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(Citation)
Memoirs of the Graduate Schools of Engineering and System Informatics Kobe University,5:7-9

(Issue Date)
2013

(Resource Type)
departmental bulletin paper

(Version)
Version of Record

(URL)
https://hdl.handle.net/20.500.14094/81005533

Memoirs of the Graduate Schools of Engineering and System Informatics Kobe University
No. 5, pp. 7–9, 2013. doi:10.5047/gseku.e.2013.002

Dynamical Visualization of Vector Field via Multiple Streamlines in Virtual Reality Environment

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(Received August 30, 2013; Accepted October 17, 2013; Online published October 28, 2013)

Keywords: Data visualization, CAVE, Virtual reality, Vector field, Simulation data analysis

In order to visualize a vector field in a three-dimensional virtual reality environment, a generalization of the streamline visualization method is proposed. In this method, multiple streamlines are traced in real-time. The seed points of the lines are placed on a virtual beam emitted from a portable controller. As one varies the position and direction of the controller by hand, the beam and therefore the seed points follow the motion, and the streamlines change their three-dimensional shape in real-time.

1. Introduction

The technique of visualization plays a key role in the analysis of vector fields produced by computer simulations. Among various visualization methods of vector fields, the streamline method[1)] is one of the most fundamental ones[2)].

A streamline $\boldsymbol{x}(s)$ with the parameter s for a vector field $\boldsymbol{A}(\boldsymbol{x})$ is defined by $d\boldsymbol{x}(s)/ds = \boldsymbol{A}(\boldsymbol{x})$. A standard numerical integration scheme is used to solve the equation to obtain a streamline $\boldsymbol{x}(s, \boldsymbol{x}_0)$ with the initial condition or the seed point $\boldsymbol{x}_0$.

In this study, we propose a generalization of the streamline visualization method for a virtual reality (VR) environment. The proposed method, called the coupled multi-branch (COMB) streamline method, is composed of multiple streamlines drawn in a VR environment. The main purpose of this method is to visualize complex vector fields such as a chaotic vector field.

In recent years, VR systems have been used for visualizations of various scientific simulations[3) 4) 5) 6)]. We implemented the COMB method as a component of the general-purpose visualization program for CAVE-type VR systems, the VFIVE[7)].

2. Coupled Multi-Branch Streamlines

The COMB streamline method is essentially applied to a snapshot of the data of a vector field, wherein the vector field itself shows no temporal variation.

We draw multiple (typically ten) streamlines at once. The seed points are located uniformly on a "virtual beam," which is emitted from a portable controller called the wand (see Figure 1). The position and direction of the wand are usually tracked by a wireless sensor system in VR systems. The beam and therefore the seed points of the streamlines are programmed to follow the wand motion in real-time.

The key point in the COMB method is its dynamical manner of analysis; the viewer observes changes in the streamlines as he/she moves the wand controller, although the target vector field comprises snapshot data.

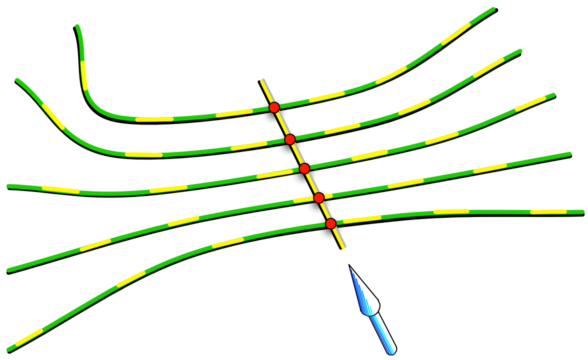

Fig. 1 Concept of the proposed method. A short beam is emitted from a portable controller wand (depicted by the arrow) in a virtual reality (VR) space. Seed points (red) of streamlines (green and yellow) are located on the beam. The integration of the streamlines is performed in real-time while the viewer moves the wand in the VR space.

3. Implementation

We implemented the COMB method in a VR system called the pCAVE system that is installed at Kobe University.

The pCAVE system is a one-screen, projector-based VR system. The screen size is 3048 mm (width) × 2441 mm (height). The computer system comprises an SGI Asterism adt08 with 2 × AMD Opteron 2350 processors (2.0 GHz, 4-core) with 64 GB memory and an NVIDIA Quadro FX 4600 graphics card. For the tracking system, the Intersense IS900 is used along with the Trackd software package. The projector is a Christie Mirage S+4K.

The line tracings are applied in both the positive and negative directions for the target vector. The standard

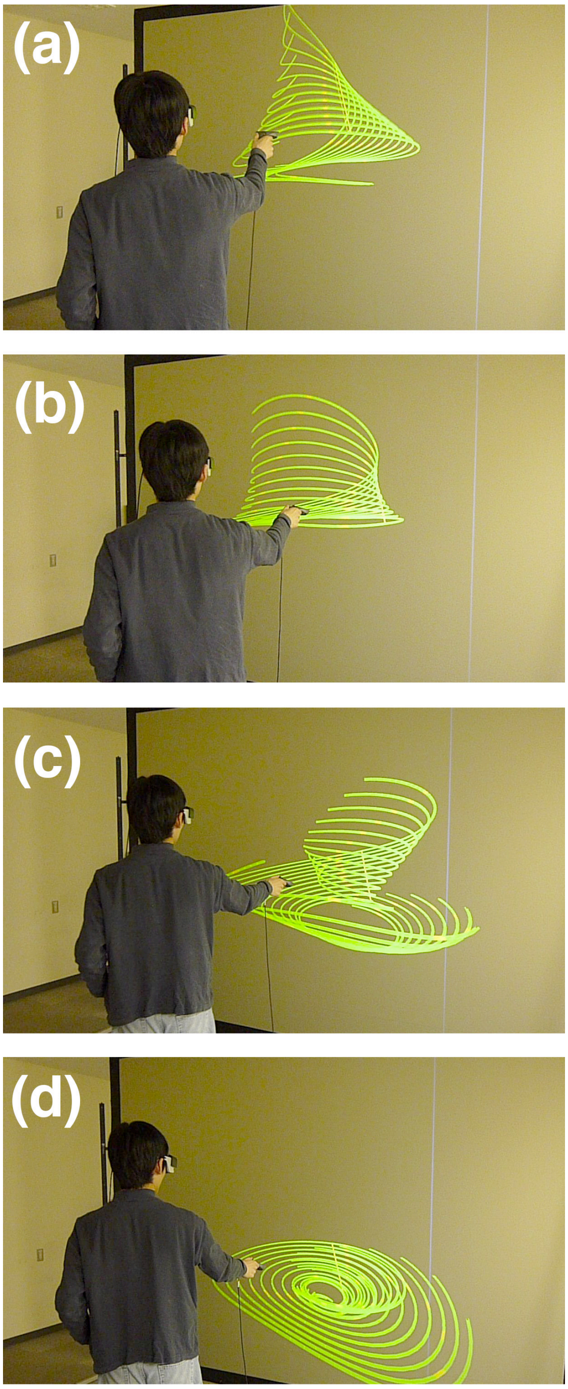

Fig. 2 Snapshot sequence of the COMB streamlines applied to a geodynamo magnetohydrodynamic (MHD) simulation. The seed points of the streamlines follow the hand motion. The displayed streamlines dynamically change their shape in real-time.

fourth-order Runge-Kutta method is used for numerical integration. A third-order interpolation is applied for the spatial interpolation of data.

The data loading, spatial interpolation, and the automatic control of the integration step $\Delta \boldsymbol{x}$ are performed by the VFIVE program. To provide ease of viewing, each streamline is drawn by a thin tube-like object.

In the present implementation, the tracing of ten streamlines costs only $O(10^6)$ floating point operations and each streamline is constructed by $O(10^3)$ polygons. Therefore, the tracing and rendering of the ten streamlines are easily processed in real-time on PCs.

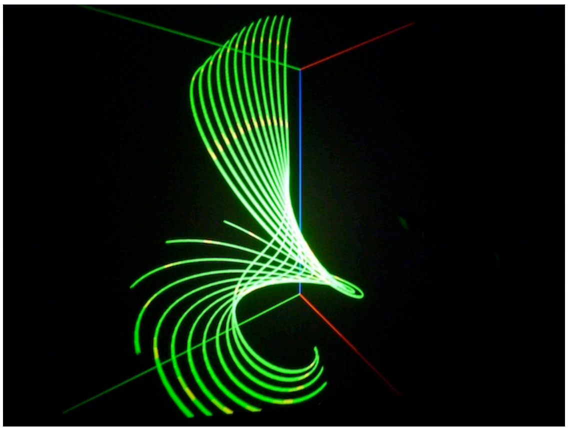

Fig. 3 Same visualization as in Fig. 2 under a different lighting condition.

As shown in Figure 1, each streamline is colored in a stripe pattern (green and yellow). The stripe pattern moves in the vector direction, and its drift speed indicates the amplitude of the vector at each position.

Figure 2 shows a typical sequence of the COMB visualization method applied to a magnetic field calculated by a magnetohydrodynamic (MHD) simulation.

The viewer places the COMB beam around a hot spot to be analyzed and observes the dynamical changes in the COMB streamlines while moving his/her hand. The fully interactive visualization with a stereoscopic view provided by the VR system assists the viewer to grasp the three-dimensional structure of the target vector field. Figure 3 shows the same visualization as in Figure 2 under a different lighting condition.

4. Summary

In this study, we proposed an interactive visualization method for vector fields in a VR system. This method, called the COMB streamline method, is a type of generalization of the commonly used streamline method.

The COMB method is essentially a dynamic visualization method in contrast to static visualizations such as classical streamlines or ribbons. In the dynamic visualization via the COMB method, the analyzer moves his/her hand around a target region (hot spot) and observes the dynamical changes in the streamlines. The temporal changes in the streamlines resulting in tandem with the hand motion convey an intuitive understanding of the three-dimensional structure of the target vector field.

The COMB method can play a crucial role particularly in the analysis of chaotic vector fields. The shapes of the streamlines are sensitive to the seed-point locations. When we apply the COMB method to such a chaotic vector field, we observe dynamical changes in the drawn lines as we move the seed beam around bifurcation points. Figures 2 and 3 show these behaviors for a chaotic vector field.

Having applied the COMB method to several vector fields, we have confirmed that this method is effective to analyze vector fields with complicated spatial structures. We have also found that it would be desirable to change the number of seed points while analyzing the data. This function will be implemented in the next revision.

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