Simulation Data Analysis by Virtual Reality System

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We introduce new software for analysis of time-varying simulation data and new approach for contribution of simulation to experiment by virtual reality (VR) technology. In the new software, the objects of time-varying field are visualized in VR space and the particle trajectories in the time-varying electromagnetic field are also traced. In the new approach, both simulation results and experimental device data are simultaneously visualized in VR space. These developments enhance the study of the phenomena in plasma physics and fusion plasmas.

Keywords: Virtual Reality, CAVE system, Simulation data analysis, experimental device data, particle trajectory

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1. Introduction

The progress in computer technology makes it possible to perform large-scale and detailed three-dimensional simulations, and then we can obtain massive and complex simulation data. As a result, in simulation research, it becomes important moreover to develop an analysis tool to bring out useful physical information from the simulation data. However, it is difficult to grasp intuitively the complex structures of visualized objects by only projection of them on two-dimensional display because of lack of the depth information. In order to understand the complex and massive simulation results, it is indispensable to analyze them in three-dimensional space with a deep absorption into the virtual reality (VR) world by scientific visualization technology. Since National Institute for Fusion Science (NIFS) installed VR System "CompleXcope" based on CAVE system [1] in 1997, it has been developed continuously. CAVE system can produce three important visual factors; stereo view, immersive view and interactive view. Developments of new software such as, VFIVE [2, 3], AVS for CAVE, sonification system [4], reactor design aid tool [5] and so on have been performed. By using these new tools, CompleXcope has been made use for scientific investigation such as analysis of magnetohydrodynamics (MHD) simulation results for MHD dynamo [6] and spherical tokamak [7], analysis of molecular dynamics simulation results for chemical sputtering of plasma particle on diverter [8], analysis of particle simulation of magnetic reconnection [9] and so on.

For scientific VR visualization using the CAVE system, we develop new software to analyze the results of the plasma simulation, and a new approach method to display both simulation results and experimental device data (ex. CAD data) simultaneously in the VR world.

In this paper, we introduce such new development in scientific VR visualization in NIFS. In Sec. 2, we demonstrate visualization of particle trajectories in temporally evolving electromagnetic field by newly added animation function to VFIVE. In Sec. 3, simultaneous visualization of both simulation results and experimental devices is shown. Finally we summarize this paper in Sec. 4.

2. Scientific Visualization of Plasma Particle Simulation

It is reported that particle kinetic effect plays an important role in the trigger and heating mechanism in magnetic reconnection phenomena [10–12]. To understand more clearly the relationship between the particle kinetic effect and other physical quantities, we expanded VFIVE for tracing the particle trajectory in VR space [9]. Because structure of particle trajectory is complex in three-dimensional space, it is an appropriate approach to investigate it in VR space using CompleXcope. However, since plasma instability is excited in magnetic reconnection region, it is considered that the time-varying electromagnetic field also performs an important function in reconnection mechanism. To investigate the function of time-varying electromagnetic field, we newly add an animation function to VFIVE. By using the new developed software, we can trace the trajectories of plasma particles in time-varying electromagnetic field obtained by simulation, that is, the trajectories of particles are calculated in temporal evolving electromagnetic field, and visualized in VR space. The orbit of a single particle is calculated by integrating the Newton-Lorentz equation. We can point the initial position of particle by the three-dimensional mouse "Wand." The initial velocity is obtained by the flow velocity which

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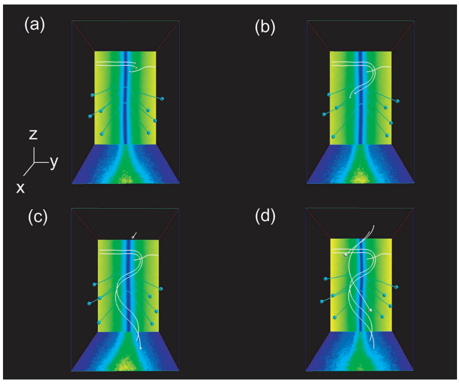

Fig. 1 Scientific visualization of simulation results of magnetic reconnection in time-varying electromagnetic field at (a) $t/\Delta T = 40$, (b) 60, (c) 80 and (d) 100, where ΔT is the interval time of updating field data. Color contours in xy and yz planes show ion temperature profile and reconnection component $B_x^2 + B_y^2$, respectively. White lines are ion trajectories.

is given by simulation data. Animation function added newly to VFIVE loads time-sequential simulation data one after another, and reproduces the visualized objects of isosurfaces, stream lines and so on about physical quantities according to the temporal changes of them in VR world. Because the seeds of objects, for example, levels of isosurface, are saved through the reproduction of the visualized objects, it is possible to observe the temporal changes of objects with same seeds in the VR space. Particle trajectory is calculated under the newly loaded electromagnetic field, that is, under the time-varying electric field. By using this software, it is possible to observe the temporal evolution of particle meandering motion strongly related to the reconnection mechanism in the time-varying electromagnetic field (Fig. 1). It is found that plasma instablity with low frequency is excited near the central region [13,14], and that the amplitude of meandering motion is almost comparable to the width of high temperature region of ion. It is reported that the particle trajectory around the reconnection region in the temporally evolving electromagnetic field is different from that in the fixed electromagnetic field. To understand the reconnection phenomena, it is surely more important to analyze the trajectories in time-varying fields.

This software can be widely applied. VFIVE can load data by any type of simulation when their data format is adjusted to the data format of VFIVE. Moreover, equation of motion for particle can be easily replaced by another equation, for example, guiding center and so on.

3. Scientific Visualization of Both Simulation Data and Device Data

It is demanded that both of simulation results and experimental device data are visualized by the VR system to analyze directly the simulation results in the device. Moreover, it is useful and effective in the design of experimental device to grasp the relationship of positions between the devices, or the device and plasma in the VR space, before setting the device in the real vessel. Recently, we succeed in the visualization of both simulation results and device data in the VR world (Figs. 2, 3 and 4). In Figs. 2 and 3, pressure isosurface of Large Helical Device (LHD) plasma obtained by MHD simulation [15] is visualized in the virtual LHD vessel, which is visualized under the CAD data, in the VR space. By using this visualization in the VR space, it is possible to grasp intuitively the position of plasma in the virtual vessel from the port of observation. In Fig. 4, experimental scientists used CompleXcope and discussed the positions of new devices in LHD vessel in the VR space. In this discussion, the contact of the new device with the LHD vessel and the relationship between the positions of the device and plasma were debated. This

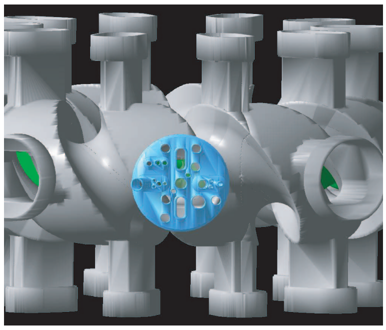

Fig. 2 Scientific visualization of both simulation result and experimental device data from outside of LHD vessel device. Simulation result about LHD is obtained by MHD simulation [15], and pressure profile is shown as green isosurface.

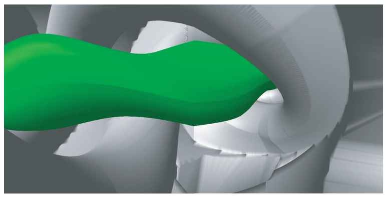

Fig. 3 The same figure as Fig. 2 but inside of LHD vessel device.

Fig. 4 Picture taken when experimental scientists discussed new devices in LHD vessel by means of CAVE system.

visualization is useful to decide which direction the observation device should be pointed in, and where the new device should be set in the LHD vessel.

This success opens a new path in contribution to the experiment.

4. Summary

We introduced new developments of VR technology in NIFS in this paper. We added animation function to VFIVE. It became possible to visualize time-varying fields, and to trace particle trajectories in the time-varying electromagnetic field in VR space. We succeeded in visualization of both experimental devices and simulation results simultaneously in VR space This success indicated that it became possible to grasp intuitively the distance between the plasma and the device or the devices in the vessel, to simulate operations in the vessel, to confirm the field of vision from observation port, and so on in VR space. VR technology is a very useful tool in analysis of simulation data and development of experimental devices. We believe that these developments introduced in this paper will enhance the study of the phenomena in plasma physics and fusion plasmas, and contribute to experiment moreover.

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