# A 3D Visualization System for Real-Time Space Weather Simulator with a Glass-less Stereoscope

**DEN Mitsue, KUWABARA Takuhito, OGAWA Tomoya, TANAKA Takashi, GONCHARNKO Igor, and AMO Hiroyoshi**

A three dimensional (3D) visualization system with a glassless stereoscope was developed for the real-time numerical simulator of interplanetary space-magnetosphere-ionosphere coupling system, adopting the 3D magneto-hydrodynamic (MHD) simulation code. The Earth magnetosphere simulator numerically reproduces the global response of the magnetosphere and ionosphere at real-time by the usage of real-time solar wind measurements obtained by the ACE spacecraft. Since November 2003, the simulator is capable of visualizing on the Web two-dimensional (2D) images of the global magnetosphere, updating every minute the images with one-hour forecast. The following 3D graphical techniques were implemented for standard and glassless stereo displays to visualize the simulated scalar and vector fields in 3D: volume and iso-surface rendering, rendering of colored slices and streamlines. A special fast interpolation method mapping the simulated data onto uniform rectilinear grids commonly utilized in computer graphics was developed for 3D monitoring of the simulated data in on-line mode.

***Keywords***
Gassless stereoscopic visualization, Three-dimensional visualization,
Real-time processing, Space weather simulator

## 1 Introduction

Solar phenomena such as solar flares and coronal mass ejections are known to affect conditions in the terrestrial and near-terrestrial environments; the Space Weather Forecast Project is currently underway at the National Institute of Information and Communications Technology (NICT) with the aim of minimizing the adverse effects of such phenomena. Advances in space physics and recent extraordinary developments in supercomputers have enabled the incorporation of physics-based numerical simulation models as a tool for space-weather forecasting. NICT has developed the world's first real-time Earth magnetosphere simulator, which generates three-dimensional numerical simulations using real-time solar-wind data acquired by the ACE satellite, and the system has been in operation since November 2003. One-hour forecasts of the conditions of the Earth's magnetosphere are on display on the web (http://www2.nict.go.jp/y/y223/simulation/realtime/)[1] for use in space-weather forecasts. The details of the system are described elsewhere[1], but in short, the system reads data on solar wind variations at one-minute intervals and uses this information as upstream boundary conditions to resolve an ideal magneto-hydrodynamic (MHD) equation. This takes place in near-real time and in three dimensions, allowing for precise minute-by-minute reproductions of the dynamic response of the global magnetosphere to variations in the solar winds.

Although this real-time Earth magnetosphere simulator represents an innovative development, presentation of results is restricted to two-dimensional visualizations (the meridian plane containing the Sun-Earth line), and so the information produced by the three-dimensional simulation is not utilized to the full extent. Generally, disturbances generated in the Earth's magnetosphere consist of three-dimensional phenomena that occur in real space, and are therefore not restricted to a single plane. Thus, all of the three-dimensional data must be used in numerical analysis of these disturbances, and we must therefore develop a three-dimensional visualization system capable of real-time processing.

In many cases, visualization of three-dimensional data requires significant processing power, which may be demanding even for relatively large computers capable of high-speed processing. The functions we required of the three-dimensional visualization system are 1) real-time processing, 2) stereoscopic imaging, and 3) simplicity. To realize real-time processing, we will have to create a high-speed system for data preprocessing and visualization, since the time required for data transmission is network-dependent. The second condition arose out of the need to add depth, parallel to the line of sight, to simulation results; this forced us to seek elements that sometimes conflicted directly with the requirements for real-time processing and with the third condition (details given in the next section). The third condition, simplicity, refers to the ease with which a researcher may construct the visualization environment, both in terms of software and hardware. From this standpoint, it was important to avoid the use of bulky or costly instruments in implementation of the stereoscopic imaging technique. Accordingly, we have decided to adopt a glassless stereoscopic method that can be executed on any commercially available PC. Furthermore, we decided to construct a library and to develop a viewer adapted to this library based on the free software program known as the OpenGL Application Programming Interface (API). The following sections will describe in detail a real-time three-dimensional visualization system with glassless stereoscope that satisfies all three requirements given above.

## 2 System architecture

Figure 1 shows the overall system architecture. The supercomputer at NICT performs continuous three-dimensional simulation of the Earth's magnetosphere, and the results are output and transferred together with the visualization data for the web to the master PC for

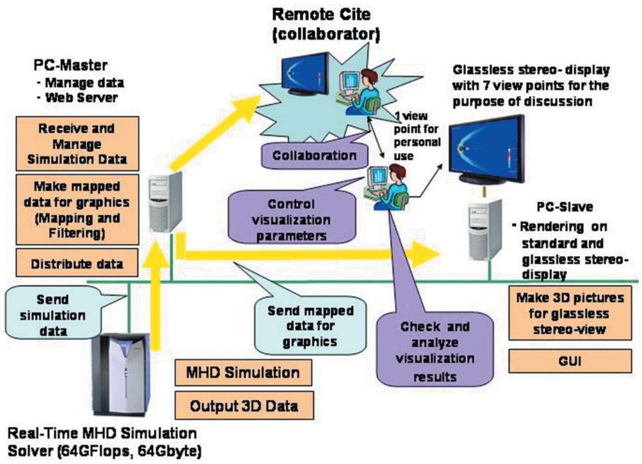


**Fig. 1** Architecture of the real-time three-dimensional visualization system

three-dimensional visualization. This master PC receives this data, and manages the simulation data as well as the library and viewer necessary for visualization. The user prepares a slave PC to download the necessary software from the master PC and to construct the visualization environment. Like the two-dimensional visualization images publicized on the web, the simulation data are updated every minute.

Two user-selectable modes, on-line and off-line, are available for data acquisition. The former mode involves real-time downloads of the latest data and automatic plotting of the latest image. Changes can be made in point of view, plot type, and visualization parameters on the slave PC, and changes made to the parameters become effective immediately in the latest set of data, even in on-line mode. Off-line mode was prepared to allow researchers to download the data of interest from the database available from the master PC for analysis. For example, a user can create a video image, based on user-selected visualization parameters, by choosing and downloading time-series data from the database. The options of choosing on-line or off-line modes and switching between stereoscopic and standard image mode represent the main features of this system.

### 2.1 Glassless stereoscopy

The visualization library and viewer described here will operate normally on ordinary computer displays. However, the use of compatible PC models will enable glassless stereoscopic imaging requiring no special equipment. Of the several available techniques for glassless stereoscopy, we decided to adopt the so-called "parallax barrier" method. When implementing stereoscopy for a single point of view, there must be two images—one for the left eye and one for the right. In the past, polarized glasses or shutter devices or the like have been used to separate the pair of images. With the method we have adopted, a barrier with slits is placed in front of the computer display to divide the images into the right-eye and left-eye images. The setbacks of this method are seen in reduced image brightness due to the barrier, lower resolution per frame (since the display must be divided into several frames), and the limited point of view from which the right-eye and left-eye images are conveyed. Two models that overcome these problems have been chosen for our system. One is a notebook PC having a single-viewpoint stereoscopic display that can present two images at a resolution of 1,024 × 384 pixels (1,024 × 768 pixels in standard mode). This model can be used as a conventional two-dimensional display by electronically switching the barrier on or off. The other model is a seven-viewpoint 22-inch display and a control desktop PC; this model is intended for simultaneous viewing by multiple users. This model can display seven images at resolution of 1,646 × 800 pixels per viewpoint, which is nearly equivalent to the resolution of normal displays. (The entire display features resolution of 3,840 × 2,400 pixels.)

### 2.2 3D-gridding

The steps in plotting the simulation results can be largely divided into three stages: data transmission, data preprocessing (3D-gridding and smoothing), and visualization. Since simulation data are updated every minute, these processes must be carried out in a total of less than one minute. Since data transmission is network-dependent and the time required for visualization is dependent on image quality and plot type, the minimum time required may generally be calculated by specifying these characteristics. In addition, in order to enable stereoscopic imaging, two images are required for single-viewpoint stereoscopy and seven images are required for simultaneous seven-viewpoint stereoscopy. Thus, efforts were made to speed up 3D-gridding in the preprocessing stage.

The MHD simulation code uses modified spherical coordinates corresponding to the structure of the Earth's magnetosphere. Although it is a structured grid (in which high-resolution mesh grids are mapped onto the necessary sections), the grid intervals are non-uniform[2]. The preprocessing stage involves mapping the physical quantities in the simulation results [in this case, plasma pressure p(i,j,k)(i=1‐40, j=1‐58, k=1‐56) and the magnetic field B(i,j,k)] in a uniform Cartesian coordinate system and to determine p(x,y,z) and B(x,y,z). However, since x(i,j,k), y(i,j,k), and z(i,j,k) are distributed irregularly, preprocessing will be significantly time-consuming if processes such as sorting are used. Therefore, we have created a look-up table to identify the corresponding coordinate values in advance and have also adopted a tri-linear interpolation filter for mapping physical quantities; together these measures are designed to enable high-speed preprocessing[3]. Table 1 shows the number of Cartesian grid points for visualization and the time required for mapping, as well as the memory required for the look-up table.

**Table 1** Number of Cartesian grid points for visualization and time required for mapping

**3D mapping time**

from Tanaka's grid to uniform rectilinear grid,
CPU Intel Pentium 4. 3 GHz, 1 GB RAM
Interpolator: tri-linear filter with look-up-table

| Output grid size | Whole grid mapping time | Look-up-table size in memory |
|---|---|---|
| $64^3$ | 0.017 sec | 3.1 MB |
| $100^3$ | 0.065 sec | 11.7 MB |
| $128^3$ | 0.15 sec | 24.5 MB |
| $150^3$ | 0.22 sec | 39.5 MB |
| $200^3$ | 0.55 sec | 93.7 MB |
| $256^3$ | 1.2 sec | 196.6 MB |

We can see that when using a PC unit with a 3 GHz CPU, the mapping process requires only 1.2 seconds even at a high resolution of $256^3$ grids. This system also features a look-up table that covers the standard plot range of x=[‐15,40]$R_e$, y=[‐40,40]$R_e$, z=[‐45,40]$R_e$ (here, Earth is located at the center at x=y=z=0; x is in the direction of the Sun-Earth line; z is in the north-south direction perpendicular to x; y is in the direction perpendicular to both x and z; and $R_e$ is the Earth's radius). In off-line mode, the look-up table can be created for any plot range.

## 2.3 Software architecture and plot type description

Figure 2 shows the software architecture; here the portion enclosed within the red line represents the core structure. At the lowermost layer is the basic visualization language known as OpenGL, and programming is performed using the corresponding library, VTK 4.2[4]. The simulation-data filtering layer corresponds to the preprocessing stage described above. The IO data interface in the topmost layer includes data reading, storage, transmission (in the master PC only), and the user interfaces (GUI, viewer). The platform-compatible layer is the hardware-dependent element required to adapt the system to the glassless stereoscopic display units. Thus, stereoscopic techniques such as polarization and shutter methods requiring special devices may be implemented simply by modifying this layer. The graphic card and the portion enclosed by the dotted line are options for speeding up visualization processing and for performing more high-grade rendering, respectively, and may be added to the system at later points. OpenGL and VTK are free, and the programs using these resources and other programs (depicted within the red line) have been developed for the present study. The core

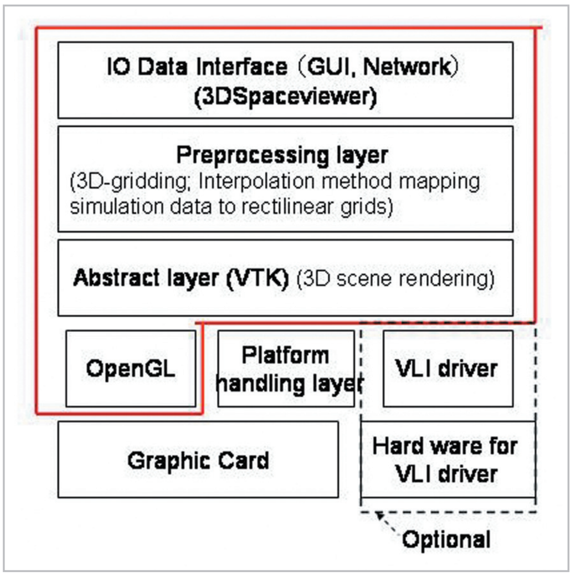


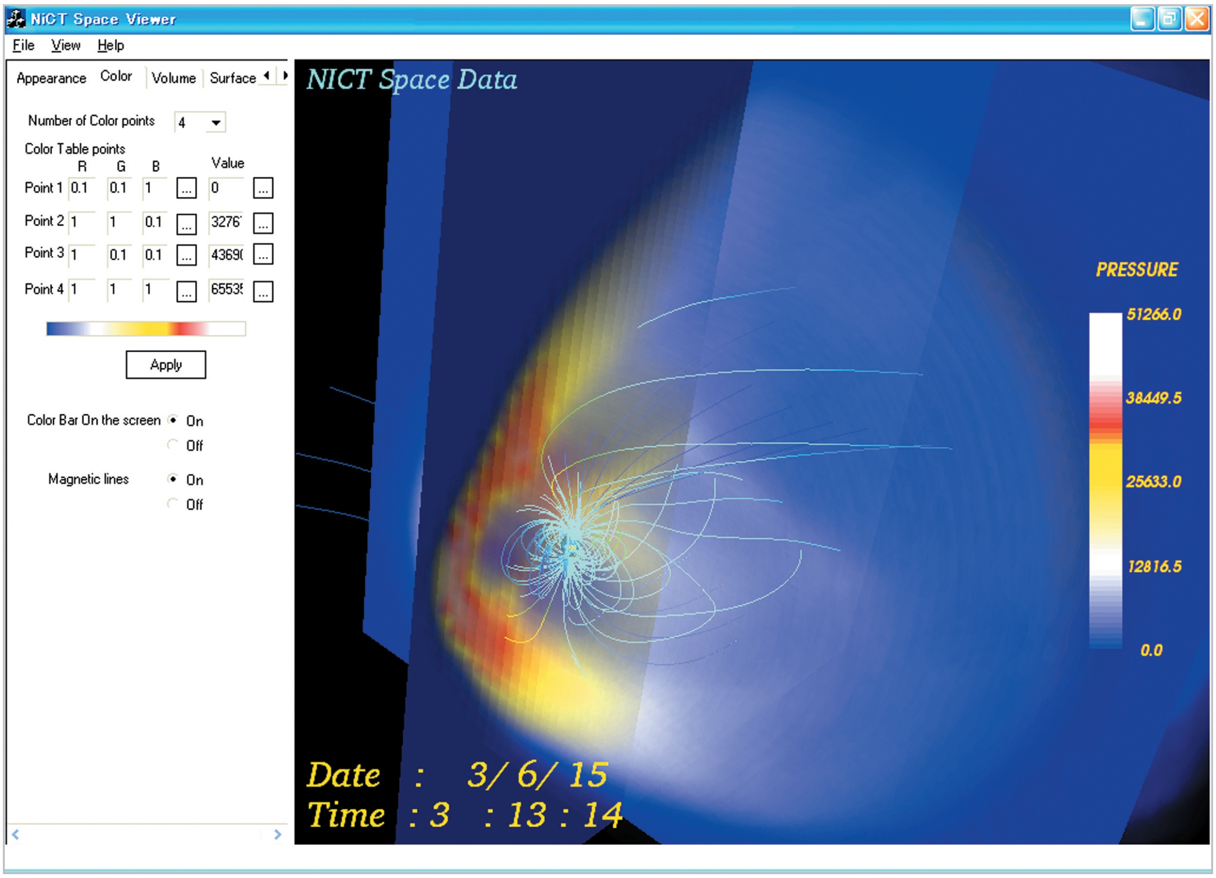
**Fig.2** Software architecture

element of this software structure may be distributed freely.

Here, we will describe the plot types available for visualization. The plots can present scalar fields such as pressure and density in general, and vector fields such as magnetic fields and velocity. The representation of the scalar field is performed by volume rendering with ray-casting/texturing methods; iso-surface rendering is performed via the ray-casting method and the marching-cube method; and rendering of color slices in the x-y, y-z, and z-x planes by combinations of these methods. Generally, the ray-casting method produces images of the highest quality, but it is also time-consuming. Smoothing is performed with a 3D Gaussian filter. In a 3D vector field, it is possible to map magnetic field lines and streamlines and to superimpose scalar fields on these lines using color contours. The user can also add figure captions, color bars, and time stamps, as well as show boundary regions representing the plot range. Figure 3 shows plasma pressure drawn with volume rendering, magnetic field lines mapped by color contours, and color slices in the x-z plane.

As stated above, the user can carry out real-time visualization and data analysis by switching between the on-line and off-line modes. In off-line mode, it is possible to create a video image based on the results of visualization for downloaded time-series data. The single-viewpoint stereoscopic display unit can be used both as a glassless stereoscopic display and as a conventional display by switching in and out of stereo mode.

Finally, we will estimate the time required for the entire process. A set of simulation data corresponding to 2 Mbytes may be transmitted from the supercomputer to the master PC within several seconds. The transmission from the master PC to the slave PC is expected to take approximately 10 seconds, even when the



Number of Color points 4

Color Table points

| | R | G | B | | Value | |
|---|---|---|---|---|---|---|
| Point 1 | 0.1 | 0.1 | 1 | ... | 0 | ... |
| Point 2 | 1 | 1 | 0.1 | ... | 3276 | ... |
| Point 3 | 1 | 0.1 | 0.1 | ... | 4369 | ... |
| Point 4 | 1 | 1 | 1 | ... | 6553 | ... |

Color Bar On the screen ● On ○ Off

Magnetic lines ● On ○ Off

Date : 3/ 6/ 15
Time : 3 : 13 : 14

**Fig.3** Results of three-dimensional visualization of plasma pressure and magnetic field lines in the Earth magnetosphere overhead in normal networks is taken into consideration. The data preprocessing time is approximately 1.2 seconds even at resolution of $256^3$ grids so the total time of data transmission and preprocessing is expected to take about 15 seconds. Thus, if visualization can be performed within 45 seconds and a single frame for seven-viewpoint stereoscopy can be created within six seconds, then it will be possible to complete the entire visualization process in less than one minute. This will involve a trade-off in terms of image quality, but it has been confirmed that this system can perform real-time processing for a plot created with volume rendering using a typical texturing method for a visualization grid number of $64^3$ with superimposed magnetic field lines.

## 3 Conclusions and acknowledgements

We have developed a three-dimensional visualization system for a real-time space weather simulator using a glassless spectroscope. Since real-time processing is required in this system, a combination of a data-mapping method known as 3D gridding and a look-up table was adopted to speed up the process. The system thus constructed has been proven capable of keeping up with minute-by-minute updating with some rendering techniques, and so it is now possible to generate a near-virtual reproduction of the Earth’s magnetosphere in real-time and in three dimensions.

The software developed by our group may be distributed freely, and we hope that it will be downloaded by many researchers in the simulation field to assist them in their studies.

The present study was conducted at NICT from 2004-2005. We are grateful to Harunobu Masuko, Executive Researcher at NICT, and Hiroshi Kumagai, Executive Director of the Applied Research and Standards Department of NICT, for their roles in providing us with the necessary R&D environment, as well as to Takahiro Obara, Group Leader of the Space Simulation Group, for his support and encouragement.

### *References*

1 M. Den, T. Tanaka, S. Fujita, T. Obara, H. Shimazu, H. Amo, Y. Hayashi, E. Nakano, Y. Seo, K. Suehiro, H. Takahara, and T. Takei, “Real-Time Earth Magnetosphere Simulator with 3-Dimensional MHD Code”, Space Weather Journal, in press.

2 M. Den, T. Kuwabara, T. Ogawa, T. Tanaka, I. Goncharenko, and H. Amo, “A Glassless Stereoscopic Visualization System for 3D MHD Real-Time Earth's Magnetosphere Simulator”, Journal of Plasma Physics, in press.

3 T. Tanaka, “Finite volume TVD scheme on an unstructured grid system for three-dimensional MHD simulation of inhomogeneous systems including strong background potential fields”, Journal of Computational Physics, Vol.111, pp. 381-389, 1994.

4 W. Shroeder, K. Martin, and Lorensen, “The Visualization Toolkit”, Third Edition. Publ. Pearson Education Inc., 2002.

***DEN Mitsue**, Ph.D.*

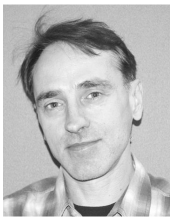
*Professor, National Institute for Fusion Science*

*Astrophysics*

***OGAWA Tomoya**, Ph.D.*

*Expert Researcher, Space Simulation Group, Applied Research and Standards Department*

*Simulation of Interplanetary Space*



***Igor GONCHARENKO**, Ph.D.*

*Chief Research Officer, 3D Inc.,*

*Virtual Reality, 3D Computer Graphics, Robotics*

***KUWABARA Takuhito**, Ph.D.*

*Research fellow, First Technical Development Department, Advance Soft Corporation*

*Numerical Simulation for Magnetohy-drodynamics*

***TANAKA Takashi**, Ph.D.*

*Professor, Kyushu University*

*Geophysics*

***AMO Hiroyoshi**, Ph.D.*

*NEC Corporation Information*

*Technology*