Scientific Visualization in Collaborative Virtual Environment with PDA-Based Control and 3D Annotation*

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Scientific collaborative visualization based on visual data mining is an efficient approach for facilitating the intellectual discovery and understanding the visualization data obtained from large-scale data sets. We think that Collaborative Virtual Environment (CVE) is one of the efficient method to achieve collaborative works by sharing a virtual reality 3D space among users at remote places. In addition, it would be more useful if we could use virtual 3D annotations during collaborative work. In this paper, therefore, we construct a HybridP2P-based CVE in which a wireless handheld PDA is used for making 3D annotations and changing some visualization parameters when necessary.

Key Words: Visualization, IPT, PDA, 3D Annotation, Hybrid P2P

1. Introduction

Scientific visualization usually requires several operations, such as visualization method and parameter control, in order to support intellectual discovery within numerical data by various observations. Virtual Reality (VR) becomes an important intellectual discovery environment providing high level of interactivity and 3D expression, which are important in the scientific visualization. In the real world, researchers have worked together to solve common problems. Their experiences and expertise contribute with new ideas and solutions to the problem. For instance, visual data mining⁽¹⁾ can be used for collaborative work based on observations from various viewpoints and fields of expertise.

Currently, geographically or systematically distributed computer resources can be interconnected to an integrated computing environment. Many researchers distributed in wide area can collaborate using this environment. The main goal of this project is to provide a shared

virtual environment for scientific visualization for these remotely placed researchers.

Collaborative Virtual Environment (CVE)⁽²⁾ involves networked participants working together in a shared virtual environment to analyze the same object from different viewpoints where one participant's action will effect every participant's environment. The purpose of a CVE is the coordination of distributed resources, the exploitation of open standard protocols or interfaces, and to offer a high quality of services, which is very difficult to construct such environment.

For making communication more realistic, written or graphical communication can facilitate the understanding of exact intentions of the participants and would become a main factor for improving the collaborative working. Taking these into consideration, we believe that virtual annotations inside the CVE can provide greater efficiency rather than using only the traditional method of communication within the virtual environment.

In this paper, we describe the proposed HybridP2P-based CVE for scientific visualization with a PDA-based control and 3D annotation, which makes it possible to control the visualization and to make annotations for scientific collaborative work.

This paper is constituted as follows. The next section presents the HybridP2P networked CVE. Section 3 presents the proposed user interface for visualization and making annotation. In section 4, we will discuss the availability of this works. Finally, we summarize this work giving a conclusion and discuss possibilities for future works.

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2. HybridP2P-Based CVE

The size and complexity of volume data sets generated from high performance computing (HPC) systems have been increasing at a proportional rate of their computational power and network bandwidth. In order to efficiently analyze and inspect these large-scale data sets, wide area collaboration among multi-field become important and visualization technique can support human insight and interpretation effectively.

The essence of the CVE is that involved participants should appear explicitly to each other within a shared environment. Moreover, they are able to move freely within this environment, while sharing objects and interesting information. For the interaction through non-verbal communication we use avatars, which have arms and hands so that they may interact through natural gestures such as inclination of head or pointing at areas of interest in the virtual environment.

Regarding making annotations, when we study using a textbook, writing a memorandum in the unfilled space or underlining an important part can become a key feature for subsequent works or for an easy review. Today, it is required for making annotation onto newly discovered knowledge from data mining for effectively researches^{(3),(4)}. Taking these into account, we can consider that the annotation function is very useful and important in CVE to promote better understanding. Also, in a collaborative working environment where more researchers are involved the facilities for making and sharing annotations become indispensable.

Conventional CVE have been implemented by using the Server-client networking model. The server is responsible for managing the participants and the shared environment. The main advantage of this networking model is the simplicity of the synchronization mechanism, as the server becomes responsible for managing the correspondence of the shared environment. In general, collaborative works in scientific field are usually restricted to known members. Therefore, dynamic group configuration becomes more interesting and practical than the facility for synchronizing undefined quantity of participants. However, Server-client model is not suitable for dynamic group configuration.

On the other hand, P2P networking model has several advantages as compared with Server-client model, such as high scalability and availability, dynamic configuration, and direct connection between peers. Moreover, the method of data sharing without managements by a fixed server is applied to Peer-to-Peer (P2P) technology. P2P uses network resources in order to make an equal connection configuration and adaptive collaborative environment. However, the management of information to other participants connected to network at present and the task of synchronization are difficult in P2P networking.

Fig. 1 Multiple IPTs connected using HybridP2P

In this paper, we apply the HybridP2P networking model to implementing our proposed remote collaborative virtual environment (See Fig. 1) in order to take advantages of both networking models.

3. PDA-Based User Interface for CVE

3.1 System configuration

VR is one of the useful visualization tools for intellectual discovery. However, when using IPT based VR systems, such as CAVE, ImmersaDesk and tiled display wall, an operator must move by turns between the IPT and host computer in order to execute even simple visualization task. Whenever the visualization task is suspended in this way, the intellectual discovery process is influenced. To overcome this problem, some input methods based on 3D pop-up menu such as VFIVE (Vector Field Interactive Visualization Environment) have been proposed⁽⁵⁾. However, 3D pop-up menus are not useful due to the difficulty in handling and it requires a practice. In addition, establishment of common input devices in all sites is difficult, as these are usually expensive.

Much research have been done on using PDA to provide collaboration with PCs⁽⁶⁾⁻⁽⁸⁾. Moreover, PDA has been utilized in Virtual Environment (VE) in some projects. Watsen et al.⁽⁹⁾ developed a 2D user interface using a 3Com PalmPilot that connects with a host computer via wireless serial network. It is reported that this wireless connection has low speed and noise which cause considerable packet loss. Tweek⁽¹⁰⁾ is a 2D user interface for VRJuggler. It is a collection of C++, Java, CORBA and Tcl based libraries made specifically for building flexible GUI. In this case, the task of building a GUI is left to the programmers. We propose a PDA-based application, which makes possible to control visualization parameters and to make annotations for scientific visualization within an IPT without movement between the IPT and host computer. Our proposed PDA application possesses a pre-defined GUI eliminating the necessity for building a GUI, thus leaving programmers free to devote themselves to de-

Fig. 2 Local system configuration

veloping host applications.

Figure 2 shows our proposed system configuration. The host computer is used for computing visualization process for CVE and the image is displayed on the ImmersaDesk VR display. The PDA used in our experiment is a TOSHIBA Genio e550GX (PocketPC 2002) with wireless LAN adapter used for communication between host machine via TCP/IP. Host machine is a dual Intel Pentium III (1 GHz) with an nVidia Quadro FX3000 video card, and it uses Redhat7.3 as OS. An electromagnetic motion-tracking receiver (Polhemus FASTRAK with Long Ranger) is attached onto the PDA case. FASTRAK has been considered one of the standard motion tracking devices for virtual reality and, other pointing devices require cumbersome manipulation. FASTRAK attached PDA becomes a 3D mouse which provides the computer with information about the PDA's position and orientation enabling easy and intuitive interaction which are required by VE. The PDA case was modified by enlarging it 10 cm in order to attach the motion-tracking receiver far enough from the PDA to eliminate the electromagnetic influence. This receiver was attached by using a piece of Velcro as we can see in Fig. 3.

We used CAVE Library for making the VR application, and QUANTA⁽¹¹⁾ for networking. PDA transmits VR control data, generated by cursor keys and buttons, such as placed in front and on sides, to the *trackd* daemon. This is a software module which obtains information from input devices and transfers them to the CAVE Library. Control and tracking data for VR are separated from the PDA application, as a result, it is possible to control another CAVE application, and we implemented similar functions to the default CAVE controller, which is called Wand.

Fig. 3 Rear and front views of the PDA case with a FASTRAK receiver

Fig. 4 Software architecture

3.2 Application

We used the Visualization Tool Kit (VTK) for visualization. However, it does not support multiple view port as CAVE Library does. Therefore we used OpenGL Performer in order to make possible the use of CAVE Library with VTK. It provides other features not supported by VTK, such as scene-graphs, intersection testing, visibility culling and multi-view port with multi-processing. Figure 4 shows the configuration of the PDA application and its interface with this implemented visualization application. We used a function called *vtkActorToPF*⁽¹²⁾ in order to convert data generated by VTK into data recognized by OpenGL Performer. This function translates the geometry, color information, and properties from a *vtkActor*, in the VTK side, and creates or modifies a corresponding *pfGeode*, which is a node within the OpenGL Performer scene-graph. Whenever the *vtkActor* changes, the *pfGeode* is automatically re-translated.

Our proposed 3D annotation function is based on OpenGL Performer. As a result, this function can be easily embedded into other OpenGL Performer based applications. OpenGL based application such as AVS cannot utilize this annotation function directly. However, this can

Fig. 5 GUI of the PDA application

be solved by converting the 3D annotation function adding some OpenGL enabled functions.

Interactive visualization task requires easy parameter and expression changing facilities. Taking into consideration, our proposed PDA application has developed to provide these functionalities. Visualization task usually requires several and different operations. Although our PDA application has a simple GUI, it has sufficient functionalities providing fast visualization control. In addition, users are not required to build their own GUI because our PDA application offers a universal GUI.

Figure 5 shows the GUI of our proposed PDA application. The PDA's menu items can be selected by using tab control.

Commands can be sent from the "Button" page to the host machine. Parameters can be changed individually through the "Slider" page whereas the "XYPad" page can send combined X and Y coordinates of the Stylus pen position on the touch screen simultaneously to the host machine. The generated data from manipulating these interfaces are packed, with the corresponding item ID and value, and transmitted to the host computer. The functionality of each command is defined in the host application. 3D Annotations can be made using the "Drawing" page and can be saved and loaded through the "File I/O" page.

3.3 3D annotations

We implemented two independent drawing methods. One is by drawing directly into the CVE by using the PDA like a virtual pen and moving it freely while pressing the programmable button "3". The other is by using the PDA touch screen then transferring the drawing into the CVE. Inside the CVE, the drawing data is converted to polygon data. This data is converted to *pfGeode* for subsequent utilization by *pfDCS*. Direct drawing is done using a virtual pen in the CVE. The pen point position is defined as 15 cm deep and 7 cm above the top of the PDA case.

Figure 6 shows the overview of collaborative visualization with 3D annotation in CVE. These avatars are other participants who access from remote place.

For making annotation through the touch screen, we must first select the "Drawing" page before drawing any annotation onto the PDA's touch screen. Pressing the

Fig. 6 Collaborative visualization in VR with some annotations

Fig. 7 Synchronized rotation of the annotations

"PostIt" button after finishing the drawing will put it into the CVE. However, it is possible to move freely and change the placement position before pressing the "Ok" button. The maximum drawing data size inside the VE is set as 32×37 cm.

In order to facilitate the visualization of the annotations, the rotation of these annotations is updated according to the motion of the user's head. The front face of the annotation which written by Touch screen will always be rotated as being in the direction of the user's viewing direction as shown in Fig. 7.

Regarding the usability of these two methods, we found that using a PDA as a writing utensil is suitable for drawing figures and the PDA's touch screen is suitable for drawing characters⁽¹³⁾.

Fig. 8 3D menu

Each participant can delete his/her own annotations and can save and load the annotations through the use of “File I/O” page of the PDA application.

Participants can join in the middle of the collaborative work and will receive all annotations made by the existing participants. This feature speeds up the process for mutual understanding, enabling coherent collaborative work.

All received and self-generated annotations can be saved to host computer in local and loaded at any time in order to use them more effectively in asynchronous off-line work. The color of annotations differ from each participant that identify the annotations property.

3.4 Usability of the PDA application

We evaluated the PDA application by comparing the required time for completing a certain task on the PDA GUI and by using 3D menu. The chosen task was to generate inside the CVE a right inclined green cube such as the example previously displayed inside the CVE. To do this, firstly an evaluator will create a cube by using “Create” command and execute necessary rotation, translation, scaling, and color change by applying necessary commands. The time was measured from the starting sign given by the timekeeper until the finishing sign given by the evaluators.

Figure 8 shows the 3D menu which appears when we push the programmable button “5”. The position of the 3D menu is synchronized with the position of the PDA in the CVE. Instead of using the PDA application, the evaluators used only the programmable buttons and cursor keys of the PDA. The size of the 3D menu is 70 cm high and 40 cm wide. The 3D cursor, which is synchronized with the motion of the PDA, is used for selecting the 3D menu item. The evaluators can choose the required action such as moving, translating and scaling an object by selecting the corresponding menu item. The latter is executed by selecting the sliders in the menu item.

Inside the PDA application, the commands are se-

Fig. 9 Evaluation of 3D menu and PDA-based user interface

Fig. 10 Wide collaborative network over JGNII and Super-SINET

lected using the “Button” page and parameters are modified using the “Slider” page. Evaluators were expected to execute the same above-mentioned task using both 3D menu and PDA application. We chose ten students, who have no experience in using these input interfaces. They have previously trained only a few times in how to manipulate these interfaces. Figure 9 shows the required time for executing both tasks. We can verify that the PDA application only requires the 60% of the time when using 3D menu.

4. Availability of HybridP2P-Based CVE

The network configuration proposed in this paper is a combination of the server-client and pure P2P networking model. The server manages each peer’s IP address. Thus, participants only need to access the server first and can then connect to other participants automatically. General P2P application naturally searches for shared data enabling them to construct connection like beads. It is possible to connect even unknown peers. However, our application addresses a collaborative environment that does not

connect unspecified peer⁽¹⁴⁾ since collaborative working team is previously decided and the machines involved are generally known in advance. As a result, there is no need for this feature in our proposed CVE. Effective interaction between participants requires continuous transportation of avatar's tracking data. We used UDP as network protocol for communicating avatar's actions. However, the packet loss caused by UDP has brought serious problems to the communication on WAN. We are investigating the use of RTP or RCTP in order to increase the reliability of transfers while using UDP.

On the other hand, the annotation and visualization control data are broadcast via TCP because this kind of data requires reliability. In addition, the connection status can be obtained by checking the socket status.

It is important to evaluate the effectiveness of this system by the end users. We constructed a simple CVE for fluid visualization on our LAN in order to observe the user's behavior. For instance, users made drawing annotations such as arrows showing the direction of the flow. We found that the task of making 3D annotations in CVE can be effective for enriching communication contents during the collaborative investigation. We believe that the task of making 3D annotations will be a useful collaboration tool.

In this paper, we have built a CVE on our LAN environment. However, useful CVE should work efficiently also on WAN environment between remote places. Taking this into consideration, we have established a wide private network connecting some remote sites over the Japan Gigabit Network (JGN II) for the purpose of this evaluation. Figure 10 shows the overview of wide-area CVE over high-speed network as JGN II and SuperSINET, and we will construct it in the future.

We express participants by avatar that is 3D model and, it is able to move following participants actions that measured by motion tracking sensor that was broadcasted via UDP. Even though, if the packet loss causes a serious problem of communications, it will need the RTP or RCTP in order to increase the reliability of transfers while using UDP.

5. Conclusion

We have proposed a HybridP2P network based CVE, which combines participant management using the server-client model and dynamic configuration using P2P model. The flexibility and effectiveness of P2P model was verified as extremely beneficial for making collaboration over the network. In addition, the solidity and robustness of server-client model were added as highly desired qualities. We expect that this networking paradigm can bring a new dimension to CVE.

We also developed a PDA application with intuitive GUI for interaction inside the VE. Through the wireless handheld PDA, users are able to change visualization pa-

rameters or methods without the need to leave the IPT based VR system. We assessed the usability of this PDA application, by comparing it with the traditional 3D menu. We found that the PDA application is able to be controlled easier and faster than the 3D menu. This is because the PDA application uses a handheld operation making it easier than the 3D menu which needs more complex movements with the whole arm. In addition, the proposed facilities for making annotations within the CVE improve mutual understanding and efficient use of visualization for data analysis.

We implemented the facilities for making 3D annotations into the CVE in order to improve the reliability of broadly communication by means of figures and comments. However, it is not able to recognize when the annotations were created, and there is a need to verify its efficiency when working with extremely huge data sets or in a more widespread collaborative environment where more participants are connected. We are planning to make this verification in the future.

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