

Data Visualization by Video See-Through Head Mounted Display

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(Received 18 September 2015 / Accepted 2 October 2015)

Recent advances in head mounted display (HMD) systems, specifically those demonstrated by the Oculus Rift, provide a new platform for three-dimensional scientific visualization. Taking advantage of this opportunity, we have constructed a cost-effective video see-through visualization system by combining a stereoscopic camera system and an Oculus Rift device. The see-through HMD system enables a researcher to analyze numerical data in a virtual reality space, with keeping visual communication with nearby collaborators in real space. We have ported our visualization software for CAVE systems, VFIVE, to the HMD system. The ported software enables its user to analyze three-dimensional scalar/vector fields in a virtual reality space while simultaneously being able to view the natural surroundings.

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Keywords: data visualization, head mounted display, virtual reality

DOI: 10.1585/pfr.10.1201087

Virtual reality (VR) technology provides scientists with a simple platform for three-dimensional data visualization [1, 2]. It enables realtime interactions with numerical data in a VR space.

There are two different types of VR display systems. One is the head mounted display (HMD) system [3] and the other is the immersive display system, represented by CAVE [4].

CAVE is a room-sized VR system that was developed in 1992. A viewer in a CAVE's VR room is surrounded by large displays on which stereoscopic images are displayed or projected. By tracking the position and orientation of the viewer's head (or eyes) in real time, the system is able to render stereoscopic images from the viewers point of view, thus allowing the viewer to walk in the room and observe three-dimensional objects from any position and direction. The head tracking system is a key technology for realizing a highly immersive experience in the VR space. In spite of the high quality VR experience provided by the CAVE system, the usage of CAVE in academic research or small commercial organizations is limited because it is too expensive.

Meanwhile, recent advances in HMD systems, as demonstrated specifically by the Oculus Rift [5] (Fig. 1), have caught the attention of researchers, and there is a clear increase in the use of HMD systems in the research community [6, 7]. The Oculus Rift provides stereoscopic images with a wide field of view at a reasonable cost. It comes with a head tracking system.

To those researchers moving from using CAVE to using the Oculus Rift, a natural idea was to attempt to port scientific visualization programs developed for CAVE to

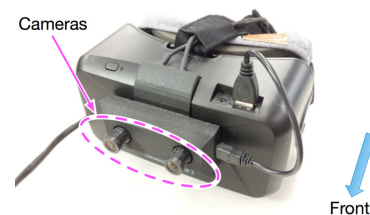


Fig. 1 A snapshot of an HMD system, Oculus Rift, on which a stereoscopic camera system is installed on the front face.

HMD. The porting itself would be technically straightforward because the main structure of the visualization program is common. The only changes needed would be for the input (from sensors) and output (to display) parts of the program. In fact, we have successfully ported our visualization program originally intended for CAVE to the Oculus Rift system with no technical problems.

However, using the ported visualization program on the Oculus Rift system gives rise to two problems. The most serious one is that the user is unable to view his or her surroundings because the HMD device covers the face. This makes it difficult for the user to communicate with his or her collaborators during visualization. When we use the Oculus Rift system for a scientific visualization, one researcher wears the HMD device on his/her face and other researchers are usually looking at the display monitor of the PC system that control the whole system. The images shown on the PC's monitor are exactly the same as those that are displayed on the HMD device at each moment. Verbal communication of the visualized data between the researcher who puts on the HMD device (wearer), and the other researchers (non-wearers) is certainly possible.

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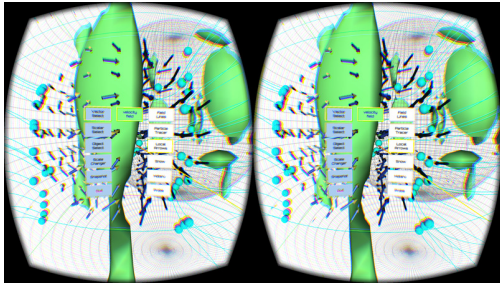


Fig. 2 A screen capture of vFive, a general purpose visualization program for HMD systems.

However, non-verbal communication is fully suspended due to the covered vision of the wearer. This reduces the value of the Oculus Rift system as a visualization tool. See-through HMD devices such as MREAL [8] are available but they are expensive, and they don't have a head tracking system built-in. The second problem of using the Oculus Rift is the specific one of not being able to view one's hands. This causes difficulties in using a portable controller as the input device for the visualization program.

The purpose of this paper is to resolve the problem of not being able to view one's surroundings when using a HMD system like the Oculus Rift. To that end, we have developed a visualization system that uses the Oculus Rift but allows its user to view his or her surroundings even when using the visualization program.

Previously, we had developed a general-purpose visualization program for CAVE-type VR systems [9–11]. This program, VFIVE, provides various visualization methods for scalar/vector fields, such as isocontouring, colored slicing, volume rendering, vector glyphs, stream lines, and particle tracers. VFIVE has been used for visualizations of magnetic reconnection [12], Earth's magnetosphere [13], geodynamo [14], general circulation models of atmosphere [11], and others.

As mentioned earlier, we ported VFIVE to the Oculus Rift system, and we renamed the ported version of VFIVE as "vFive." A screen capture of vFive is shown in Fig. 2. We used the Oculus SDK ver. 0.5.0.1, because this version of SDK provides multi-platform framework including Windows, Linux, and Mac OS X. For the basic API for graphics, we used OpenGL and GLFW ver. 3. For rendering fonts, we used FreeType and FTGL. The program was written in C++.

For porting, we first removed all function calls of CAVELib from the source code of VFIVE. CAVELib is a basic library for VR construction in CAVE systems. The synchronization of multi-screens, view-point adjustment via the head tracking system, and stereoscopic image generation are handled by CAVELib.

In the Oculus Rift system, the head tracking is automatically done by Oculus SDK. The tracked position/orientation data are processed by a program that was

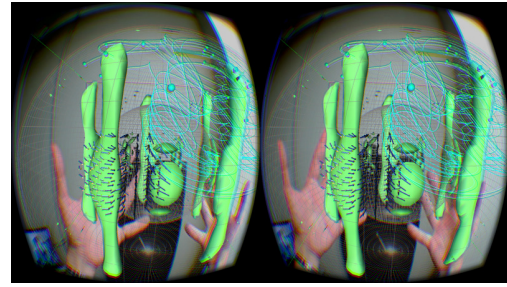


Fig. 3 A screen capture of the video see-through HMD system. The view of the surroundings is overlaid by images from the visualization.

developed by us, to develop a proper viewing projection in real time. Following the standard procedure to generate stereoscopic images on Oculus Rift, we render two images (for the left and right eyes), placed side-by-side, with a natural parallax. The images are automatically rendered in a distorted, barrel-like shape, in order to fit to the Oculus Rift's lens system. This is done by functions of SDK. The main visualization methods of VFIVE are already ported to vFive on Oculus Rift.

To make the Oculus Rift a see-through HMD, in effect, we put an external stereoscopic camera (Ovrvision [15]) on the front face of the Oculus Rift device. The two small short cylinders that can be seen attached on the front face of the Oculus Rift device in Fig. 1 are cameras for the left and right eyes. The video images of the Ovrvision are imported through a function in Ovrvision SDK, and the images of the surroundings are overlaid by those rendered by vFive in real time. As a result, the video see-through HMD is realized. A sample screen capture is shown in Fig. 3.

One of the potential applications of vFive on the see-through HMD is a scientific visualization of magnetohydrodynamics (MHD) data produced by the so-called geodynamo simulations, in which time development of the MHD equations is solved to resolve the generation mechanism of the geomagnetic field. VFIVE was successfully used in a CAVE system to analyze a geodynamo simulation data and a new structure of electric field current (spiral current) was found in the CAVE's VR space [14]. Since most visualization functions of VFIVE are implemented in vFive, we can expect that similar new physics is found with vFive on a much cheaper, see-through HMD system.

In summary, we have constructed a cost-effective video see-through visualization environment by combining a stereoscopic camera system with an Oculus Rift device. The total cost of the camera-attached Oculus Rift system, including the controller PC system, would cost us about $O(10^5)$ yen. On the other hand, a CAVE system amounts to $O(10^7)$ to $O(10^8)$ yen. We ported our visualization software intended for use for CAVE systems, VFIVE, to the HMD system. The ported software, vFive, enables its user to analyze scientific data of three-dimensional

scalar/vector fields in a VR space, while simultaneously being able to view his or her natural surroundings.

Problems remaining to be solved for this video see-through HMD system include its usability in terms of being able to simply specify the spatial position and orientation for the input of vFive. Currently, we are using a mouse, but a more suitable device can be used as the main input device.

This work was supported by JSPS KAKENHI Grant Number 25730080 and 23340128.

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