Interactive Seismic Data Visualization via Virtual Reality Devices

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Abstract

Seismic data visualization and analysis play a role in exploring the distribution of petroleum and gas, which can help domain experts, e.g., geologists and oil or gas exploration experts, to better understand the distribution of geological materials and stratigraphic structures. Underground flow paths(UPFs) are one of the significant stratigraphic structures because they are connected with the distribution of oil or gas. Traditional seismic data visualization system usually utilizes traditional external devices, e.g., computer screens, mice and keyboards to present rendering results and provides users with interaction. However, deficiency of depth information and inconvenience of manipulation have become problems confusing users for a long time. Virtual reality technologies have broad applications in experimental teaching, flight simulation, reconstruction of cultural relics and so on. The immersive experience it brings to users makes up for disadvantages of traditional interaction devices. In this paper, we design a seismic data visualization system implemented in virtual reality devices to bring users immersive exploration experience. First, users can adjust transfer functions to get optimal rendering results of seismic data by controllers equipped with the virtual reality devices. Second, normal interactions such as rotation and scale can be conducted to have an overview of the seismic data. Third, quadratic-surface distance or slice queries can help explore UFPs and their contexts within a local region in detail. Results show that the proposed approach is capable of taking the place of traditional equipments to some extend and making users immersed in exploration interaction.

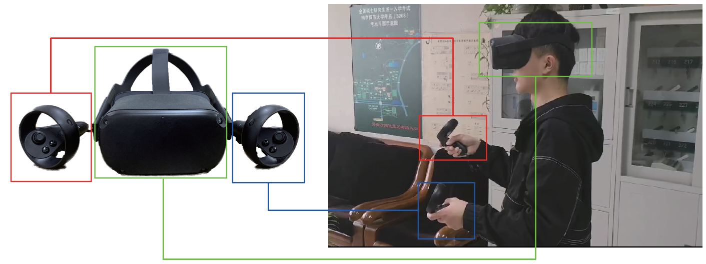

Figure 1: The virtual reality device we used is Oculus Quest, which composes of a headset and two controllers. It can bring users immersive exploration experience and replace traditional interactive devices, e.g., mice and keyboards. As shown on the right, an user is trying to explore seismic data with Oculus Quest.

1 Introduction

Seismic reflection is a method to estimate the properties of the Earth's subsurface from reflected seismic waves according to seismology. The seismic data collected from seismic reflection method often have the characteristics of noisy, discontinuity, low resolution and feature locality [1]. Underground flow paths(UPFs) are vital stratigraphic structures different from horizons and faults. They are closely connected with the migration and deposition of oil or gas [2]. It is difficult to visualize and analyze seismic data, especially for UFPs, because of the above characteristics.

Traditional seismic data visualization systems are displayed on 2D computer screens and manipulated by the keyboard and the mouse. However, there are some deficiencies of traditional interaction mode. First of all, 2D screens are unable to present the depth information of 3D volume data, so internal details are often neglected. Besides, the mouse is often used for the exploration of 2D space. Users cannot explore the depth direction unless the mouse is used in conjunction with the keyboard.

Virtual reality(VR) technology is a kind of computer simulation system that can create a virtual world. It exploits data int real life and convert them into a phenomenon that can be felt by users with the electronic signals generated by computer technology and various output devices. VR has been recognized by more and more people because the authenticity of its simulated environment is indistinguishable from that of real word. Last but not least, the strong simulation system of VR truly realize human-computer interactions so that people can operate at will and get the most authentic feedback from the environment.

In this paper, we take advantage of virtual reality technology to visualize seismic data to bring users with immersive exploration experiences. The VR headset is a substitution for 2D display screens and controllers equipped with the VR headset replace mice and keyboards.

Transfer functions play an important role in volume rendering, which classify volume data according to the distribution of them and contribute to generate rich rendering results. Users can edit transfer functions by trial and error to get optimal rendering results by pressing specific triggers on the controllers. Rotation, translation and scale are basic interaction operations in the field of visualization. They provide users with an overview of seismic data. The visualization results may induce too much visual cluster on account of the four characteristics of seismic data, so tools for exploring details are necessary. We offer quadric queries and slice queries simultaneously in order to assist in interpreting seismic data in different ways.

2 Our Method

The inspiration of choosing VR to conduct interactive exploration of seismic data in this paper comes from the inconvenience of traditional interaction mode. We believe the introduction of VR interaction mode is a good improvement of the seismic data exploration.

2.1 Ray casting algorithm and transfer function

Considering the above-mentioned design goals, we need to render the volume data in VR space. To assign different schemes of color and opacity for each voxel in volume data, we adopt ray casting algorithm. Starting from the viewpoint, the rays traverse almost all voxels in the dataset at the specified inclination. In order to record the results, an image plane whose size is same as that of single input slice is placed between the viewpoint and the volume data. Rays originating from the viewpoint are sampled within the volume data at equidistance. These samples are stacked trilinearly and synthesized all interpolation of a single ray to correspond to the image plane pixels that cross the corresponding light. The volume voxels will be transformed into visualization results with different colors and opacities by adjusting transfer functions.

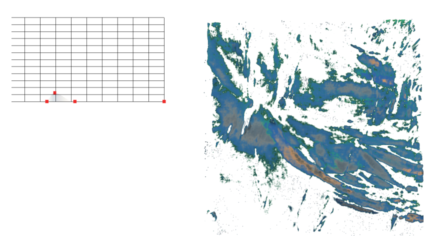

Figure 3: The grids and control points on the left make up the transfer functions control panel. Users can adjust the color and opacity schemes of rendering results by adjusting transfer functions. The final rendering results will be shown in the center of users' sight.

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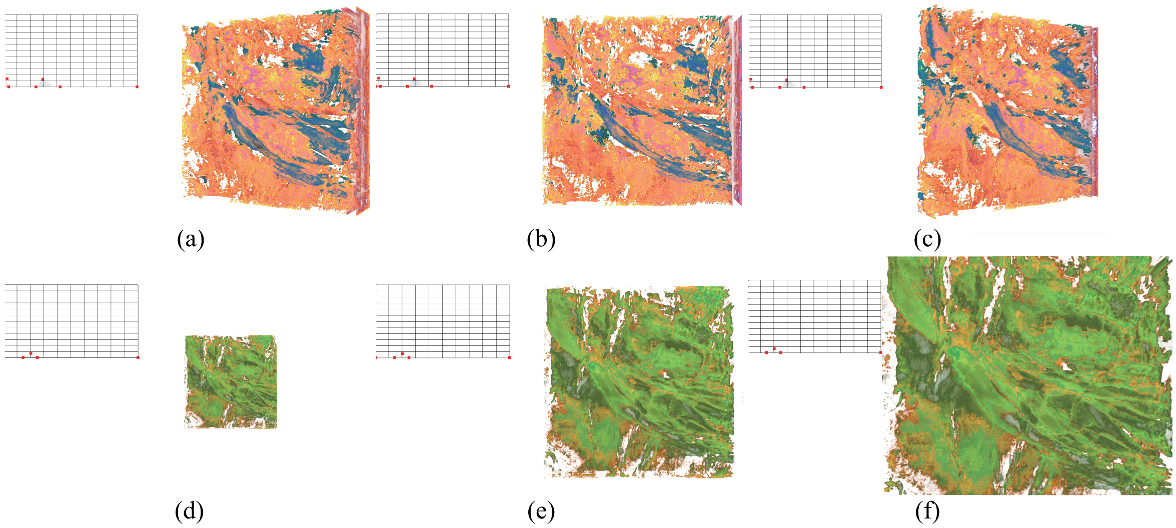

Figure 2: The rendering result of seismic data can be rotated or scaled. (a) rotate the rendering results to the left.(b) no rotation.(c)rotate the rendering results to the right. (c) zoom out the rendering results.(d) no scaling.(e) zoom in the rendering results.

2.2 Basic operations for overview

The exploration example on volume data is to use a seismic visualization to demonstrate its usability and customizability. Rotation and scaling are done by dynamically modifying the position and size properties of the data. We establish a binding between the controller and the changes in the volume data. With simple interaction, users can drag, rotate, scale and set unique transfer functions to view data features from different perspectives.

2.3 Quadratic-surface distance and slice queries

In order to avoid the inconvenience of using traditional devices and enable users to obtain a more immersive experience in VR space, quadratic-surface distance and slice queries are introduced.

In the rendering process of fragment shader, a ray emitted from the fragment passes through the front and back texture. We obtain the 3D coordinates of the penetration points on the front and calculate the direction vector of the ray. The direction vector is divided into several unit vectors, ray marching one unit vector in each step. With the help of the transfer functions, the intensity extracted from volume date at current position can be converted to color, which turns into data source of integration process. Specifically, when the penetration point is located in the ellipsoid body, it can be descripted by the following equation.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1 \quad (1)$$

We pay attention to two characteristics variable, direction vector and the last front penetration point. By iteratively simulating the process of ray marching, the color and opacity are updated depending on amplitude of accumulation. After simulating all of such divided unit vectors, color and opacity of every component are determined.

Finally, through this calculation, we allow users to fully examine the overall shape of the data. Besides, it can effectively help to alleviate the problems of seismic data with high noise, discontinuity and low resolution in the observation of slices.

3 Results, Discussion and Conclusion

To demonstrate the effectiveness of our method for seismic data exploration, we conduct several evaluation tests on seismic datasets to produce different views. Notably, volume data visualization results can be queried by quadric queries and slice queries to help users get a better understand of the data. When they can't get a clear and sharp visual effect directly, the design of transfer function lets them feel free to change the color and opacity, which enables them to explore in VR space from multiple perspectives at ease. Although nearly all the description in our paper focuses on seismic data, we shall argue that our method is not limited to the seismic data. It is available for kinds of volume data, such as medical data like human lung or hand. Our method could express both the overview and their details even in some sophisticated cases.

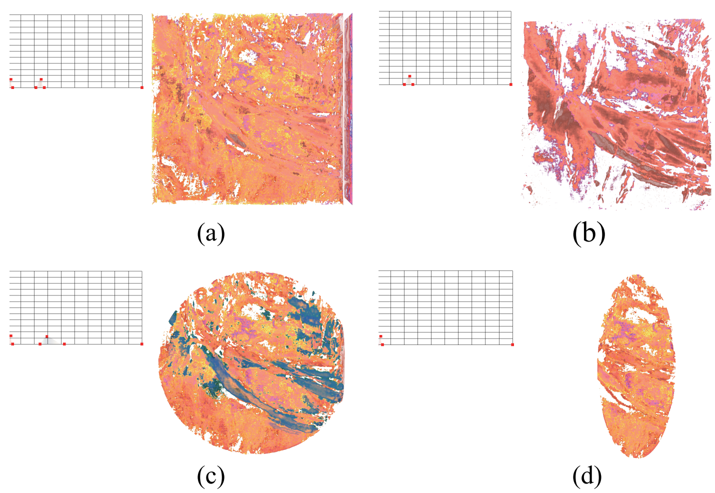

Figure 4: This picture shows the rendering results of our method. (a) shows the original rendering result. (b) is the slice of the rendering result in the z-axis direction. (c) shows the rendering result when using the sphere to limit the render range. (d) is the result of using the ellipsoid.

There are still some limitations in our work at present. First, the rendering results in VR sometimes looks choppy and torn. We will improve data flow transmission efficiency and adopt parallel rendering techniques to make frame switching more smoother. Second, the available interactions that users can conduct are confined. Some domain specific interactions such as stratigraphic display modes can be implemented to help geological experts better understand and analyze seismic data. Besides, most interactions currently depend on controllers of the VR device. Gesture recognitions can be applied to free users' hands.

References

[1] M. Gao, L. Wang, J. Jia, Y. Chen, R. Liu, L. Shen, X. Chen, and M. Su. Interactive geological visualization based on quadratic-surface distance query. *Journal of electronic imaging*, 28(2):021009.1–021009.11, 2019.

[2] R. Liu, G. Ji, and M. Su. Domainspecific visualization system based on automatic multiseed recommendations: Extracting stratigraphic structures. *Software Practice & Experience*, 50(2):98–115, 2019.