Collaborative Flow Field Visualization in the Networked Virtual Laboratory

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Abstract

Scientific visualization in the three-dimensional virtual space is an effective method for discussion and examination among researchers. In this study, a collaborative scientific visualization system that can be used in the shared immersive virtual world was developed. This system integrated several elemental technologies, such as synchronized visualization, video avatar, shared database and i-mode interaction, in order to realize the functions required for the collaborative research. This system was applied to the collaborative flow field visualization experiment between remote sites, and the effectiveness was evaluated. In particular, in this experiment, the most effective arrangement of the shared virtual space according to the collaboration style was examined.

1. Introduction

Scientific visualization is one of the important application fields of virtual reality technology [1][2][3]. In particular, visualization of numerical simulation data or experimental data in three-dimensional virtual environment is an effective method for discussion and examination among researchers. On the other hand, recent advances in the broadband network, such as the Internet2 and the JGN (Japan Gigabit Network), have allowed us to transmit a large amount of data between remote places. Then, it has become possible to share a high presence virtual world by connecting several immersive projection displays [4][5]. Therefore, it is expected that remote researchers can discuss and examine scientific data while sharing them with a high quality of presence in the networked immersive virtual environment.

Although several researches on the collaborative scientific visualization using the networked environment have been conducted, most of the systems only implement the functions of sharing visualized data or communication [6][7][8]. The purpose of this study is realizing a networked virtual laboratory where remote researchers can explain their work or discuss the phenomenon with other researchers while sharing various kinds of data and reference materials in the high presence shared immersive virtual world. This study is being conducted as part of the MVL (Multimedia Virtual Laboratory) project promoted by the Ministry of Public Management, Home Affairs, Posts and Telecommunications [9].

In this study, a networked immersive projection display environment was constructed, and a prototype of collaborative flow field visualization system was developed to realize the objectives described above. This paper describes the system requirements needed for the collaborative flow field visualization, talks about the elemental technologies used in the system that we implemented, and gives details of a visualization experiment using this system to show how it can be used for the collaborative research.

2. Requirements for Collaborative Flow Field Visualization

In order to construct a collaborative flow field visualization system using the networked immersive projection display, the following functions are required.

a. synchronization of visualized data
b. natural communication
c. sharing reference materials
d. data operation at both site

Synchronization of visualized data

First, in order to realize collaborative flow field visualization, it is required for the researcher between remote places to be able to see the same data at the same time. Fluid dynamics data is often visualized using an animation to represent the behavior of time-varying flow field. Therefore, it should be guaranteed that not only the same data is visualized at both sites but also the same frame of the animation data is visualized synchronously between remote places.

Natural communication

Next, in order to realize an effective discussion in the shared virtual world, it is necessary that the remote researchers can naturally communicate with each other through the network. This means that a local user can see a remote user's figure and hear the remote user's voice by transmitting image and sound information. In this case, it is important that this information should be sent with a high quality of presence so that the user can recognize what the remote user is explaining or which point the remote user is emphasizing.

Sharing reference materials

It is also desirable that various kinds of reference materials can be shared with the visualized data between remote researchers in order to realize an effective examination in the shared virtual space. For example, explanation documents about the fluid analysis method or video clips that filmed the wind tunnel experiments are typical of the reference materials. By taking these materials into the shared virtual space, remote researchers are able to discuss and examine the visualized phenomenon effectively.

Data operation at both sites

Finally, it is required that the researchers at both sites can operate the visualized data and the reference materials displayed in the shared virtual world. In this case, if different commands were input from two sites, a process of exclusive control should be conducted in order to manage the shared virtual world without contradiction. In addition, an interface device that the ordinary people can easily operate should be used for that purpose.

3. Elemental Technologies Implemented in the Prototype System

In this study, we developed a collaborative flow field visualization system that can be used in the immersive shared virtual world. The following elemental technologies were developed and used in this system to meet the above-mentioned requirements.

3.1. Synchronized Visualization

First, a function of sharing visualized data was developed in order to construct a collaborative flow field visualization system. The visualization tool used in this study has several visualization functions for flow field data, such as streamlining, particle tracing, contour lines, surface layer rendering, and also of creating animations of these phenomena (Figure 1). In this system, the simplest method of running the same program at both sites is used in order to share the visualized data. These programs must run while communicating with each other and transmitting the data to guarantee the consistency of the shared virtual world.

The operation commands used in the visualization system include selecting the visualization method, changing the size and position of the visualized data, starting or stopping the animation and so on. When the visualization programs are run at both the server site and the client site, a communication path is created between them, and when an operation command is input at the server site, it is also transmitted to the client site as well as being operated at the server site. Thus, the same data is visualized at the server and at the client sites, due to the command communication. The method for the server to receive the operation command from both sites will be mentioned in Section 3.4.

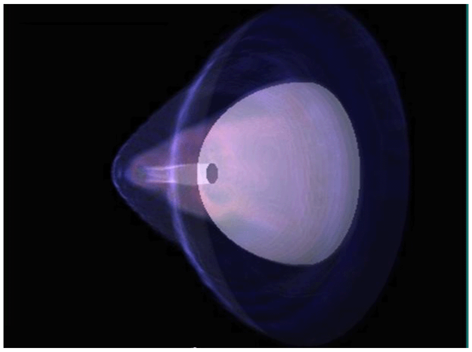


Figure 1. Visualization of flow field data using surface layer rendering

In addition, when animation data is visualized in the shared virtual world, it is necessary for remote researchers to be seeing the same frame of the animation data at the same time. In this system, the frame rate of the animation speed is specified, and it can be controlled at a fixed speed while the animation is being played, by measuring the rendering time for every rendering loop. By using this method, the animation can be played at a fixed frame rate at each site.

Moreover, when an operation command is input, such as starting or stopping the animation, the frame number of the animation data that is just being rendered at the server site is sent to the client site with the command data. At the client site, when the frame number is received, the error of the rendering frame due to the variation in communication lag and rendering time is adjusted so that the frames being rendered at both sites are consistent as shown in Figure 2.

In this study, the accuracy of the synchronization was measured between Tokyo and Gifu sites, by recording the visualized images with a time signal. From the result, the time gap between both sites was less than 0.06 seconds. Thus, we can understand that the remote researchers are able to discuss the visualized data with each other in the shared virtual world looking at the synchronized animation.

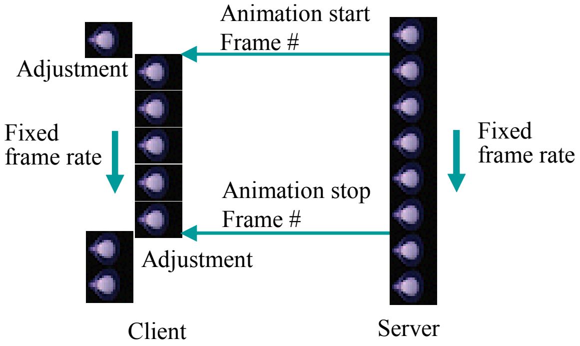


Figure 2. Frame control mechanism for animation data

3.2. Video Avatar

Next, in order to realize natural communication in the shared virtual world, it is necessary that the remote researcher's figure can be represented with a high quality of presence. In particular, gestures and facial expressions should be transmitted in such a way that a user can recognize which point the remote user is emphasizing or whether the remote user understands his speech. Therefore, video avatar technology was developed and used in this system, which does not rely on computer graphics characters, but utilizes a live video image of the user.

This technique can represent a high presence figure of the remote user. The user's image is captured by a video camera at each site, and these images are mutually transmitted to the companion site. These images of the users can assist communication in the shared virtual world. Since this method transmits a live video image of the user, the gestures and facial expressions of the remote users can be directly represented in the virtual world. A particular feature of this study was the development of stereo video avatar technology [10]. This method utilizes a stereo video camera and creates a three-dimensional video image that incorporates a geometric model of the user's body.

Figure 3 shows the method of making a stereo video avatar. In this method, the user's figure is captured by a stereo video camera and the depth data for each pixel are calculated from the stereo images. Once the depth image is calculated, the user's figure can be segmented from the background using a threshold of the depth value, and a geometric polygon model of the user can also be created. Finally, by texture-mapping the segmented user's image onto the polygon model, a video avatar that includes a three-dimensional geometric model can be generated.

This process operates in real-time and the generated video avatar is mutually transmitted to the remote site along with the positional data. When the video avatar data is received, it is superimposed at the position where the remote user is standing in the shared virtual world. Therefore, the positional relationship between users, such as standing side-by-side or meeting face to face, can be represented. Thus, the stereo video avatar technology can be used effectively for the communication in the three-dimensional shared virtual world.

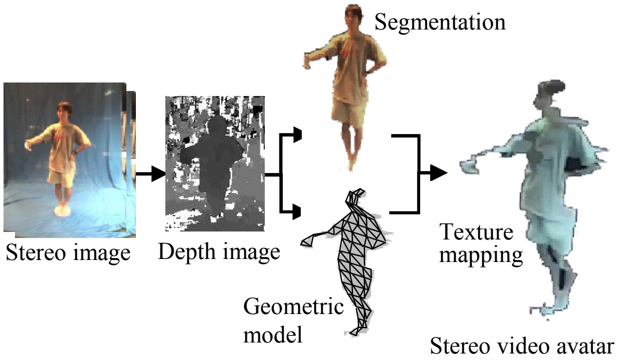


Figure 3. Method for making a stereo video avatar

3.3. Shared Database

In this study, in order to construct a framework for taking various kinds of reference materials such as slides or video clips into the shared virtual world, a shared database named CCBASE (Cyber Communication data BASE) was developed.

CCBASE provides an interface that allows a user in the virtual world to access a database through the network and to manage the retrieved data in the shared virtual world. Data taken into the virtual world is represented as being filed in a book using a book metaphor as shown in Figure 4. By using the CCBASE, various kinds of data such as images, video clips, three-dimensional models and PowerPoint files can be manipulated in the virtual space.

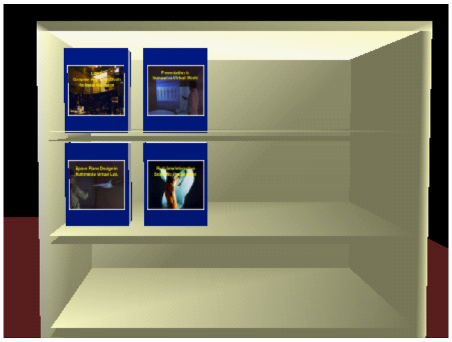


Figure 4. Reference materials taken in the virtual world using CCBASE

When the CCBASE is used in the collaborative flow field visualization system, the PowerPoint file that explains the numerical calculation method and the video clip that filmed the behavior of the flow field in the wind tunnel experiment can be referred in the visualization environment.

In order to share the reference materials in the shared virtual world, any operations that are carried out on them must be shared throughout the network. Figure 5 shows the data-sharing mechanism of the CCBASE. When the input command is received by the server site, it is transmitted to the client site. Thus, the same commands are operated at both sites.

In this case, important commands that cannot be missed in order to share the data, such as turning the pages of the slides or starting the video clip, are transmitted using a TCP/IP protocol, and data for which only the latest version is required, such as the tracked position of the user's hand, are transmitted using a UDP protocol.

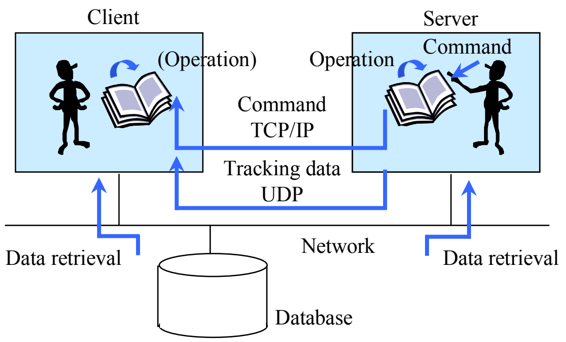


Figure 5. Data sharing mechanism of the CCBASE

3.4. i-mode Interaction

Finally, in order to realize an effective collaborative visualization in the shared virtual world, it is necessary that the researchers can operate the visualized data freely at both sites. In this system, i-mode of the cellular phone was used for the interaction device [11]. i-mode is an Internet access service provided by NTT DoCoMo, Inc., and it can be used to interact with a computer system through a web written in compact HTML and CGI.

In an application system used in the shared virtual world, a control mechanism for interaction commands being input from both sites is required. For example, if different commands are input from two sites, a process of exclusive control should be conducted in order to manage the shared virtual world without contradiction. Since the i-mode communicates with the server computer using a wireless network, both the users at the local site and at the remote site can access the same computer directly. Therefore, commands input from both sites can be treated consistently, by processing them in order in the server computer.

In this system, the computer at either site is used as a communication server. When it receives the commands that are input from both sites, it transmits them to the client computer as well as processing them in the server computer. Figure 6 shows the processing mechanism of the i-mode interaction in the shared virtual world. Since this technology is well suited to the above-mentioned operations, such as used in the synchronized visualization and the shared database, it can be used as a common interaction method.

In application systems used in the immersive projection displays, an interaction method using a three-dimensional menu and a wand interface is often used. However, it is difficult for an inexperienced user to operate a menu directly in the three-dimensional space. In the case of the i-mode interface, the user can easily operate the menu displayed on the LCD of his own cellular phone.

Figure 7 shows the examples of the interaction menus of the i-mode interface. (a) is a menu used in the visualization tool, and (b) is a menu for referring to the PowerPoint slides. In these examples, since each command is assigned to the dial buttons from 0 to 9, the user can easily send an operation command by pushing just one button.

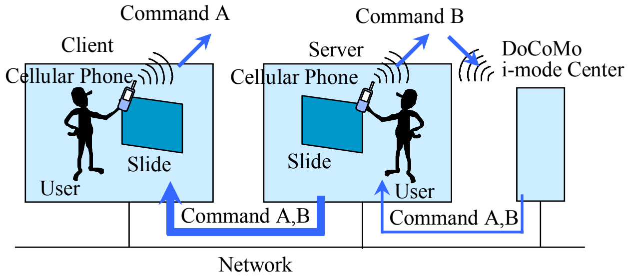
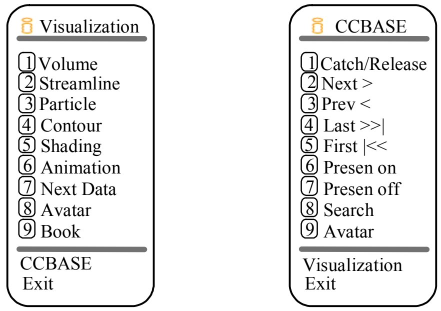


Figure 6. i-mode interaction in the shared virtual world



(a) Visualization tool (b) PowerPoint slide

Figure 7. Interaction menu of the i-mode interface

4. Collaborative Flow Field Visualization Experiment

4.1. Experimental Environment

In this study, a collaborative flow field visualization system was developed by integrating several elemental technologies mentioned above, such as the synchronized visualization, the video avatar, the shared database and the i-mode interaction, and it was used for a visualization experiment. In this experiment, the networked environment between CABIN at the University of Tokyo and COSMOS at the Gifu Techno-Plaza was used as shown in Figure 8. CABIN and COSMOS are CAVE-like multi-screen immersive projection displays that contain five and six screens respectively, and they are connected through the JGN (Japan Gigabit Network) [12][13].

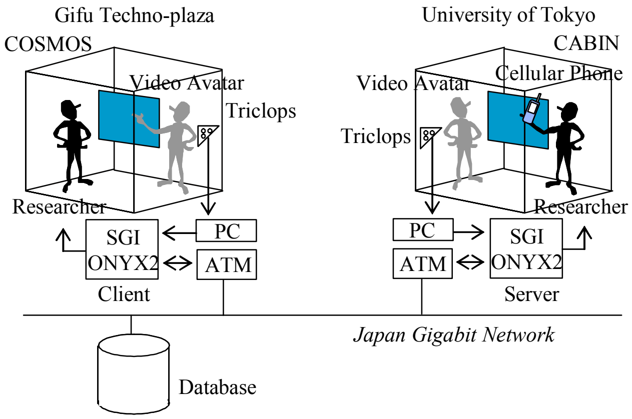


Figure 8. System configuration of the collaborative flow field visualization system

In the experimental system, a Triclops stereo video camera made by Point Grey Research Inc. was placed in the display space of the immersive projection display, and was used for creating a stereo video avatar. The PowerPoint sheets and the video clips were stored in the database system connected with the JGN network, which could be accessed from each site. In order to share the virtual world, the graphics workstation SGI Onyx2, which is used to generate the computer graphics images displayed in the CABIN site, was used as the communication server, and it received the commands sent from each site.

Figure 9 shows the software construction of the collaborative flow field visualization system. CABIN library was used to make a basic program of visualizing three-dimensional flow field in the multi-screen immersive projection display. In addition, the MVL library was developed to implement the functions of the synchronized visualization, the video avatar, the shared database and the i-mode interaction, and it was linked to the visualization program.

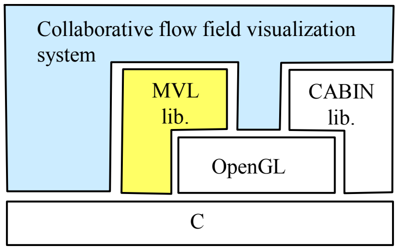


Figure 9. Software construction of the collaborative flow field visualization system

4.2. Experimental Task

In this experiment, we asked researchers in the field of fluid dynamics analysis to use the prototype visualization system for their collaborative research between remote locations. The researchers at the University of Tokyo site gave an explanation of their work using PowerPoint slides and had a discussion with the collaborative researchers at the Gifu Techno-Plaza site. Their research topics included the numerical analysis method for the supersonic opposing jet flow and the visualization method for the three-dimensional flow field animation [14].

The researchers at both sites discussed and examined the flow field data while visualizing them using several different kinds of visualization methods, such as streamlining, particle tracing, contour lines, shading and surface layer rendering. The PowerPoint slides were used to explain the numerical analysis method, and the video clips that filmed the wind tunnel experiments were used to compare the results between the numerical simulation and the experiment in the shared virtual world. Figure 10 shows the examples where the researchers at both sites were discussing with each other looking at the visualized data, and Figure 11 shows the examples where they were referring to some reference materials in the shared virtiual world.

4.3. Discussions

In this experiment, a prototype of collaborative flow field visualization system was used for the actual collaboration research on the fluid dynamics analysis. The remote researchers carried out discussions with each other using this system in the shared virtual world for a total of about one hour. These users generally expressed a favorable impression of the system, and they told us after the experiment that they did not feel the need to meet with each other in the same location to carry out further discussions.

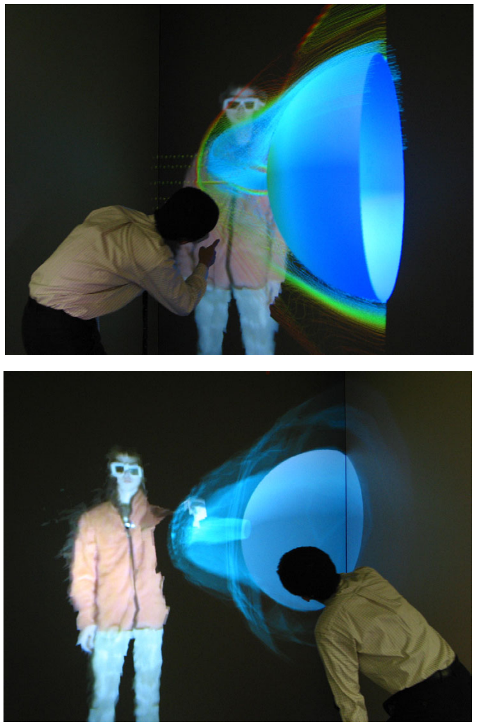


Figure 10. Researchers are discussing with each other looking at the visualized data

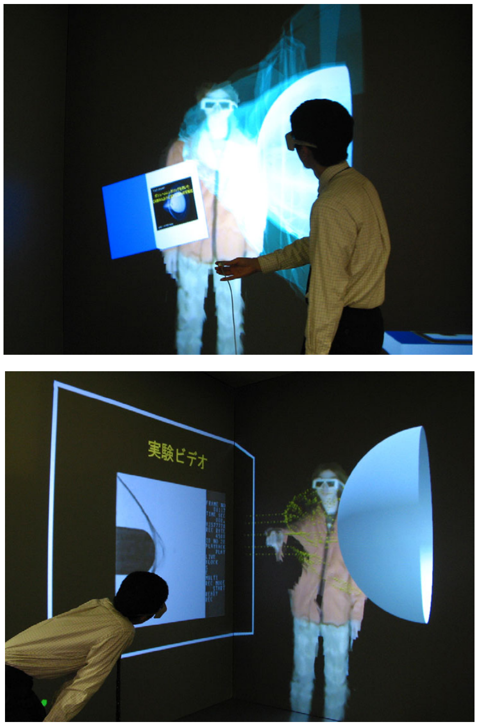
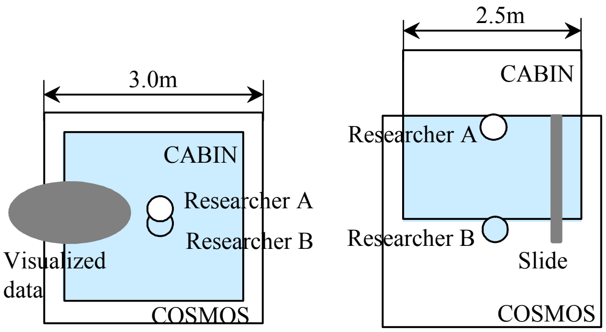


Figure 11. Researchers are referring to slides or video clips with visualized data

In this experiment, the users were able to move in the virtual space using a walk-through function as well as walking in the actual space of the immersive projection display. From the observation of the user's behavior, we understood that the effective positional relationships between users in the shared virtual world were different according to the collaboration styles. For example, when the users discussed only looking at the visualized data, it was important that they could see the data freely from various viewpoints, and they often looked at the visualized data from the same viewpoint while standing at the same position in the shared virtual world. On the other hand, when the user gave an explanation to the remote users using the PowerPoint slides, it was important that the user could see the other users' faces so that he could recognize whether the other users understood his speech. In this case, the remote researchers usually stood face-to-face keeping some distance between themselves.

The differences of the effective positional relationships between remote users influenced the arrangement of the shared virtual space. In the case of experiencing the visualized data, the display spaces in CABIN and in COSMOS were overlapped on the same position, as shown in Figure 12 (a), so that both users could move in the same space in the shared virtual world. On the other hand, in the case of referring to the explanation slides displayed with the visualized data, the display spaces in CABIN and COSMOS were arranged as shown in Figure 12 (b), so that the remote users maintained some distance between themselves in the shared virtual world. From these results, we understood that we must examine the effective arrangement of the shared virtual space according to the collaboration style in order to realize effective communication in the actual applications of the networked virtual laboratory.



(a) Looking at visualized data (b) Referring to explanation slide

Figure 12. Effective arrangement of the shared virtual space

5. Conclusions

In this study, the collaborative flow field visualization system using the networked immersive virtual reality environment was constructed. This system integrated several elemental technologies, such as the synchronized visualization, the video avatar, the shared database, and the i-mode interaction. An experiment on the collaborative flow field visualization was conducted using the networked immersive projection displays that are available at the Tokyo and Gifu sites, and the effectiveness of this system was evaluated. In future work, we will apply the framework of this system to further practical collaborative visualization in several different fields and will examine effective techniques to realize the networked virtual laboratory.

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7. References

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