seismic data to users in the form of three-dimensional interpretation, greatly improve the efficiency and accuracy of seismic interpretation, at the same time, also can provide a powerful conditions for further data interpretation and analysis.

Keywords: *Seismic data; 3D visualization; Volume rendering; Visualization Toolkit*

1. Introduction

The goal of scientific computing visualization is drawing the three dimensional space data field to make people see the intuitive, vivid image or graphics. 3D visualization for seismic is applying the scientific computing visualization specifically to the field of seismic exploration, through converting the huge amounts of data from seismic exploration into a 3d image, and making a three-dimensional interpretation for 3d seismic data. Therefore, all detailed information about the geological surface and internal are intuitively and vividly displayed to help the researchers quickly comprehensive grasp the geological structure and accurately analyze geological phenomenon that hidden in the 3d seismic data [1].

Most of the 3d seismic data visualization still adopts display method of the traditional two-dimensional seismic section and horizontal slice or fence diagram composed by multiple slices to gain insight into the three-dimensional characteristics of geologic body. In essence, this kind method still not gets rid of the limitations of 2d interpretation for 3d data. This kind of algorithm has some deficiencies, mainly are the following two aspects:

(1) For large 3d data volume, even if display each vertical section and horizontal section, the complete information for three dimensional geologic body also is scattered in various independent two-dimensional image, which makes the researchers could not accurately associated with the three-dimensional shape of geological body.

(2) Information utilization rate is low. In the practical work, it is impossible to analyze and explain for each profile and horizontal slice, and it just uses only a small part of the information, most of the information has not been used.

Focusing on above problems, this paper adopts the improved light projected volume rendering method and 3d visualization technology, based on the analysis and refer the existing research work, to realize 3d display for 3d seismic data and to greatly improve the efficiency, accuracy and integrity of seismic interpretation.

At present, domestic 3d visualization tools that are widely used, in the more or less, has some shortcomings, for example, low code execution efficiency, poor computing power and so on [2]. This article uses the Visualization Toolkit (VTK) which is an open source and free access and support for parallel visual processing library created by Will Schroeder and others. VTK is a tool that is used in 3d graphics, image processing and Visualization, and it has more advanced than OpenGL graphics library [3].The VTK development kit supports a variety of programming languages, such as Java, C++, Python, etc.VTK has powerful graphics processing and visualization function, it encapsulate the commonly used algorithms in the field of graphics and visualization. While using VTK, users can not consider the details of algorithm, at the same time, by calling the algorithm class library can be rapid and efficient for visual development to achieve the desired visual effect. But the VTK lack of flexible interface, so that it must be combined with other graphical user interface (GUI) development libraries (such as MFC, GTK, etc.), then, we can truly achieve the visualization system.MFC is one of the most popular user interface development library at windows platforms, it has the rich interface development space and can quickly build a visual prototype system. So, in this paper, a study on 3d visualization combines VTK with MFC, which aims to find a way to improve the effect of 3d visualization. At the same time, this paper reconstructs the 3d seismic data with the modified volume rendering method, and explores a way which uses VTK for 3d reconstruction.

Because the amount of seismic data that acquired on-site is quantity, when use computer for visualization drawing, the calculation is too large, seriously affect the rendering speed. So, the volume rendering algorithm needs for optimized. In this paper, some improvements were made on the basis of Ray casting volume rendering algorithm according to the characteristics of seismic data. For example, ignoring the illumination effect, no longer set the sampling point between the layers, skipping empty voxel and so on, accelerating the rendering speed. Finally, this paper realizes a 3d visualization display system under the Microsoft Windows environment with MFC and VTK for seismic data field, and it can provide the seismic data in SEGY data formats with 2d and 3d displaying.

2. 3D Seismic Data Visualization Method

2.1. Introduction to the Visualization Algorithm

Data Visualization converts science and engineering calculation for large-scale data into graphics, image in the form of visual representation. It involved in computer graphics, image processing, computer vision, computer aided design and graphical user interface and other research areas, has become an important direction of current research of computer graphics and permeates all areas [4].The purpose of visualization is making a lot of data become intuitive and easy to understand through the graphics or images to reveal the inner link between the data and make people can observe the invisible objects.

Trees discussed in this paper are the tree model that computer simulated, it only includes trunk, branches and leaves of a natural tree those visible parts on the ground. Generally, visible parts of a natural tree on the ground are mainly including trunk, branches and leaves. Note that, if there is no specified, both tree trunk and branches can be referring to branches. The tree trunk system consisting of branches

supports the whole tree and determines the shape of the tree; Leaves grow on the branches, cover the tree trunk system, forming the overall appearance of the tree. Locally, each leaf and its veins patterns, bark's concave and convex texture etc. constitute the detailed features of the tree. The general process of visualization technology is shown in Figure 1.

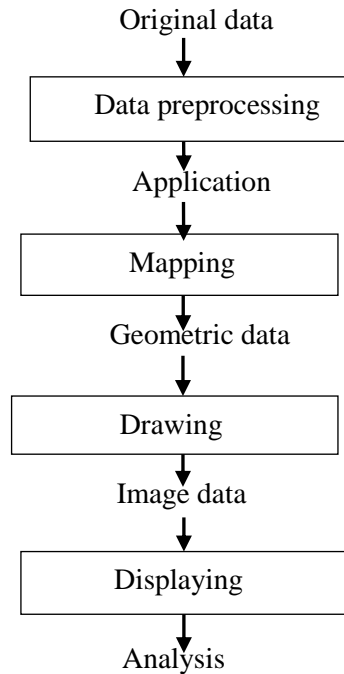


Figure 1. The Visualization Process

2.2. 3D Visualization Mainly Drawing Method

3D visualization rendering methods of images usually can be divided into surface rendering and volume rendering these two major categories [5], according to whether has tectonic geometry elements in data field.

(1) Surface rendering. Using classification operation to extract interested parts of the 3d spatial data field and constructing geometric primitives (such as the planar triangle, surface, etc.), commonly used is the level set, then using the traditional method of graphics to drawn graphics to the screen [6]. Every time this method can only display a level set for a value, cannot response the relationship of various factors in data field. It is difficult for researchers to grasp the global situation of the data field.

(2) Volume rendering. Unlike surface rendering, volume rendering does not need to construct the middle geometric primitives, can directly compute with the optical model in 3d spatial data field and generates the screen projection images. Volume rendering technology is the implementation of re-sampling and image synthesis process in 3d data filed, which in order to ensure the reconstruction images are not out of form, must meet sampling theorem when re-sampling. Volume rendering takes voxel as basic unit, and the data field is composed of a large number of voxels. In visualization of 3d seismic data, converting each data sample point into voxel of three-dimensional data, and the values of sample point is mapped to a color and transparency values of voxel, then making color synthesis for optical properties of each individual to get the final 2d image as a result, which convert seismic data into seismic data cube composed by voxels [7].

3. Basic Principle of Ray Casting Volume Rendering Algorithm and Improved Algorithm

3.1. Basic Principle of Ray Casting Volume Rendering Algorithm

Ray Casting is the most commonly used in the direct volume rendering algorithm, and it is a classical algorithm of volume rendering based on image empty scanning. In the ray casting volume rendering algorithm, firstly, it needs some pretreatment, such as, format the data in the data field, delete redundant data and store the data with the required format. In order to reasonably and clearly show all sorts of different material or different properties of a substance at the same time, the data need to be classified, according to the size of the data values. All data is divided into several classes, and set the corresponding mapping relationship between all classes of data and the color and opacity values. Then re-sampling is conducted, takes each pixel on the screen as a starting point, launches a light through the entire three-dimensional data field along the view direction, selects K equal interval sampling points along the emission light, does thrice linear interpolation with the color value and opacity value of the eight grid point closest to the sample point to calculate this sampling point's opacity value and color value, and converts it into the corresponding image space coordinates. And then, in turn from the front to rear, synthesizing the color value and opaque value of each sample point to get color values of the pixel. Each pixel is calculated as the above to get the whole image finally (see Figure 2).

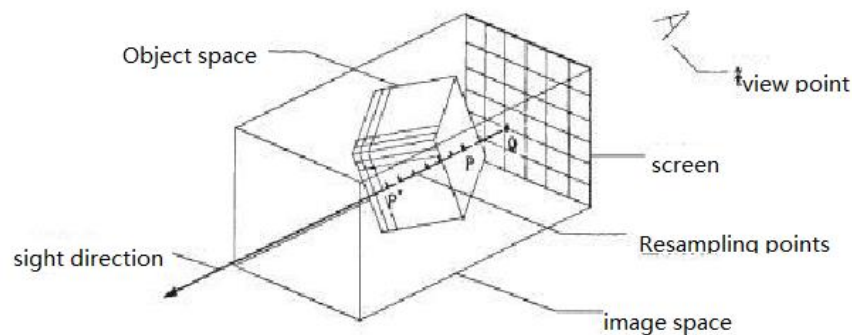


Figure 2. The Concept of Ray Casting

3.2. Improved Ray Casting Algorithm

Ray casting algorithm has inherent defects, that is, heavy calculation. Its time overhead and space overhead will increase with the increase of the amount of data. However, the characteristics of seismic data is large scale, distributed scattered material with different eigenvalues, no clear interface, the gradient direction of each voxel is desultory, lighting effects is weak, paying more attention to macroscopic and overall stratigraphic characteristics and so on. Through analysis of the process of volume rendering algorithm, focusing on the characteristics of 3d seismic data and requirements of seismic interpretation, in this paper, the ray casting algorithm was simplified and improved. In this paper, the thought of speeding up volume rendering mainly from three aspects: firstly, on the premise of guarantee, reflect the characteristics of global to reduce amount of calculation; secondly, avoid time-consuming operation and the no-contribution calculation; finally, simplify algorithm and improve efficiency. The improved aspects are mainly follows:

(1) Because gradient values of seismic data change disorderly, the lighting effect is weak and almost no influence for the seismic interpretation, thus this paper ignores the lighting effect to minus gradient calculation.

(2) Most of the ray casting volume rendering algorithm do classifying data firstly, then take interpolation operation. However, it makes the generated image is not clear, the reason for this is that the convolution operation of this kind of algorithm is not for original discrete 3d data field to realize the refactoring, while for data that after data classification, color assignment and opacity assignment. So as a result, it will filter out high frequency components of the color value after light and shade computing. This paper adopts classification data after interpolation.

(3) Because in re-sampling, sampling points is often not an integer, so we need to get the sampling point data by interpolation. Because the image generated by recently adjacent interpolation has obvious edges, and most of the 3d visualization use three linear interpolation algorithm. However, a disadvantage of the thrice linear interpolation is lager computation, in this paper, VTK uses fixed-point number instead of floating point operations to avoid some time-consuming operation, such as, floating point arithmetic and intercept the decimal part, so as to improve the operation efficiency.

(4) In image synthesis, when calculate the opacity value α , this paper uses synthetic algorithm by the former-to-backward, so α is increasing. When α closing to 1 indicates that the image of this pixel has been close to completely opaque, the following voxel will not contribute to this pixel image, which can skip over the back of the voxel to early terminate calculation and eliminate the invalid computation.

(5) Skipping up empty element has no contribution to generate images.

4. 3D Seismic Data Field Visualization Display System

3D seismic data field Visualization display system in this paper uses data visualization technology, which displays 3d seismic data in the form of three-dimensional and two-dimensional surface to the user, to achieve the effect of the three-dimensional interpretation for 3d data.

4.1. VTK Visualization System Process and the Seismic Data Format

At present, most of the proposed 3d visualization system is based on OpenGL, despite OpenGL currently is taken as a graphic language standard, but it does not guarantee that the future will not be replaced by other more popular image language. VTK has more advanced than OpenGL graphics library, in some aspects of graphic processing, is more efficient than OpenGL [8]. The basic process of VTK visualization is shown in Figure 3.

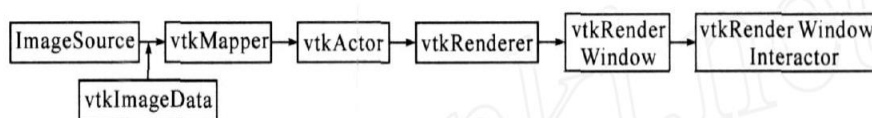


Figure 3. The Flow of VTK Visualization

In Figure 3, the Image Source used to generate data; vtkImageData represents the original image data structure in processing, VTK will distribute different filter for different image data structure to get new image data objects; vtkMapper implement a mapping relationship from data to graphic; VtkActor (vtkVolume for volume rendering) Materialize the mapping relation obtained by vtkMapper and control the display attributes of image by calling the attribute object (vtkproperty), thus making display image more vivid; vtkRender and vtkRender window to realize the image display in the window of a computer; vtkRender Window Interactor to realize the interoperability

between the user and the image, the researchers can use the mouse operation for image rotation in order to see the image from various angles.

Using VTK to realize visualization, the most important thing is to know what image data structure is in processing, just so, we can choose the right method for processing. In this article, the data used to implement the visualization is the most widely used in seismic exploration with SEG-Y format. Seismic data belongs to a scalar field, these data have no direction are not dependent on the coordinate system, so as to keep the value unchanged when coordinate transformation. Standard SEG-Y format including 3200 bytes header string section, 400 bytes binary head segment and 240 bytes trace header word [9]. 3200 bytes head string and 400 bytes binary paragraphs collectively referred to as the header file of earthquake data, a total of 3600 bytes. Seismic data is controlled by the equidistant line, equidistant view point and equidistant sampling point, so it is a structured regular grid volume data field in three-dimensional space [10].

VTK can provide file read and write functions for a variety of data format, for example, images, volume data, structured data and unstructured data, etc. However, it does not provide support for the professional data format. For example, there is no class in VTK that used to directly read seismic data with SRG-Y format. So in this system, building the work area to storage raw data that needed by system displaying, and then each work area is corresponding to a folder which save the convert data that is result from converting raw data into special format data for VTK.

Because the amount of 3d seismic data generally is very big, if use the common file read and write mechanism, it is easy to take up a lot of system resources, affecting the efficiency of program. So when designing the system, this paper used memory-mapped files mechanism, which maps a part of the file that data reside in to the process address space, in order to improve the efficiency of reading.

4.2. System Framework, Method and Steps

This paper designs and realizes a 3d seismic data field visualization system. On the basis of Visualization Toolkit software package, this system combines with Microsoft Foundation Class to implement the combination of the external user interface and the underlying visual function. The overall framework of this system is as shown in Figure 4.

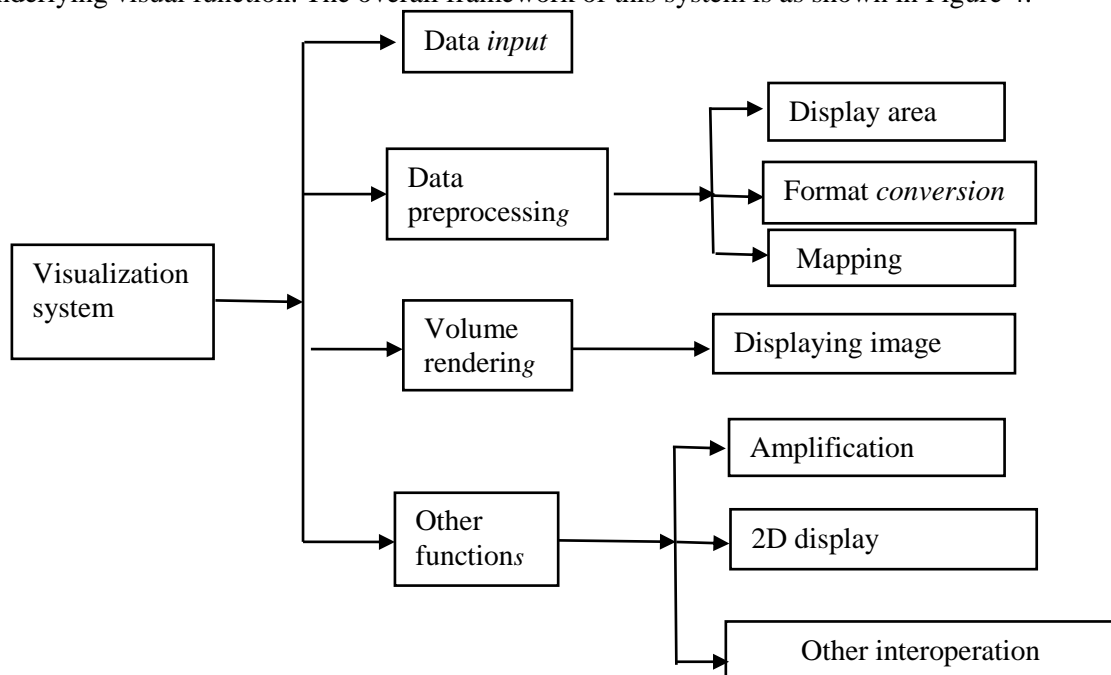


Figure 4. Overall System Framework

The main function of data input module is using `Imagesource` series class in VTK reads data. Data preprocessing module include: create display area, format conversion and mapping. Display area module mainly creates a new work area for input SEG-Y seismic data; format conversion means that converting the input seismic data into system internal data format; Mapping means mapping the seismic data to color value and opacity value. The function of the volume rendering module is completing the volume rendering based on improved ray casting algorithm. It is the key to set different transparency and color values for voxels that have different grey values. Our system uses `AddPoint()` method in `vtkPiecewiseFunction` class to implement transparent property Settings, and uses `AddRGBPoint()` method in `vtkColorTransferFunction` class to implement color property Settings. Other function module mainly includes the interoperability of the image, such as, amplification, rotating and 2D display and so on.

In volume rendering module, this paper uses ray casting to implement the 3d reconstruction, and the `vtkVolumeRayCastCompositeFunction` class in VTK realizes this algorithm. The basic process of the reconstruction as followings:

- (1) Use `vtkStructImageReader` class to read the seismic data which after pretreatment.
- (2) Use `SetDirectoryName()` function to set the path of the image sequence.
- (3) Use `vtkPiecewiseFunction` class to set the opacity value for seismic data.
- (4) Use `vtkColorTransferFunction` class to give color attribute values.
- (5) Use `vtkVolumeProperty` class to set solid properties.
- (6) Use `AddRGBPoint()` function to assign different color value for different grey level.
- (7) Use `AddPoint()` function to give different transparency value for different grey level.
- (8) Use `SetColor()`, `SetScalarOpacity()`, `ShadeOn()`, `SetInterpolationTypeLinear()` function respectively set data body color, opacity, light and shade to open, attributes of the interpolation method.
- (9) Use `vtkVolume` classes to build new data object.
- (10) Use `vtkVolumeRayCastCompositeFunction` class to implement ray casting volume rendering algorithm
- (11) Use `vtkRender` class to render engine object and use `vtkRenderWindow` to establish drawing window object.
- (12) Use `vtkRenderWindowInteractor` class build interaction between window objects, and use its function `AddVolume()` to add the 3d cube that will be drawn to the rendering engine.
- (13) Use `Initial()` function to initialize the incident and cycle.

The above process achieved the 3d visualization of seismic data based on ray casting volume rendering algorithm. But, when used `vtkVolumeRayCastCompositeFunction` class to specifically implement the ray casting volume rendering algorithm, this paper implement the improved ray casting algorithm by modifying the original algorithm in VTK. And in the process of ray casting, only the non-empty voxel that within the sampling seismic data or on the boundary is effectively.

5. The Experimental Results and Analysis

5.1. The Experimental Environment and Data Sources

This paper uses MFC single document application framework and the 3d visualization tools in VTK to implement the 3d seismic data volume rendering under Windows system. Integrated development environment is VS2005, the computer configuration is: 4.0 GB of memory, CPU for Intel Core i5 3.20 GHz Windows 7 System. The seismic data used in experiments are available at <http://pubs.usgs.gov/of/2009/1151/data/seismics/segy/>. This site is a famous foreign geological information website, and the data in this site is authentic and is standard SEG-Y format seismic data.

5.2. The Initial Interface of 3d Seismic Data Field Visualization System

In this paper, the initial interface designed by 3d seismic data field visualization display system is as shown in Figure 5.

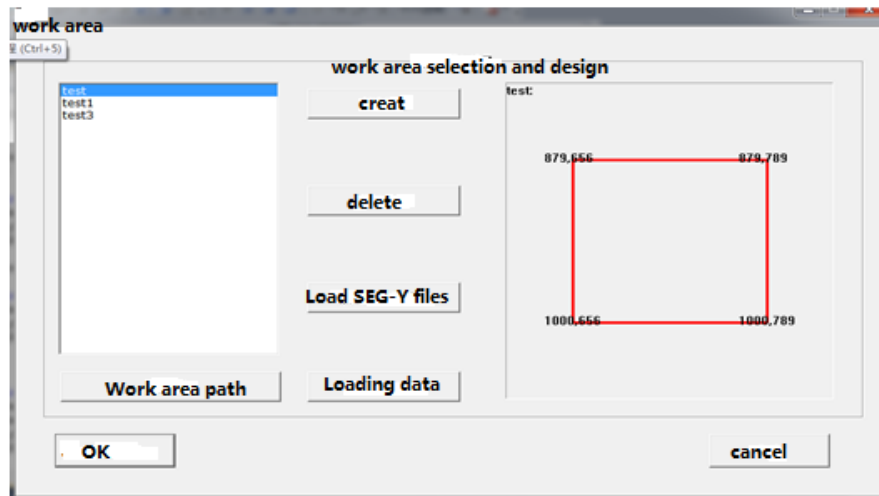


Figure 5. Initial Interface

The function of the left work area include creating a new work area, choosing a SEG-Y file for scanning, obtaining work area information, deleting the existing work area, loading SEG-Y file header and loading SEG-Y data. The right work area is the scope of input SEG-Y data. Click OK to enter the display system.

5.3. Display Interface

The main display interface of this system contains jump interface for 2d and 3d display. The main display interface is as shown in Figure 6.

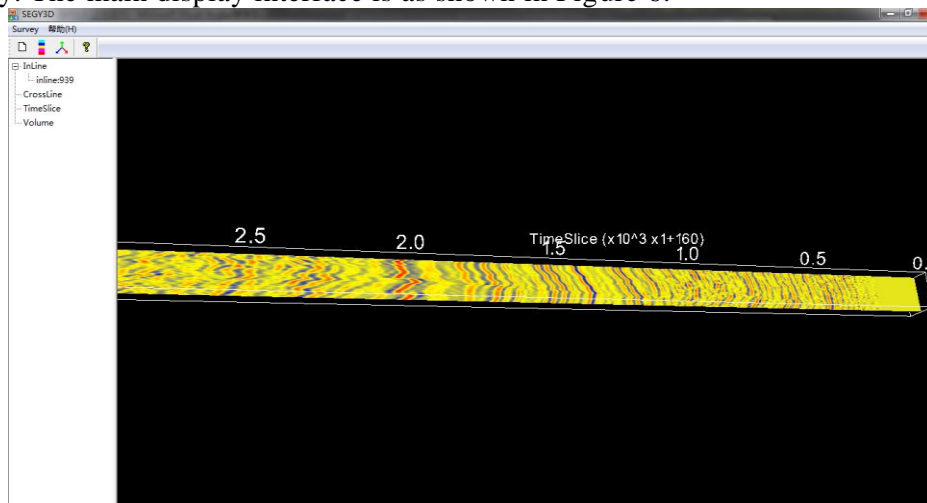


Figure 6. Main Display Interface

- (1) The InLine is on behalf of the master line (X-axis), which can add the slices in x- axis direction.
- (2) The CrossLine represents the cross-track line (Y-axis), which can add slices in y-axis direction.

(3) The TimeSlice represents the time line (Z-axis), which can add the slices in z-axis direction.

(4) The Volume is on behalf the volume rendering which makes a volume rendering to slices we have choose.

The following Figure 7(a) and Figure 7(b) respectively shows the 3d and 2d display interface.

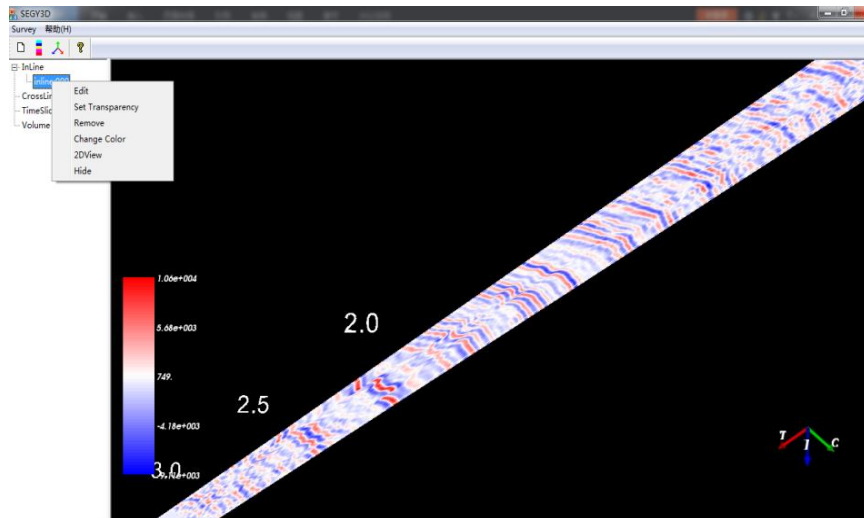


Figure 7(a). 3d Display Interface

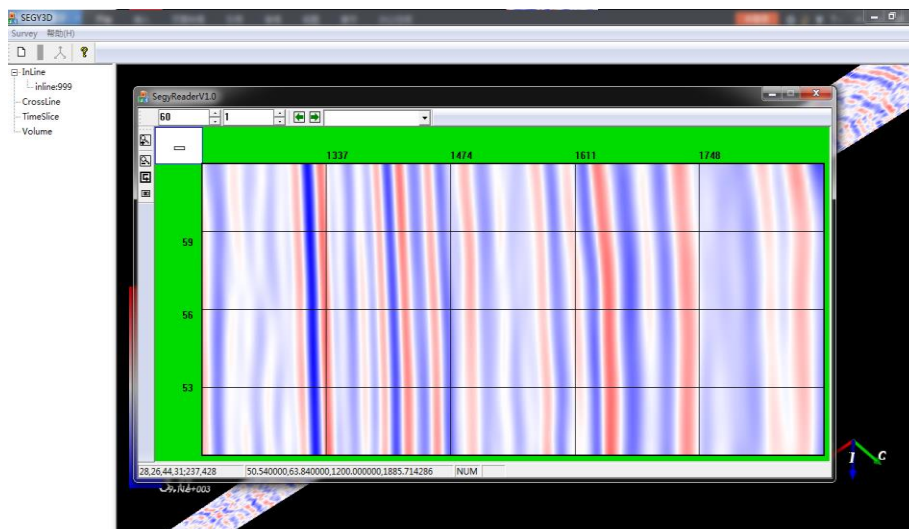


Figure 7(b). 2d Display Interface

As shown in Figure 7(a), the three dimensional section can be edit, move, remove, rotate, hidden, set the transparency and so on. For example, the interested part of slices can be set to transparent or set to the corresponding color values according to the user's need; the uninterested parts can be hidden temporary. As shown in Figure 7(b), display the slices in a two-dimensional perspective, can enlarge the selected area for observation, so as to better observe slice information.

5.4. 3D Seismic Data Volume Rendering

For seismic data after pretreatment, this system firstly uses the improved volume rendering algorithm for 3d reconstruction, and then, uses VTK 3d rendering tools OpenGL packaged in VTK to volume rendering for seismic data field. Based on VTK rendering framework, all render requests are handled by `vtkMapper` class [12] whose derived class `vtkVolumeMapper` can process volume rendering. This paper uses derived class `vtkFixedPointVolumeRayCastMapper` to conduct ray casting volume rendering. The `vtkFixedPointVolumeRayCastMapper` class adopts Vertex counting and can generate `MinMaxVolume` (optimum values to optimize ray casting) in the pretreatment stage to skip up the empty voxel. Note that, calculation results will be cached, so there is no need to recalculate next time. Through the experiment results we can find that the image rendered by ray casting algorithm can keep many details and have high image quality.

Figure 8 is the result figures of volume rendering, (a), (b), (c) are three two-dimensional rendering slice of the SEG-Y data that respectively be along the x-axis, y-axis and z-axis direction.

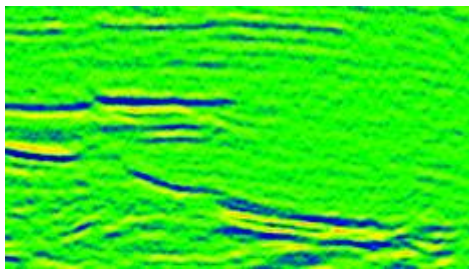


Figure 8(a). Slices in x-Axis Direction

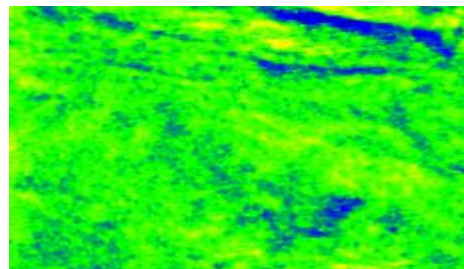


Figure 8(b). Slices in y-Axis Direction

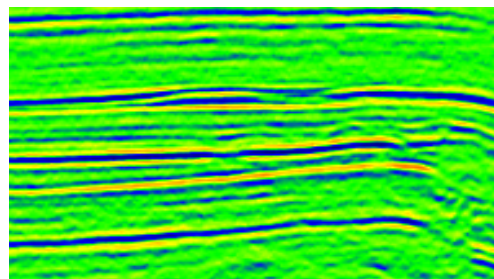


Figure 8(c). Slices in z-Axis Direction

In Figure, different color represents different strata, and it shows the conditions about geological fault. We can see that the scope of the green component is bigger, which indicates amplitude of the seismic data is low. On the other hand, the interface between strata along z-axis direction is very obvious, If connect the fault line of the related section, it will form the fault surface, providing the basis for the research on later fault surface.

The effect figure about 3d rendering of seismic data is shown in Figure 9. User can drag the mouse to make data volume rotate, thus user can get multi-angle observation. Under the effect of stereo display, each slice can be placed respectively according to their spatial location, and we can find that there is a clear dividing line between layer and layer and the slice in each direction is consistent with their two-dimensional slice shown in Fig 8. By comparing the Figure 7 and Figure 8, we can

know that 3d rendering figures have more abundant spatial information and richer display effects, are more vivid and clearly show the geological structure, facilitating the researchers for analysis.

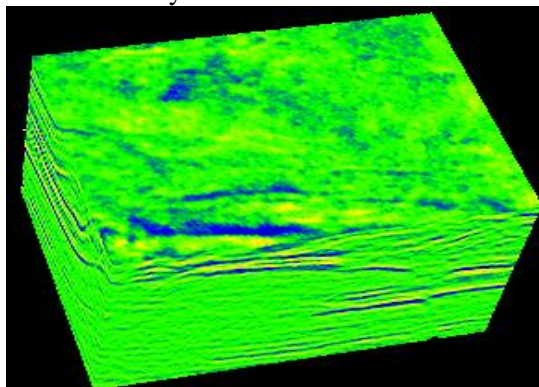


Figure 9. 3D Rendering Effects

Figure 10 shows the effect figures that converting the sliced along three directions in three-dimensional space to magnified 2d rendering. Researchers can choose interested parts make a local amplification, thus details and geological characteristics of fine geology can be displayed more clearly to help researchers have a good observation and get more details about section.

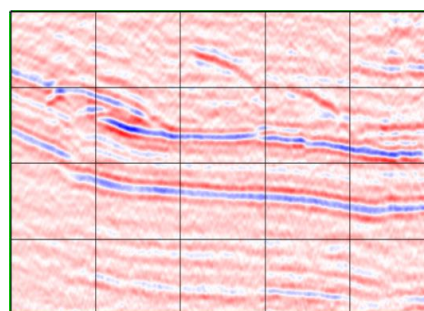
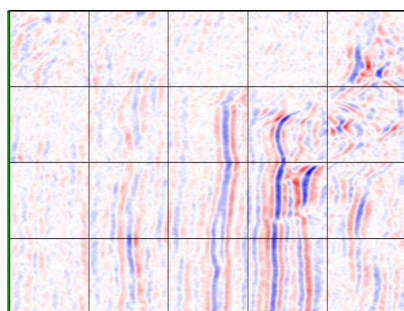


Figure 10(a). Magnified 2d Slice (z-axis) Figure 10(b). Magnified 2d Slice (y-axis)

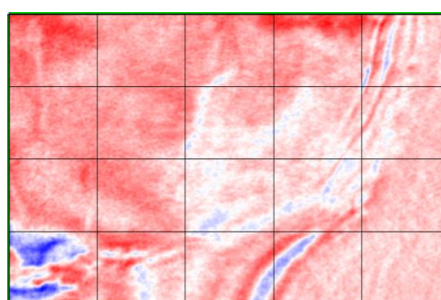


Figure 10(c). Magnified 2d Slice (X-Axis)

The 3d visualization system this paper design mainly used VTK to make a 3d reconstruction. The experiment results show that VTK not only has a good visual effect, but also is more convenient to implement volume rendering. In addition, VTK has a strong flexibility and is a very practical tool for visualization. Of course, this paper just uses this software and has a preliminary exploration about VTK. In the future, we will continue to study on 3d visualization of VTK.

6. Conclusion

This paper used MFC and VTK tools build an extensible 3d visualization system under Windows common microcomputer system. As for seismic data with SEG-Y format, this paper completed pretreatment for data volume, volume rendering and editing and other processes to achieve a good 3d interpretation results for three-dimensional data and provide geological personnel with vivid and rich 3d seismic information, thus it is beneficent for researchers to make the correct explanation about the original data. Moreover, based on the characteristics of seismic data and the volume rendering algorithm packaged in VTK, this paper improved and simplified the traditional ray casting algorithm, making the speed of displaying image has a larger increase. This paper adopted the tools provided by the VTK development kit to provide users with a good interactive interface.

Combining with the improved algorithm proposed by this paper, the next step will be committed to research on VTK 3d visualization, and strive to extend the functions of this software. At the same time, this paper will focuses on parallel volume rendering algorithm to improve the drawing speed and further improve the performance of the volume rendering.

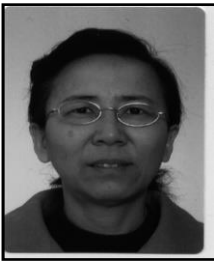
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