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An Interactive Visualization System for Near-Earth Space Exploration Data

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Abstract. Aiming at the actual needs of efficient and convenient visual analysis of near-Earth space exploration data, this paper studies the functional realization mode, data flow and interactive method, analyzes the functional framework and data flow of the interactive visualization system of near-Earth space exploration data in detail, designs a multi-level, loosely coupled and easily extensible system architecture, and focuses on solving the logic model design, the fusion rendering of the multivariable data, the shadow calculation, the data clustering analysis, and other key technologies. The application of the system has realized the interactive and visual analysis of the massive and multi-source near-Earth space exploration data, and provided convenient data analysis service for the vast number of scientific research and application users, which helps to better play the potential value of near-Earth space exploration data.

1. Introduction
Near-Earth space exploration data is the product of human spaceflight application activities, and it has become an important data source of multidisciplinary research and socioeconomic life, such as space science research, Earth system science [1]. Its research has important value both in theory and in practice. However, due to the complexity and particularity of the Earth's space environment, the data obtained have the characteristics of large amount of data, complex internal structure and overlapping of attributes in space. At the same time, the static graphs and curves traditionally drawn from these data cannot make people understand the space environment deeply, which hinders the understanding of the changing law and the correlation of spatial environment elements.

As an important content of scientific visualization, data interactive visualization has important applications in large-scale scientific and engineering computing fields such as earth system simulation, nuclear physics simulation, computational fluid dynamics and medical image simulation. Its purpose is to explore the phenomena and laws contained in complex data by visualizing and using virtual interaction, to show the evolution process of complex scientific phenomena, and to help researchers understand and analyze physical phenomena. At present, many research organizations at home and abroad have done in-depth research in the field of interactive visualization of near-Earth space exploration data [2, 3, 4, 5]. In this paper, the current situation of interactive visualization of near-Earth space exploration data is analyzed, based on various data visualization system technologies, this paper designs and realizes an efficient interactive visualization system for near-Earth space exploration data, which is aimed at the direct and convenient display and analysis of space exploration data. The system can provide researchers with the fusion display and interactive analysis of many types of near-Earth space exploration data, such as atmospheric temperature and mixed ratio of ozone.

The paper introduces the function architecture and data flow of the interactive visualization system for near-Earth space exploration data, and designs the system architecture with multi-level, loosely coupled and easily extensible characteristics. The key technical problems of the system are discussed in detail, such as the fusion rendering of multivariable data, shadow calculation and so on. Based on these technologies, we developed the interactive visualization system for near-Earth space exploration data, which provides an important technical platform for the further application and research of the data.

2. System Design and Main Interface

2.1. Overview of the System Function Architecture

The functional architecture of the system determines the composition of the system components and their communication modes, which will affect the quality of the interactive visualization system of near-Earth space exploration data, which is expressed as the system's ease of use, interoperability and scalability requirements [6]. According to the actual requirement of interactive visualization of near-Earth space exploration data, the system functional architecture is designed as a three-layer architecture mode based on MVC (Model View Controller), including the data layer, the computing layer and the application layer. The three logical layers are connected through a set of industry-standard protocols and services, making it easy to use, maintain and extend the functionality of the system. The function architecture of the system is shown in Fig. 1.

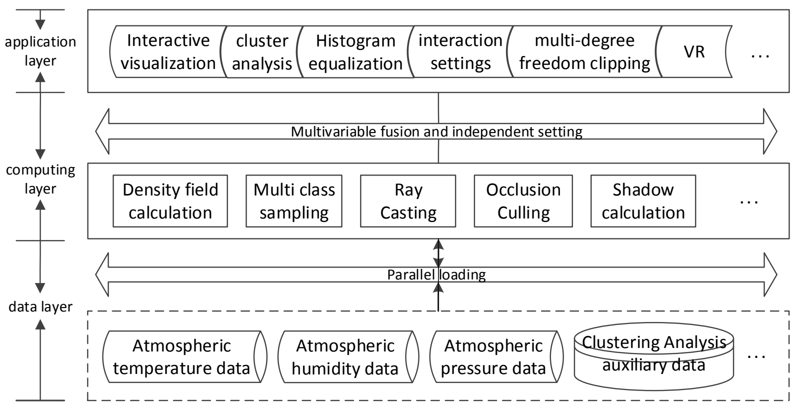

Figure 1. The function architecture of the system.

The data layer is the foundation of the whole system, which provides a unified storage for all kinds of near-Earth space exploration data. At the same time, the data layer also provides auxiliary data storage functions for functions such as cluster analysis.

The computing layer is the core of the whole architecture organization, and it provides the parallel computation and operation response for the function of cluster analysis, multi-degree freedom clipping and other functions.

The application layer is them man-machine interface of the whole system, which provides the visualization display of the near-Earth space exploration data, and provides the intuitive and convenient application interactive tool. By receiving various operation instructions from the user and passing them to the computing layer for logical processing, the user finally obtains the various functional services provided by the system.

2.2. Data Flow of the System
VTK (The Visualization Toolkit) is a powerful graphic and image application function library, with good architecture, high flexibility and portability, which has been widely used in universities and research institutes all over the world [7, 8]. The system uses VTK as the base graphics library, and the data visualization is realized by VTK's pipelining mechanism. The powerful visualization function of VTK is used in the system to visualize the near-Earth space exploration data in three dimensions, and it is applied to the visualization display of the internal section and illumination effect of the data so as to provide intuitionistic and accurate information of the data for the users of the system, which can achieve relatively ideal results. The system also integrates HTC VIVE virtual glasses and handles to further enhance visual perception and interactive experience. The data flow of the system is shown in Fig. 2:

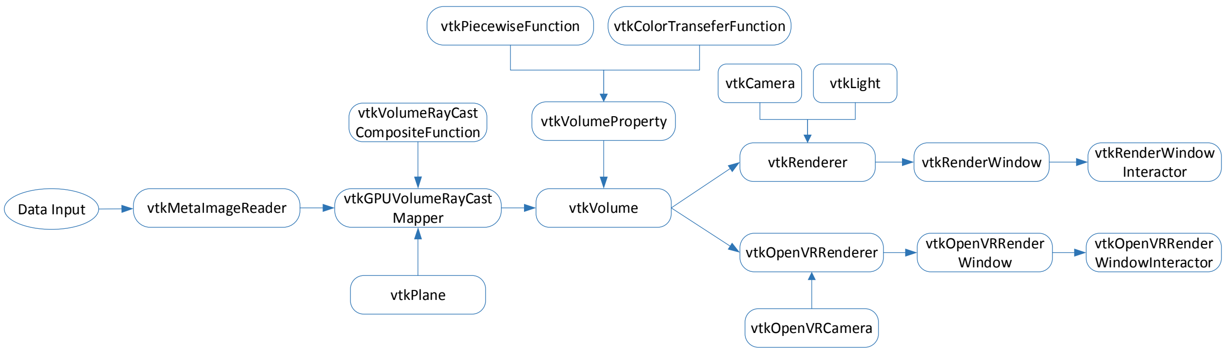

Figure 2. The data flow of the system

2.3. System Main Interface Components
On the basis of the system function architecture and data flow, the interactive visualization system of Near-Earth Space Exploration data is realized with VTK as the base graphics library and QT as the interface development frame. The main interface of the system is divided into four parts: menu bar, property setting window, transfer function setting window and main window, as shown in Fig. 3.

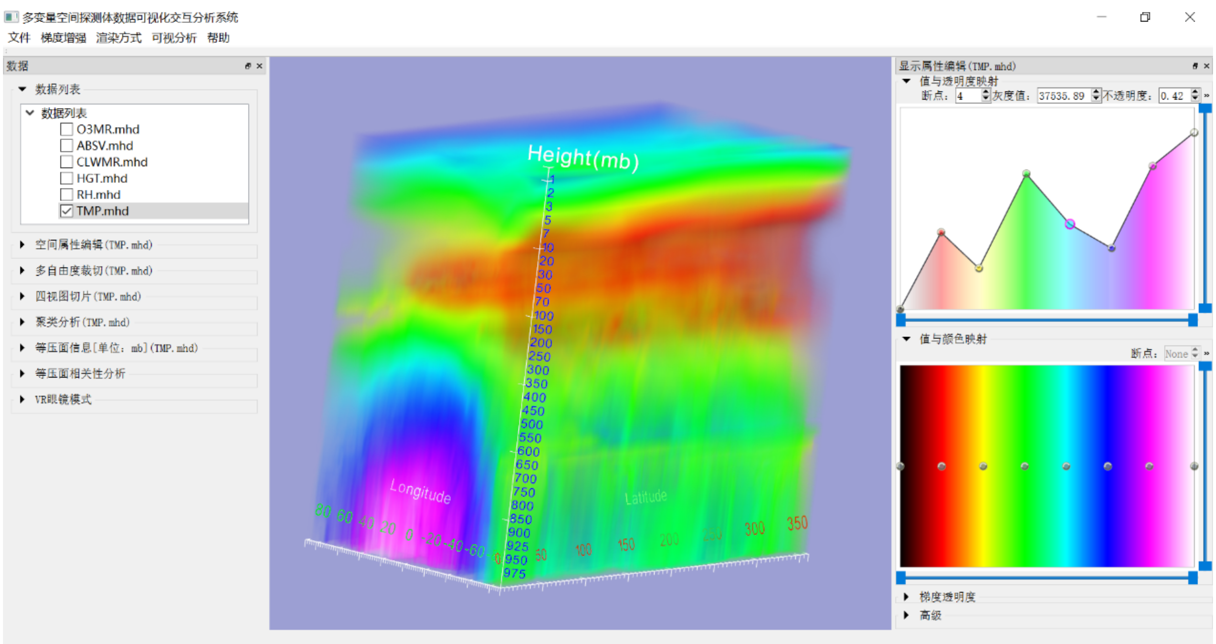

Figure 3. Components of the system main interface.

3. Data Visualization and Interaction in the System

3.1. Multivariable Data Fusion Rendering and Transfer Function Independent Setting

Near-Earth space exploration data is often composed of many variables. Fusion rendering of multivariable data can represent and describe the spatial structure characteristics and changing trends of multivariable data more comprehensively, in detail and accurately, as well as the interrelationships among variables. Fusion rendering of multivariable data often results in mutual occlusion, which affects the judgment of data variables by users. The visualization system developed in this paper realizes the fusion rendering of multivariable data by dynamically adding volume in the global renderer, and sets the interface for each data to bind the transfer function which can be operated independently [9, 10]. As shown in Fig. 4 is a rendering of the fusion of two variable data, from which it can be seen that the changes in the characteristics of each data can be clearly displayed.

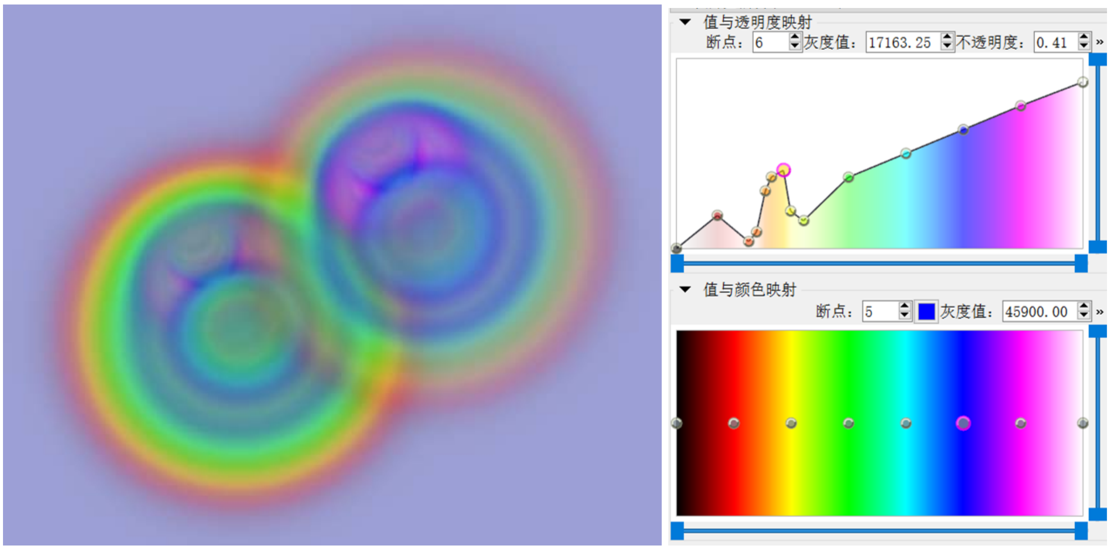

Figure 4. Fusion Rendering of Two Variable Data and the Transfer Function Setting of One Data

3.2. Shadow Calculation and Interaction Settings

Shadow calculation can not only draw the shadow of discrete points, but also draw the collection effect of homogeneous region well to improve the shape and realistic representation of objects [11]. In this paper, the problem of enhancing display of homogeneous region in data is studied. Interactive shadow setting man-machine interface is designed. As shown in Fig. 5, it is clear that the eddy current characteristics in the data are more pronounced when shadow is turned on.

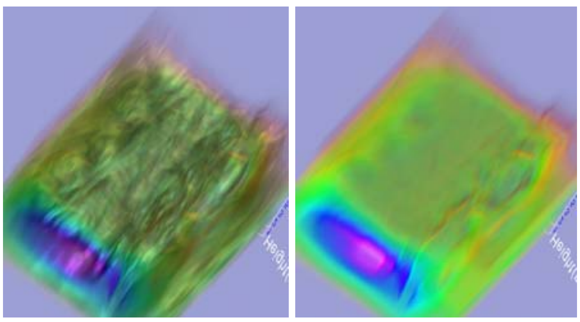

Figure 5. Fusion Shadow Effect Comparison

Shadow effect is mainly affected by three parameters of ambient light coefficient, diffuse reflection coefficient and specular reflection coefficient. Generally, the sum of these three parameter values is 1. In order to improve brightness, the sum of the three values in this paper can be greater than 1. Of these three parameters, the shadow effect is not obvious when the ambient light coefficient is dominant. The display effect is coarser when the diffuse reflection coefficient is dominant. The display effect is smoother when the specular reflection coefficient is dominant. In addition, a new highlight coefficient is added to the visualization system developed in this paper, which is used to control the appearance smoothness of the data rendering.

3.3. Data Clustering Analysis
Mapping between data values and colors is mainly used to passively classify the data value domain. In some cases, users want to artificially classify the data and analyze the data through the classification display. Therefore, this visualization system has designed the data clustering analysis function, studied the combination of K _ Means clustering algorithm and data visualization. The clustering function is used to classify the different data distribution and to maximize the display of these categories. The visualization system also designs how to bind the results of cluster analysis with the transfer function, as well as the independent display and hiding control of different classification results. Fig. 6 is the result of cluster analysis.

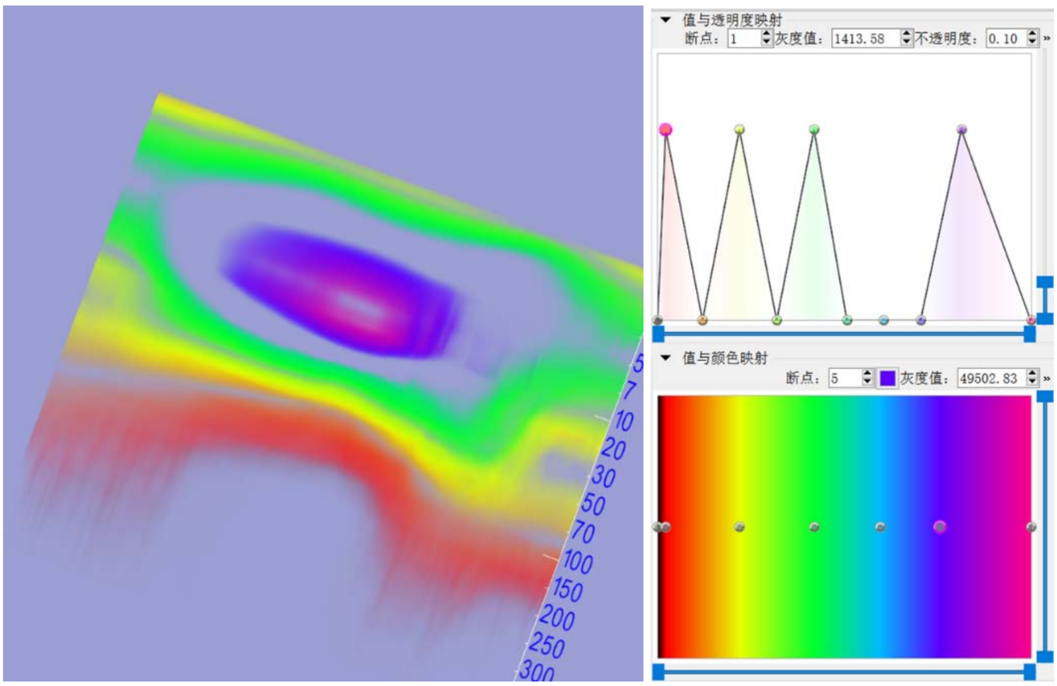

Figure 6. The Data is Clustered into Five Categories (Class 4th is Set to Hide)

3.4. Multi-degree Freedom Clipping
It is difficult to show the internal details throw the volume rendering for some large and complex data. The visualization system designed in this paper realizes the function of multi-degree freedom clipping, and can cut the image in any direction [12, 13, 14]. It is easy to observe the interior details of the data. The principle of the clipping is that the clipped part of the data is removed from the sample process of the data rendering. As shown in Fig. 7 are two variable data clopped independently.

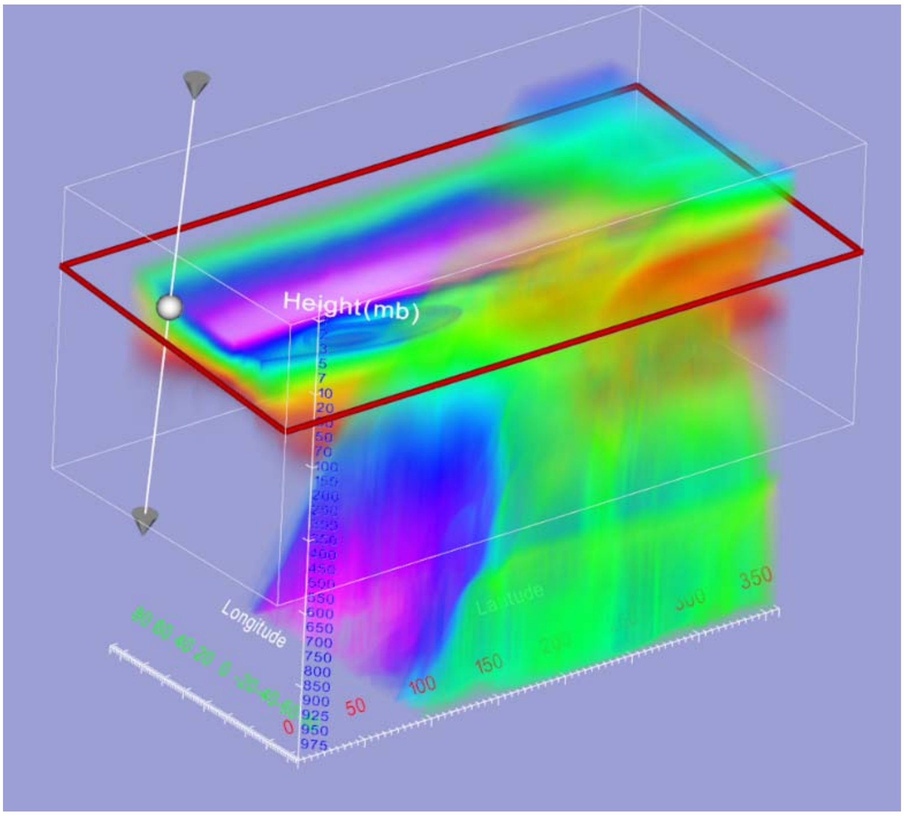

Figure 7. Multi-degree Freedom Clipping of Two Data

The multi-degree freedom clipping function designed in this paper can control the clipping surface of each data independently. The clipping surface is displayed as a plane with arrow direction in the three-dimensional space. The arrow direction represents the normal direction of the plane. The position and direction of the cutting plane can be controlled by dragging the plane or the direction of the arrow, and the circular ball inside the plane can be dragged to control the rotation center of the plane.

3.5. Display with VR Glasses and Interact with Handles

This visualization system integrates HTC VIVE virtual glasses to provide a more stereoscopic display and interactive means for multivariable data. It guides the user to create a feeling of being in a virtual environment, allowing the user to analyze the near-Earth space exploration data more intuitive [15, 16]. The use of VR glasses in the system includes the view of the scene, the view point movement, as well as the data collection, rotation, magnification and operation through the handle. The VR views and manipulates the data is shown in Fig. 8.

Figure 8. Display with VR Glasses and Interact with Handles

4. Conclusion

In this paper, the actual requirements of the interactive visualization system of the near-Earth space exploration data are analyzed. This paper designs the overall architecture based on the layered architecture, details the solution of the key technical problems such as the fusion rendering of the multivariable data, the shadow calculation, the data clustering analysis, and completes the integration and realization of the whole system. The application shows that the system can realize the interactive visualization of the near-Earth space exploration data, satisfy the user's actual demand, and promote the application of data in economic and social development and scientific research.

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