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Collaborative virtual reality space for analyzing numerical simulation results

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Abstract. One of the most practical objectives for the use of virtual reality (VR) systems in science is facilitating an intuitive understanding of complex physical phenomena. We developed a VR system, called CompleXcope, which can represent a 'real' three-dimensional visual and aural environment. However, communication with other researchers at a remote site (VR space) regarding simulation results is difficult, since this system is very large and is not portable. Therefore, it is important to construct a multilateral communication network system, in which researchers at any remote site are equally able to observe simulation results from any point and take initiative in controlling the display of the image in a virtual environment (VE), and in which the control is simultaneously transmitted to all of the remote sites. In the present paper, we describe a collaborative virtual environment and an example in which the simulation results are applied.

1. Introduction

Rapid advances in computer software and hardware have resulted in dramatic increases in the data set sizes generated for large-scale modeling and simulation. Along with these enhanced computational capabilities come new challenges. First, how does one effectively visualize, interact with, and comprehend the sizeable volume of information that is generated? Second, in this age of team-oriented approach to design using geographically distributed workgroups, how can such large amounts of information be efficiently and simultaneously shared among groups? One solution to these questions is to use virtual reality (VR) systems and share the output generated by each group through a high-speed network. We have therefore proposed a VR system for scientific visualization, called CompleXcope. The CompleXcope system is based on the CAVE system (Immersive Projection Display) [1]. The CAVE system was originally a stand-alone system, but the sharing of numerical simulation results (three-dimensional (3D) image data) among remote sites is becoming more important for promoting numerical simulation research. Collaborative environments for Immersive Projection Display have been proposed (e.g. [2]). However, many of these applications are not practical for real-time visualization and transfer of large-scale data. We have therefore constructed a collaborative environment in our virtual environment (VE). The purpose of the present study is to develop a viable VR system and to demonstrate the viability and practicability

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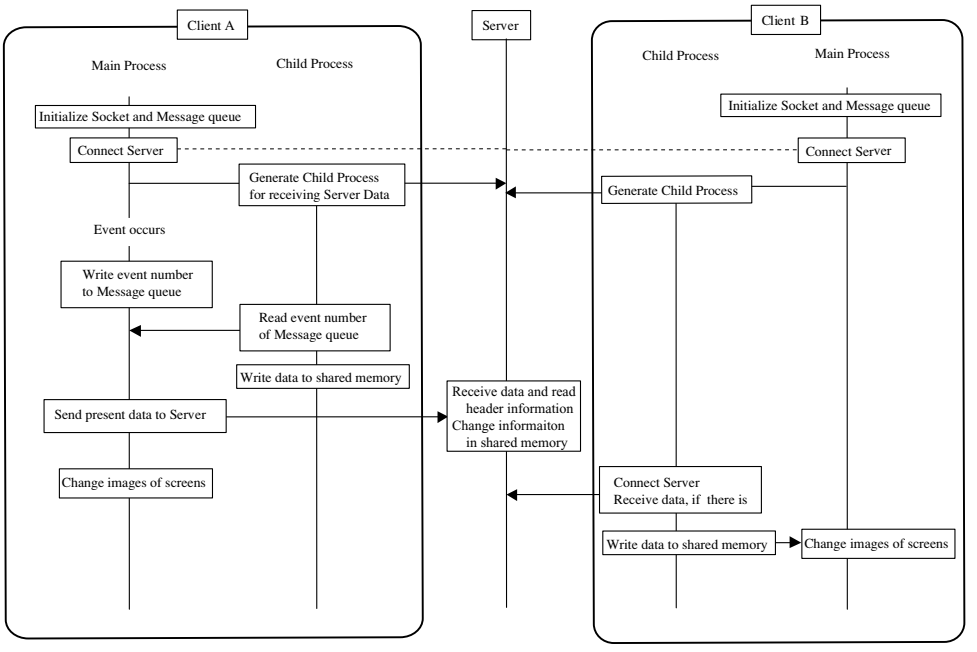


Figure 1. Data flow among a server and clients.

of the system for assisting in the comprehension of complex evolution of physical phenomena.

2. VR system

The CompleXcope system has four screens ($3 \times 3\,\mathrm{m}^2$), which are arranged to form a cube (front, right, left and floor) on which stereo images are projected. The correct stereoscopic perspective projections are calculated by a graphics workstation (SGI ONYX4) in real time. The user wears a pair of stereo liquid crystal shutter glasses and a six-degree-of-freedom head-tracking device. The workstation redraws images on each wall in response to changes in the eye position and direction of the user. In addition, the CompleXcope system has a 3D-sound system that enables sonification of numerical simulation data [3].

3. Network configuration of the collaboration system

In the collaboration system, a VR network is accomplished by socket communication (client–server model). Figure 1 shows the components of the collaboration system. The collaboration system consists of server and client programs. The client programs can connect to this network group at any time, if the server program is running. In this system, all clients already have the same numerical simulation data and have the same applications installed for representation. The procedure for connecting with clients is as follows.

3.1. Preparation

Let us assume that two remote sites (site-A and site-B) want to connect to each other. First, the server process starts, preparing a socket to connect with any client

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processes. After that, the server process requires the shared memory space to store the interaction data from any remote sites.

On the other hand, client-A at site-A initializes a socket to connect to the server, a message queue to manage the event number, and the shared memory space to store data received from the server. The event number refers to numbered interaction mode data, for example 'drawing line' is numbered 1. By storing this number, the client process can know what event is occurring and order the drawing process to change the scene or the values of the visualized data. In the shared memory space of the client computer, the values of the interaction data (for the example of drawing a line, the starting point position data) are stored. After this preparation, client-A requests connection to the server and generates its own child process to receive data from the server. The procedure for connecting client-B at site-B is the same.

3.2. Event processing

The main functions of the main process in the client computer are to draw 3D objects while referring to the values in the shared memory space and to send data changed in the client computer to the server. If an event occurs in client-A, the main process of client-A writes the event number to the message queue and sends the current data (interaction mode data) to the server. At the same time, the child process of client-A refers to the event number. If this value is changed, then the process writes the changed value to the shared memory space in the client computer. On the other hand, if an event occurs in client-B, then client-B processes the same procedure as client-A. In client-A, the child process accesses the server at certain intervals, and if new data are stored in the shared memory of the server, then this process retrieves these data and writes them to the shared memory space of site-A. Since the main process also draws images using this stored data, client-A and client-B can share the same images. By processing these procedures, each client shares the present interaction data in real time. Moreover, if another client wants to participate in the group, then the client can join at any time because the server stores the entire data set written by clients that are already connected. Although this section describes only the sharing of interaction data, the collaboration system can also share the position of the observer, i.e. the position and direction of the observer's hand and head. The procedure for sharing this position information is the same as that for sharing interaction data.

Figure 2 shows an example visualized by this system. In this example, the results for the numerical simulation of a spherical tokamak are shared, and the remote user position is displayed by a 3D computer-generated figure. At the remote site, the user can view visualized numerical simulation results from his/her favorite position and angle.

3.3. Estimation of data transfer rate

For estimating the data transfer rate of the system, we connected two VR systems and investigated the practicality of the system. The numerical simulation data were downloaded and stored in a local hard disk drive of each client computer before connecting the VR systems. The transferred data were the information used to control the visualized simulation data and the information of positions of remote users. The two systems were connected only by a 1.5-Mbps computer network. The data communication rate was, at worst, 21.9 Hz. The fastest stereo image projection speed of the CompleXcope was 48 Hz for each eye, which is higher than

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Figure 2. An example of the over-network collaboration for VR visualization. A pressure isosurface of the spherical tokamak [3] is shown. The remote user is represented by a 3D figure. If the remote user moves, this information is sent to the other sites, and the figure is redrawn in accordance with his/her original motion. In the same way, when he/she changes the visualization parameter, the information is automatically sent to other sites, resulting in the same visualization in all sites.

the communication rate. However, the maximum projection speed obtained was, at best, 30 Hz, so the system appears to pose no serious problems for communication. Therefore, this software is practical and useful for the communication of simulation data.

4. Conclusion

In the present paper, we discussed 3D data sharing among any number of remote sites via the CompleXcope system using socket communication (server–client model). In order to enable the sharing of virtual reality space and numerical simulation results among remote sites, using the CompleXcope system (originally a stand-alone system), VR spaces at remote sites are connected by networks, and information on controlling virtual objects and on the position of the observer is shared. Finally, the speed at which these data were sent and received was confirmed to be sufficient, so that users felt no delay due to network communication.

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References

[1] Cruz-Neira, C. et al. 1993 Surround-screen projection-based virtual reality: the design and implementation of the CAVE. *Proceedings of the SIGGRAPH '93 Computer Graphics Conference* New York; ACM Press, pp. 135–142.

[2] Leigh, J. et al. 1998 LIMBO/VTK: a tool for rapid tele-immersive visualization. *CDROM Proceedings of IEEE Visulization '98* Research Triangle Park, NC, October 18–23.

[3] Tamura, Y. et al. 2001 Virtual reality system to visualize and auralize numerical simulation data. *Comput. Phys. Commun.* **142**, 227–230.

[4] Mizuguchi, N. et al. 2000 Dynamics of spherical tokamak plasma on the internal reconnection event. *Phys. Plasmas* **7**, 940–949.

https://doi.org/10.1017/S0022377806005241 Published online by Cambridge University Press