

Design and Implementation of EAST Data Visualization in VEAST System

D. Li, B. J. Xiao, J. Y. Xia, Y. Huang, S. L. Chen, K. R. Wang

Abstract—The Experimental Advanced Superconductive Tokamak (EAST) Device began operation in 2006. EAST’s inner structure is very complicated and contains a lot of subsystems which have a variety of different functions. In order to facilitate the understanding of the device and experimental information and promote the development of the experiment, the virtual EAST system has established an EAST virtual reality scene in which the user can roam and access to information by interacting with the system. However, experiment-related parameter information, diagnostic information and magnetic measurement information are displayed in the form of charts, figures, tables and two dimensional graphics. In order to express the experimental results directly, three-dimensional data visualization results are created using computer graphics technology. Data visualization is the process of visualizing data based on the characteristics of the data, the selection of the appropriate data structure and the proper sequence of visual pipeline. We use the visualization toolkit (VTK) to realize the data visualization in VEAST system and give the detailed steps of data visualization of plasma column, electron cyclotron emission diagnostic and plasma magnetic field. Besides, the general format is defined for the users to organize their data so that they can visualize their data in our system.

I. INTRODUCTION

EAST is a complex device and not be easy to access, moreover, it contains many different subsystems which have respective functions. In addition, since EAST’s experiment produces a large quantity of experimental data, the virtual EAST (VEAST) system has been established in order to help the experts understand the device [2].

The calculation analysis and numerical simulation have been used in EAST experiment for getting the distribution results on the temperature, magnetic field and electron field, so as to verify the correctness and integrity of the theory and guide the experiments. However, the visualization results are mostly presented in respective analysis software on 2D screens [3].

Three kinds of data visualization results have been completed and integrated with EAST model visualization. The integration of data visualization with the visualization of EAST model can make users observe data in virtual EAST. It also enable a collaborative environment among people with different background. Data visualization in VEAST system

allows users to interact with experiment data using immersive visualization.

Although experiment data from different systems cannot be visualized in the same way, the basic process of visualization is mainly divided into data generation, data refining and processing, visualization mapping, drawing and display [4]. This paper introduces the overview of the VEAST and discusses how these kinds of data visualization are realized. The visualization results which show all-around information of the electron temperature, magnetic field distribution and finite element analysis of plasma column are displayed intuitively by using the visualization toolkit. Finally, visualization results are presented together with the EAST model on the autostereoscopic device for achieving an immersive display.

II. VEAST SYSTEM

A. Overview of the VEAST

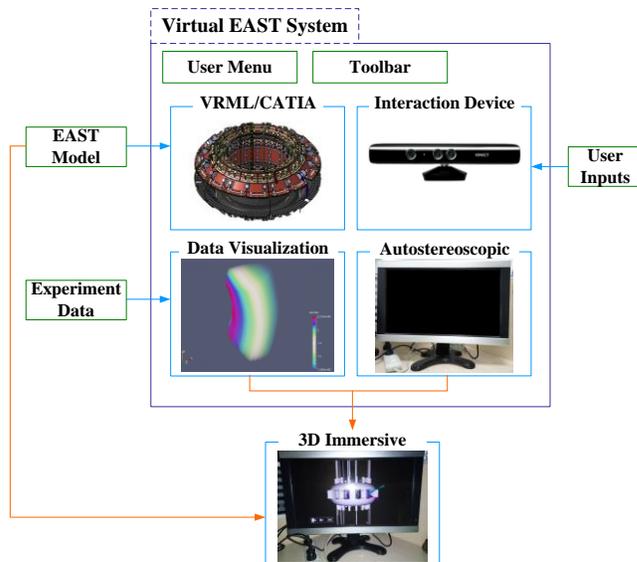


Fig. 1. Schematic of the VEAST system

The schematic of the VEAST system is shown in Fig. 1. EAST models which are simplified and optimized by CAD/CAE software such as CATIA [5] or 3ds Max [6] are exported to .wrl or .stl 3D model format. The virtual scene is constructed and rendered with the Visualization Toolkit (VTK). The data results which are processed by other software such as ANSYS or generated from experiment are visualized in the system. The data visualization results can be integrated with the EAST models to make it more immersive. Inputs hardware (Kinect or mouse) and outputs hardware

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D.Li, B.J.Xiao, J.Y.Xia, Y.Huang, S.L.Chen and K.R.Wang are with the Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, Anhui, China (telephone: +86-551-65592397, e-mail: lidan@ipp.ac.cn).

(autostereoscopic display) are configured to improve the effect of interaction. Users can also interact with the data visualization results in the system. Therefore, the VEAST system enables model and data visualization and interaction with visualization results.

B. Function Structure of the VEAST System

The VEAST system is divided into several modules according to the function. The function structure of the VEAST system is shown in Fig. 2. The system has three modules, that is, client module, model and data manager, hardware module. Data visualization is the sub module of the client. The user can visualize the data and save the visualization result in the system.

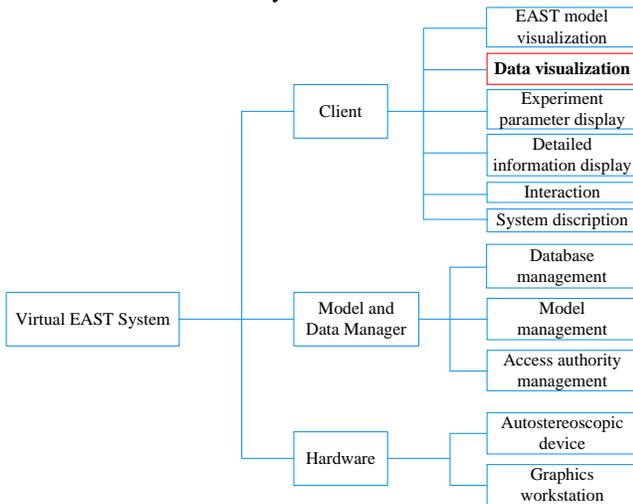


Fig. 2. Function structure of VEAST system

III. DESIGN AND DEVELOPMENT

A. VTK Pipeline Mechanism

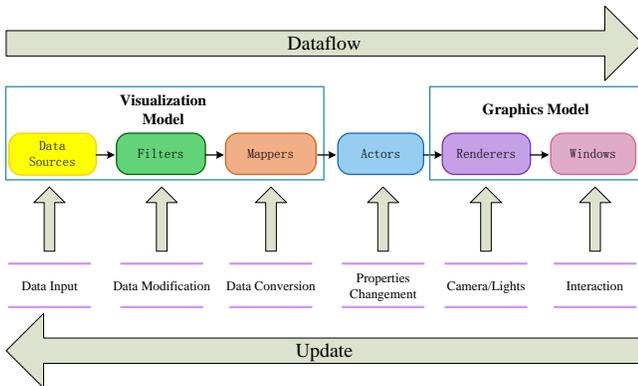


Fig. 3. Structure of VTK pipeline

Data visualization is realized using VTK pipeline mechanism, as shown in Fig. 3. Although the types of data are different, the visualization processes are basically similar, mainly for data generation, data refining and processing, visualization mapping, rendering and display.

Sources are the source of data through the visualization pipeline. The files which are the analysis results of other software such as ANSYS or the output results from some programs such as Matlab or EFIT are the sources. Filters are

VTK components that modify the data in some way. Mappers convert data into objects and the properties are changed in Actors. After all actors are added to the rendering window, data visualization results can appear on the screen. Interaction methods can be rewritten to meet the users' demands.

B. Class Diagram of Data Visualization

Three kinds of data visualization are realized in the system. The corresponding classes are designed for the three kinds of data types, namely, CVTKReader, CQuadReader and CGfileReader, as shown in Fig. 4. These three classes are inherited from the parent class CPipeline which is based on the VTK visualization pipeline for achieving the visualization processing. The visualization effects of different data types can be realized by inheriting and rewriting the parent class.

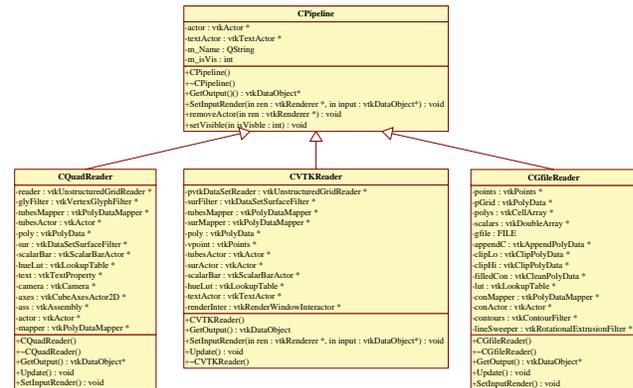


Fig. 4. Data visualization class

IV. DATA VISUALIZATION IN VEAST SYSTEM

The scientists get the distribution results through the calculation analysis and numerical simulation on the temperature, magnetic field and electron field, so as to verify the correctness and integrity of the theory and guide the experiments. A few examples of data visualization have been realized in the virtual EAST system, the efficiency of data visualization has been improved by displaying on the same platform with the EAST model.

A. Plasma Column

The visualization of plasma column is mainly based on finite element analysis results of plasma column, it contains surface visualization, wire-frame visualization, roaming of the visualization results and so on. The visualization of the finite element analysis results includes the visualization of scalar field and vector field, and the visualization of the plasma column data is the former.

The finite element analysis results of the plasma column is the spatial distribution of the magnetic field, including the hexahedral mesh number, hexahedral mesh vertex number and the sequence of vertices, coordinates and magnetic field values of the vertices. The process of plasma column data visualization is to read the magnetic field value at each grid point according to the results of the finite element analysis, and to form the value distribution with different color according to the magnetic field value.

The visualization process of plasma column data is as follows:

1. Read the analysis results of the finite element software (ANSYS);
2. Read the coordinates of element nodes, the topology of elements, the element type, magnetic fields and other attributes;
3. Create the vtkUnstructuredGrid object, and add the information to the vtkUnstructuredGrid object;
4. Visualize the data using VTK library.

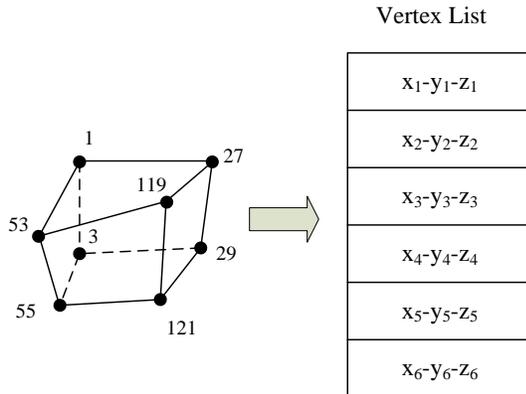


Fig. 5. Vertex list of hexahedron element

The dataset is composed of one or more elements, and the element is composed of the type of elements and the vertex lists. In the process of the plasma column visualization, the element is hexahedral mesh, as shown in Fig. 5, topology structure of hexahedral elements is defined by vertex lists (such as 29-27-1-3-121-119-53-55, vertex lists can be identified by the point of the index number, the coordinates of the point can be retrieved in the vertex list by the index number). The cell type of the hexahedral element is VTK_HEXAHEDRON in VTK.

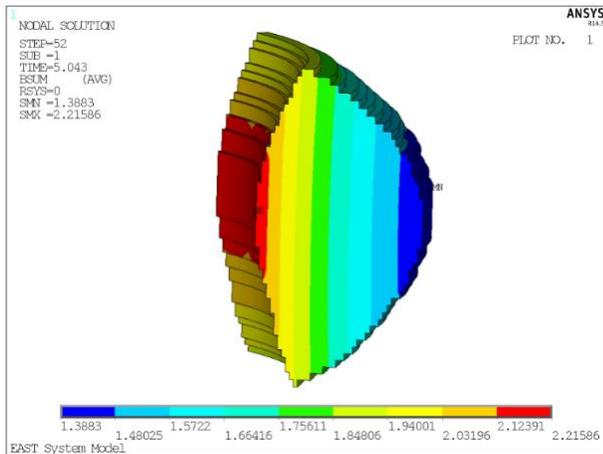


Fig. 6. Analysis in ANSYS

Take the analysis result of ANSYS magnetic field of plasma region in an experimental shot for example [7], the analysis result of the plasma column in ANSYS is shown in Fig. 6. Each hexahedron element is composed of eight grid points. The numbers of each grid point, coordinate values and magnetic field value are read and stored. The object of the class vtkUnstructuredGrid can be constructed through those values. Before visualizing, different filters can be set for

displaying different results, Fig. 7 is plasma column surface data visualization results, Fig. 8 is plasma column wire frame data visualization results by setting the filter vtkTubeFilter, Fig. 9 is the result of roaming in plasma column wire frame data visualization. In the visualization results, the value of the magnetic field can be seen from the scalar bar according to a segmentation of a color space.

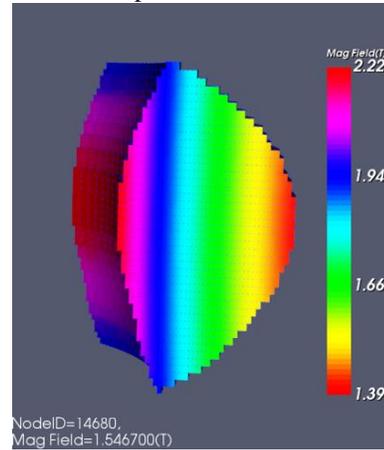


Fig. 7. Plasma column surface data visualization

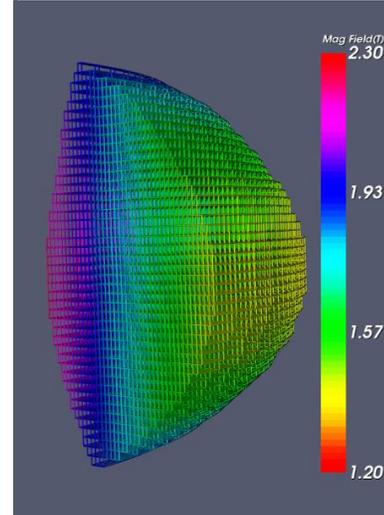


Fig. 8. Plasma column wire frame data visualization

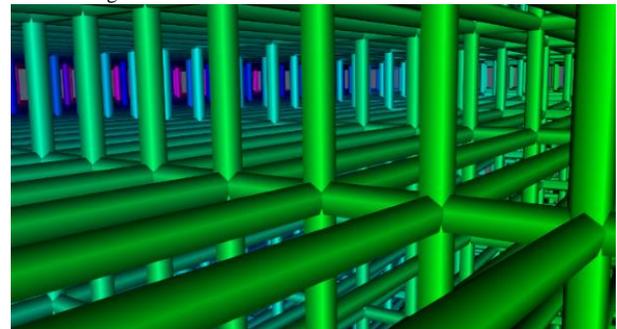


Fig. 9. Roaming in data visualization

In order to provide the interaction function of visualization result data, the interaction class InteractorStyleGetVertex which is inherited from vtkInteractorStyleTrackballActor is defined. When users press the middle mouse button, the ID number and the magnetic field value of the grid point are displayed by rewriting the OnMiddleButtonDown() function.

The method of plasma column data visualization can be used for those physical experiment calculation results which have the similar format with ANSYS magnetic field analysis results of plasma regions. The input and output file type are described below.

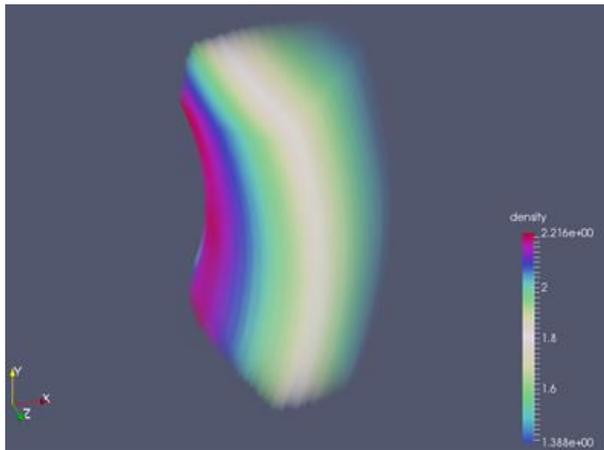


Fig. 10. Volume rendering

The input file is mainly composed of three parts: The order number of vertices and their coordinate values are stored in X_plas.txt file; the order number and the vertex sequence of element are stored in IX_plas.txt file; the order number of vertices and magnetic flux values are stored in B_plas.txt file. Therefore, the meaningful data file types can be used as the input file of data visualization in principle. The file which is input to the system is converted to .vtk format file after reading, and relevant visualization results are displayed according to different types of visualization selection. The .vtk format file can be used as the input of VEAST system or other commercial visualization software for the subsequent calculation. The volume rendering [8] result of the plasma column data visualization is opened in ParaView (Fig. 10).

B. Electron Temperature

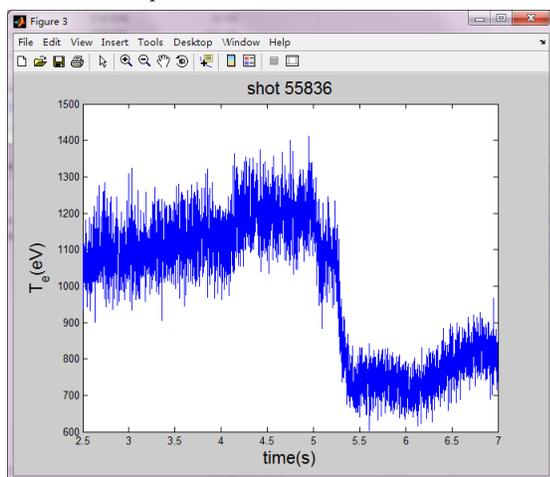


Fig. 11. Electron cyclotron intensity in Matlab

The diagnosis of electron cyclotron emission is a routine diagnosis of the electron temperature profile in Tokamak.

In tokamak, electron moves around the spiral magnetic field. The motion produces electron cyclotron radiation at the cyclotron frequency and its harmonic frequency. Electron cyclotron intensity depends on the optical thickness and the

local electron temperature T_e , and the electron cyclotron emission intensity is proportional to the electron temperature in the optically thick plasma. Therefore, the distribution of electron temperature along the R direction can be obtained by the measurement of the electron cyclotron radiation spectrum. The change of the electron temperature of the 55836 shot with the time was realized with Matlab, as shown in Fig. 11. In order to visualize the temperature field in the three-dimensional space, all changes of electron temperature have to be rendered along the R direction, namely, the ECE temperature field visualization result, as shown in Fig. 12.

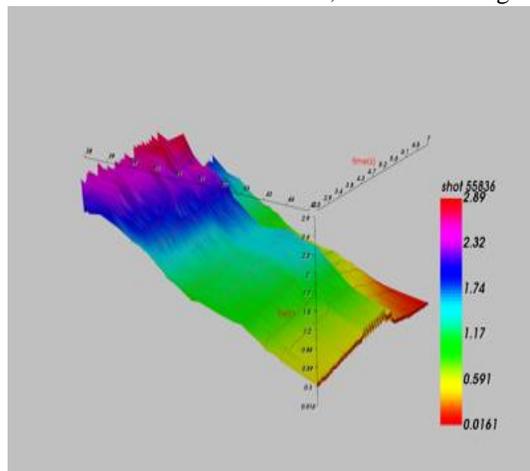


Fig. 12. Electron temperature visualization

Take the 55836 shot as an example, the radius R is a 13×1 matrix and the time t is a 4501×1 matrix, the electron temperature T_e is a 13×4501 matrix. The class vtkPolyData is constructed according to the matrix, then the filters are set and visualization results of the three-dimensional temperature field of ECE are realized by setting the scalar value based on T_e . The cell type in VTK is VTK_QUAD, that is, the two-dimensional quadrilateral.

C. 2D Magnetic Field

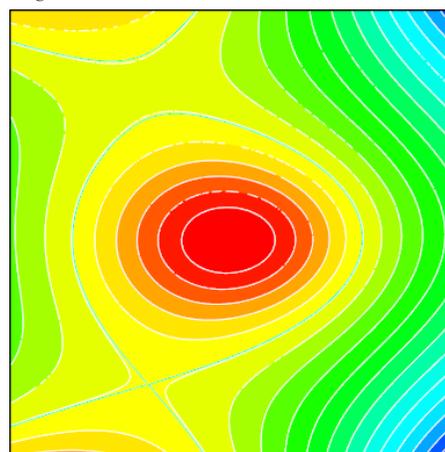


Fig. 13. Contour of magnetic flux

EFIT is widely used for solving the problems of plasma two-dimensional balance in tokamak, GFILE is the standard output file of the EFIT program. At the same time, GFILE is also the standard input file format of some other programs. GFILE has its specific output format, the corresponding

information is read according to the interface description. GFILE contains all the basic information about the two-dimensional plasma balance in tokamak, such as the number of grid points, flux value of calculation grid, plasma boundary location, and plasma profile information.

Two-dimensional magnetic field visualization is to draw the two-dimensional equilibrium magnetic field by rotating the contour of the boundary magnetic flux which is built according to read the GFILE file, and get the grid information and boundary magnetic flux and render through the visualization algorithm. Users only need to open the GFILE file so that they can get the corresponding two-dimensional balance magnetic field structure.

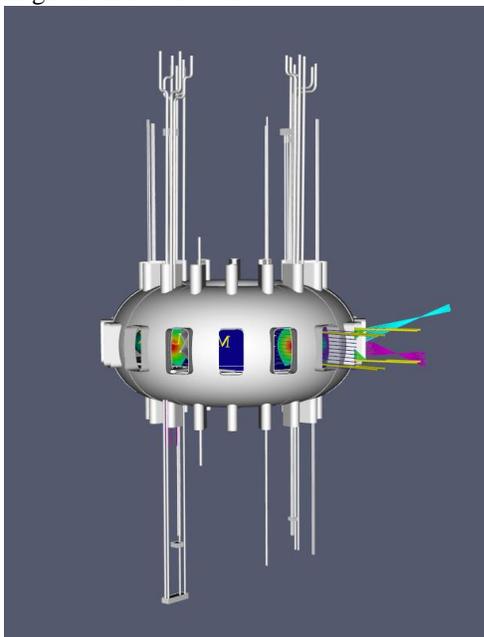


Fig. 14. Magnetic field visualization in VEAST

Take the file g054416.03600 which has 129*129 grid points for example, specific lines of the file are read first and the variable values are stored. The coordinates of grid points are calculated and stored to point object of vtkPoints and cell object of vtkCellArray according to R direction width, Z direction width, initial coordinates of R direction and center coordinates of Z direction. The magnetic flux values are assigned sequentially to each grid point. The number of contour lines is set and the contour is drawn according to the magnetic flux. Two-dimensional equilibrium magnetic field is rendered by setting the rotation angle. The grid of GFILE is evenly distributed, so the cell type is VTK_PIXEL. Fig. 13 shows the two-dimensional magnetic field contour map of the GFILE file g054416.03600, the green line in the figure represents the contour of the boundary magnetic flux. The visualization of two-dimensional magnetic field integrated with EAST model is shown in Fig. 14. Visualization of magnetic field are presented together with the EAST model on the autostereoscopic device for achieving an immersive display, as shown in Fig.15.

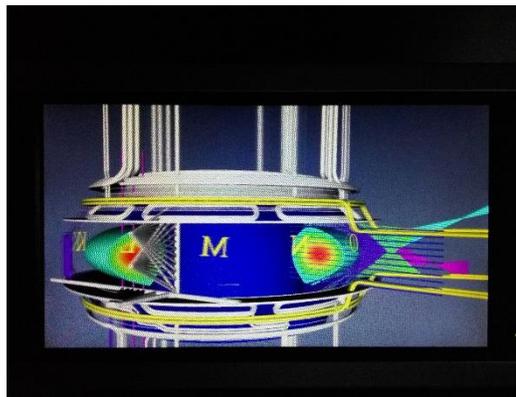


Fig. 15. Magnetic visualization in autostereoscopic device

V. CONCLUSION

This paper presented a solution for data visualization in VEAST system. Data visualization of plasma column, electron cyclotron emission diagnosis and plasma magnetic field was completed using the visualization toolkit and integrated into the VEAST system. Detailed data processing procedure and visualization steps were specified in this paper. The visualization results are intuitive to experts. Finally, visualization results are presented together with the EAST model on the autostereoscopic device for achieving an immersive display.

As future work additional data visualization will be realized and added to the virtual environment. Experiment data will be fetched from the database and rendered in real-time.

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