A Three-Dimensional Visualization System for Real-Time Earth’s Magnetosphere Simulator

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We have developed a 3-dimensional (3D) visualization system for the real-time numerical simulator of interplanetary space-magnetosphere-ionosphere coupling system, adopting the 3D magento-hydrodynamical (MHD) simulation code developed by Tanaka. Our real-time Earth’s magnetosphere simulator numerically reproduces the global response of magnetosphere and the ionosphere at the same time with the real world by adopting the real-time solar wind data as upwind boundary conditions, and is now running routinely on the NICT’s super computer system from November, 2003. However, three-dimensional visualization is need for this system because the 2D visualization may miss revealing some important phenomena which may cause severe space environment disturbances.

We have implemented such 3D graphical techniques as volume and iso-surface rendering for visualizing scalar variables and also done colored 3D streamlines for representing 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 to monitor the real-time Earth’s magnetosphere simulated data in on-line mode.

1. Introduction

Recently, as the first step of space weather forecast based on physical model, we have developed a real-time global magnetosphere simulation system using 3D MHD code [Tanaka, 1994] that adopts an unstructured grid system to cope with the different special scales between the magnetosphere and ionosphere, and the finite volume TVD scheme to realize an effective capturing of discontinuities [Den, et al., submitted]. To get simulation results for the real magnetosphere in real-time speed, we adopt the real-time solar wind data obtained by the ACE spacecraft as an upstream boundary condition and optimize the parallelization and vectorization of the code in which the grid numbers are reduced to a necessary minimum.

Three-dimensional simulations obtain physical values at every mesh point in the 3D space, however, visualization is confined on the \( x-z \) plane for the plasma pressure and the magnetic field in our operating real-time Earth’s magnetosphere simulator because the real-time processing is required also for visualization. Namely our 2D visualization can miss revealing some important phenomena which may cause space environment disturbances.

We have developed a 3D visualization system for our real-time Earth’s magnetosphere simulator. On-line visualization of 3D magnetosphere data is still a challenge-able task in the community of researchers using numerical simulations because of 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 given in 3D rectilinear grids for fast 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. The core of the system is the fast 3D-gridding methods simplifying the graphical rendering.

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

2. System Configuration

The outline of operating real-time Earth’s magnetosphere simulator was explained in Den, et al. Here the system is intended for 3D visualization of the plasma pressure \( p \) and the magnetic field \( B \) output in the real-time Earth’s magnetosphere simulator on the supercomputer at PC-based client sites equipped by standard and glassless stereo (1-viewpoint Sharp Mebius and 7-viewpoint Sanyo) displays. In the real-time simulation loop the data are dumped once per minute and transferred to the clients with the usage of file exchange protocol built on top of FTP. The size of one transferred portion of the data is about 2MB, therefore, network bottlenecks are critical to visualize the data on-line. There are three main steps in the dataflow scheme: · original data transfer via the network; · preprocessing (3D-gridding and smoothing); · 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), density of magnetic field lines calculated by Runge-Kutta integration, and the size of preprocessed 3D grids. For the preprocessed data mesh sizes of 643-1283,
the whole rendering time is from 0.1 to 7 sec for one display frame, and stereo glassless displays require 2-7 frames to be rendered. Finding the trade-off among the rendering methods, volume sizes, and visual quality, the frame rate was achieved around 2 sec even for the 7-viewpoint display. Typically, with high-quality 3D-gridding, slight smoothing by fast 3D Gaussian filter, the usage of OpenGL-based volume rendering method gives sufficient visual quality. The whole OpenGL system is based on VTK 4.2 [Shroeder, et al] on top of OpenGL, with a thematic core graphical library developed especially for magnetosphere visualization. Other part of software includes network support, stereographic tools, preprocessing library, and GUI. All the rendering methods rely on fast 3D-gridding procedure described below.

3. Fast 3D-gridding method

The simulated 3D scalar fields \( p \) or magnetic field components \( B_x, B_y, B_z \) are inputted to the graphical system in the form of the non-uniform 3D grid [Tanaka, 1994] \( p[i,j,k] \) \((i=1..40, j=1..58, k=1..56)\), 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 the simulated data into the target uniform rectilinear grids. The original simulated data of sizes \( 40 \times 58 \times 56 \) are mapped to the uniform rectilinear grid of size 643 within 0.01 sec for a 3GHz PC. Then, the target grid is used for volume rendering, iso-surface rendering, 3D line drawing, etc.

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 texturing volume rendering, ray-casting or marching cube iso-surfaces rendering, color slices, and both of them. Three-dimensional magnetic field lines are rendered as streamlines, and color of any scalar variables can be mapped on them (pressure or magnetic field component). The colored 3D magnetic field lines and partially cropped volume of the plasma pressure are shown in Figure 1.

Dynamic movie loops of the processed simulated data with the time step of 1 min demonstrated that the damping one-minute interval is sufficient for real-time movie loop rendering. Any planes and any combinations of planes such as \( x - y, y - z, z - x \) can be overlapped on 3D figures shown in Figure 2. This figure also shows that GUI operation is being prepared at present.

4. Summary

We have developed a 3D visualization system for the real-time global magnetosphere simulator using Tanaka’s 3D MHD code which is now operating for the space weather forecast. 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 described in the paper.

In future, the 3D data available for 3D visualization in our system will be distributed on our Web site as well as visualization program, so that researchers possessing glassless stereo-display can analyze the real-time Earth’s magnetosphere simulation results in full 3D space.

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References


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

Fig. 2. The \( y - z \) plane is overlapped on the volume of the plasma pressure and on the colored 3D magnetic field lines with GUI operation menu.