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A glassless stereoscopic visualization system for a 3D MHD real-time Earth's magnetosphere simulator

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Abstract. We have developed a glassless stereoscopic visualization system for the real-time numerical simulator of the interplanetary space–magnetosphere–ionosphere coupling system, adopting the three-dimensional (3D) magnetohydrodynamical (MHD) simulation code. Our real-time Earth's magnetosphere simulator numerically reproduces the global response of the magnetosphere and the ionosphere at the same time with the real world by using the real-time Solar wind data, and has shown two-dimensional (2D) figures of the global magnetosphere of about 1 hour in advance in virtual reality at every minute on Web since November 2003. We implemented 3D graphical techniques such as volume and iso-surface rendering for visualizing scalar variables and also colored 3D streamlines for representing the magnetic field for standard and glassless stereo-displays. A real-time interpolation method mapping the simulated data to structured uniform rectilinear grids commonly utilized in computer graphics was developed, so that this 3D visualization system is capable of monitoring the real-time Earth's magnetosphere simulated data in on-line mode.

1. Introduction

As the first step of space weather forecasting based on a physical model, we developed a real-time global magnetosphere simulation system using three-dimensional (3D) magnetohydrodynamical (MHD) code (Tanaka 1994) that adopts an unstructured grid system to cope with the different special scales between the magnetosphere and ionosphere (http://www2.nict.go.jp/dk/c232/realtime/) (Den et al. 2006). To obtain simulation results for the magnetosphere of about 1 hour in advance in real-time speed, we use the real-time Solar wind data obtained by the ACE spacecraft as an upstream boundary condition and optimized the parallelization and vectorization of the code in which the grid numbers are reduced to a necessary

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minimum. The real-time processing is also required for visualization, so that our visualization is confined on the $x-z$ plane for the plasma pressure (p) and the magnetic field (B) in our operating real-time Earth's magnetosphere simulator because 3D visualization is time-consuming in general. However, we may miss finding some important phenomena in the two-dimensional (2D) graphical system which may cause space environment disturbances, so a fast, real-time 3D visualization system is needed.

We developed a 3D visualization system for our real-time Earth's magnetosphere simulator. On-line visualization of 3D magnetosphere data is still a challenge in the community of numerical simulations because of the relatively large simulation data sizes and high requirements imposed on processing and rendering time. The task is becoming more difficult if one takes into account the fact that the simulated data are non-uniformly distributed, while the standard graphical procedures require the data to be given in 3D rectilinear grids for fast rendering. Our 3D visualization can be seen on standard and glassless stereo-displays. Stereo-viewing is a powerful method for the analysis of 3D data and for feeling the virtual reality. Some methods with devices such as polarization glasses can show realistic 3D figures, however, they need special displays or screens or rooms, and this equipment can be very large. Our purpose of stereo-viewing is the real-time numerical analysis of the simulation 3D data and we require that stereo-viewing is possible at one's desk. It is well known that two sets of 3D graphical data for both eyes are needed at least, which is in contrast to the real-time processing. Hence, the core of the system is the fast 3D-gridding methods simplifying the graphical rendering. This paper describes a 3D visualization system for volumetric rendering of magnetic pressure and magnetic field lines with output on standard and glassless stereo-displays.

In Sec. 2 the system configuration is described, and a technical explanation of 3D visualization is given as well as sample pictures in Sec. 3. A summary is provided in Sec. 4.

2. System configuration

An outline of the system configuration of operating a real-time Earth's magnetosphere simulator was described in (Den et al. 2006). Here the system is intended for 3D visualization of p and B output in the real-time Earth's magnetosphere simulator on the supercomputer at PC-based client sites equipped with standard and glassless stereo-displays. In the real-time simulation loop, the data are dumped once per minute and transferred to the clients. As for stereo-viewing method, we selected glassless methods as mentioned in the previous section. Glassless stereo-viewing is still a developing technique. In the parallax barrier method adopted in our system, graphical data for both eyes are split by the barrier at the display, so the resolution per one frame gets lower and figures per one viewpoint get darker as viewpoints increase. We selected the one-viewpoint display on a laptop computer due to portability and the seven-viewpoint 22-inch display due to high resolution, 3840×2400 pixels, which corresponds to 1646×800 pixels per viewpoint.

There are three main steps in the dataflow scheme: original data transfer via the network; preprocessing (3D-gridding and smoothing); and 3D scene rendering at the client sites. 3D rendering includes volume/iso-surface rendering, 3D magnetic field line rendering, layout and annotation display. The whole rendering time depends on the selected methods of volume rendering (software-based ray casting or 2D-texturing done by OpenGL), the density of magnetic field lines

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calculated by Runge–Kutta integration, and the size of preprocessed 3D-grids. For the preprocessed data mesh sizes of 64^3–128^3, the whole rendering time is from 0.1 to 7 s for one display frame, and stereo glassless displays require between two and seven frames to be rendered. Finding the trade-off among the rendering methods, volume sizes, and visual quality, a frame rate was achieved of around 2 s even for the seven-viewpoint display. We estimate the time taken from damping the 3D simulation data at the supercomputer to 3D visualization at the one-viewpoint display. On condition that the simulation data size is 0.5 MB for one variable, four variables (p, B_x, B_y, B_z) are visualized and the network speed is 1 Gbps, transferring simulation data to a PC-master takes 2 s, meaning mapped data for graphics takes 20 s, sending mapped data to a PC-slave takes 5 s and drawing 3D pictures takes 2 s. It takes about 29 s in total, so dynamic movie loops of the processed simulated data with a time step of 1 min demonstrated that the damping one-minute interval is sufficient for real-time movie loop rendering. Typically, with high-quality 3D-gridding, slight smoothing by a fast 3D Gaussian filter, the use of the OpenGL-based volume rendering method gives sufficient visual quality. The whole OpenGL system is based on VTK 4.2 (Shroeder et al. 2002) on top of OpenGL, with a thematic core graphical library developed especially for magnetosphere visualization. Other parts of the software include network support, stereographic tools, a preprocessing library and a GUI. All of the rendering methods rely on the fast 3D-gridding procedure.

3. Software components

3.1. Fast 3D-gridding method

The simulated 3D scalar fields (p, or magnetic field components B_x, B_y, B_z) are input into the graphical system in the form of a non-uniform 3D grid (Tanaka 1994) $p[i, j, k]$ $(i = 1, \ldots, 40, j = 1, \ldots, 58, k = 1, \ldots, 56)$, where the Cartesian coordinates of the grid $x[i, j, k]$, $y[i, j, k]$, and $z[i, j, k]$ are highly irregularly distributed. However, this grid is topologically structured, and the field value at arbitrary Cartesian position $p(x, y, z)$ can be evaluated if the original grid cell (spatial input grid voxel with the corners at $[i^*, j^*, k^*]$ and $[i^* + 1, j^* + 1, k^* + 1]$) containing (x, y, z) is known. The task of finding the cell container can be done, for instance, by sorting. The sorting procedures are very time-consuming and we implemented a lookup-table method for real-time mapping of the simulated data onto the target uniform rectilinear grids. The original simulated data of sizes $40 \times 58 \times 56$ are mapped to the uniform rectilinear grid of sizes 64^3, 128^3, 256^3 within 0.017, 0.15, and 1.2 s, respectively, for a 3 GHz PC. The lookup tables can be built in off-line mode for different regions of interest (ROI). At present the algorithm of lookup-table generation is based on gradient-less minimization in multi-dimensions, which accelerates the creation of tables for selected ROIs.

3.2. Graphical contents

The thematic module of the software system acquires the preprocessed data and renders several graphical objects and/or volumes to visualize in 3D pressure and magnetic lines. The scalar variable can be rendered by the following methods: ray-casting or texture-based volume rendering, ray-casting or marching-cube iso-surfaces rendering, color slices, and combinations of these methods. Three-dimensional magnetic field lines are rendered as streamlines, and the color of any scalar variables can be mapped on them (pressure or magnetic field component).

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Figure 1. The x–z plane is overlapped on the volume of the plasma pressure and on the colored 3D magnetic field lines with the GUI operation menu.

The colored 3D magnetic field lines and partially cropped volume of the plasma pressure are shown in Fig. 1.

The standard lookup tables were generated for the area of interest around the Earth: $x = [-15, 40]$, $y = [-40, +40]$, $z = [-40, +40] R_e$, where R_e is the Earth radius. Any planes and any combinations of planes such as x–y, y–z, z–x can be overlapped on 3D figures as shown in Fig. 1. This figure also shows that GUI operation is being prepared at present.

4. Summary

We have developed a glassless stereoscopic visualization system for the real-time 3D global magnetosphere simulator which is now operating for space weather forecasting. With the system, it is possible to visualize high-quality graphical scenes including volumes, surfaces, and streamlines at a frequency rate sufficient for on-line monitoring through standard and glassless stereo-displays. Three-dimensional visualization techniques rely on the core 3D-gridding method as described in this paper. We can say that real-time analysis of the Earth's magnetosphere simulation results in full 3D space is possible.

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