Multimedia Virtual Laboratory:
Integration of Computer Simulation and Experiment

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Abstract

It is important that the researchers can examine the physical phenomenon by comparing the numerical simulation data and experimental results. In this research, the framework of the virtual laboratory in which the computer simulation data and the experiment data can be visualized together in the networked virtual environment was constructed. In order to represent the dynamic phenomenon, the mechanism of the time control in which the different kinds of data can be visualized synchronously between remote sites is necessary. This paper discusses the functions of the time passage control and the clock adjustment. These functions were implemented to realize the synchronized visualization in the networked virtual world, and the effectiveness of these functions was evaluated.

1 Introduction

In the fields of science and engineering research, the numerical simulation method is often used to analyze the phenomenon. In this case, it is important to visualize the data output from the computer to understand the large amount of data intuitively. In particular, the visualization method that uses the three-dimensional computer graphics image in the virtual environment is effective (Van Dam at el., 2000).

On the other hand, the experiment that is performed in the real world is also an important method in order to verify the hypothesis or analyze the phenomenon. Even when the computer simulation is used, the experiment is also conducted to confirm the validity of the calculation model or the calculation method. Therefore, it is an important approach to construct the research environment in which the researchers can examine the phenomenon by comparing the numerical simulation that is performed in the computer and the experiment that is conducted in the real world.

However, it is generally difficult to compare them directly because the data types and the formats are different between the computer simulation data and the experimental results. The computer simulation outputs a large amount of numerical data, while the result of the experiment is obtained as the numerical values measured by the sensors or the observation records.

This study aims at integrating both data in the immersive virtual world to compare the results of the computer simulation and the experiment in the common environment. Moreover, the shared virtual laboratory environment can be constructed by connecting the immersive virtual world through the network between remote places. This type of networked research environment is called MVL (Multimedia Virtual Laboratory). Particularly, this paper discusses the problems of defining the time scale and sharing it between remote places that are required in the MVL environment.

2 Integration of Computer Simulation and Experiment

In order to compare the computer simulation data and the experimental data in the virtual environment, both data should be expressed in the same form. Currently, the visualization for the numerical simulation data is used to visualize the invisible physical data or to represent the realistic image of the phenomenon using the numerical data to enable the users to understand it intuitively. On the other hand, the visualization for the experimental data is often used to visualize the invisible measurement data or to replay the video that recorded the phenomenon in the experiment.

Therefore, when these data are integrated in the virtual environment, various kinds of visualization methods are considered. For example, the simulation data can be visualized as a realistic image in order to compare it with the video recorded in the experiment, or both of the invisible data that were obtained from the computer simulation and the experiment can be comparably visualized. Moreover, the method of visualizing all data overlapped each other in the same space can be devised so that the user can understand the whole phenomenon while looking at the visualized images.

In this study, the visualization system in which the users can intuitively compare the video images and the numerical simulation data in the virtual world was developed, as the first step of integrating the computer simulation and the experiment. Figure 1 shows the concept of the integrated visualization environment. In this system, the numerical simulation data and the experimental video can be visualized together in the immersive virtual environment. In this case, it is necessary to express the numerical simulation data as an animation image so that the dynamic phenomenon can be represented.

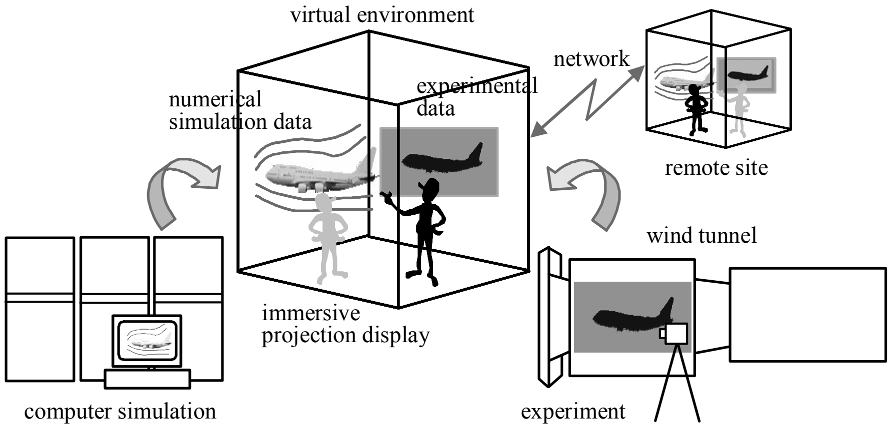

Figure 1: Concept of the visualization environment in which the computer simulation data and the experimental result are integrated

As for the visualization environment, the networked immersive virtual reality environment was constructed by connecting several multi-screen immersive projection displays, such as the C.C, CABIN and COSMOS (Hirose, Ogi, Ishiwata & Yamada, 1999) (Yamada, Hirose & Iida, 1998). In the networked visualization environment, an accurate time control mechanism should be introduced, so that the visualization images of the dynamic phenomenon should be synchronized between different data and between different places. In this study, the framework of constructing the MVL environment in which the users in the remote places can discuss with each other while looking at the same phenomenon at the same time was developed.

3 Synchronization between Different Data

3.1 Time Passage Control Function

It is important to introduce the concept of the accurate time control when the physical phenomenon is analyzed in the virtual world, because the most phenomena are described as functions of time. However, in the most virtual reality systems used in the current applications, the virtual world is purely changed according to the user's movement or it is updated in the simple simulation loop. In such a virtual world, the concept of the strict time scale doesn't exist, and the time passes irregularly according to the change of the calculation load.

The calculation load in the virtual reality applications depends on various factors such as the calculation time of the dynamic objects and the rendering time of the virtual world. It would be changed even when the user's viewpoint simply moved in the virtual world. In order to represent the dynamic phenomenon correctly in the virtual world, the visualization of data on the accurate time scale independent of the changes of the calculation load is necessary.

In this study, the function of time passage control was implemented in order to introduce the concept of the time scale in the virtual world. In order to realize the accurate time control, it is necessary that the application program itself has the correct clock in it. In this method, the application program runs while referring to the built-in clock in the computer using the system call function. The elapsed time to render the current images is measured in every rendering loop, and the next time step Δt for drawing the next image in the simulation loop is determined using the rendering time in the previous loop.

Even when the different kinds of data are visualized, they would be synchronized using this function. For example, the time resolution of the recorded data is different between the numerical simulation data that is calculated in the fixed time step and the video image that filmed the appearance of the experiment. However, it becomes possible to replay the both images on the same time scale without depending on the change of the calculation load, by selecting the appropriate frame using the time passage control function. Moreover, when the numerical simulation data is visualized while being calculated in real-time, it could be also represented on the constant time scale by updating the next time variable using this method.

In this method, the progress of the time is not strictly accurate because it always uses the previous rendering time for the next rendering. Moreover, since the users only see the rendered image after the refreshment of the display screen, this method has an unavoidable error in the perceived time within the refreshing interval. However, when the visualized data is changed continuously, this method can be used for the approximate time because the calculation time rarely changes suddenly in a great deal. Figure 2 illustrates the mechanism of the time passage control and the potential error included in it.

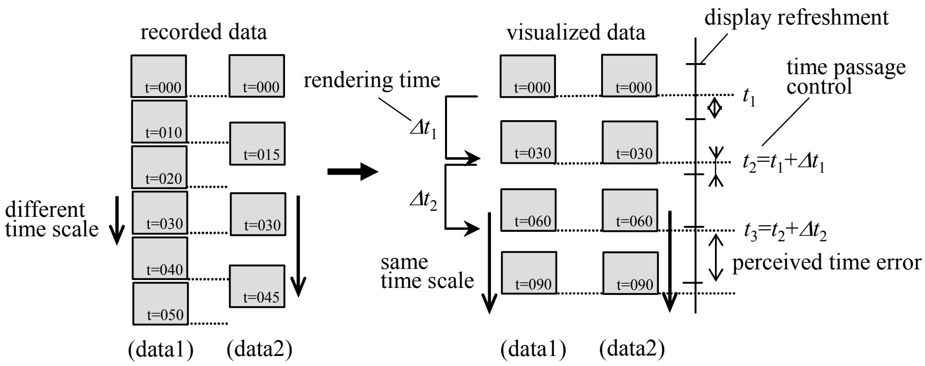

Figure 2: Mechanism of the time passage control method and the potential error

3.2 Application to Fluid Analysis Data

In this study, the time passage control method was applied to visualizing the fluid analysis data in the immersive virtual environment. This problem treats the analysis data of the supersonic jet flow that is generated by the reverse thrust at the nose of the supersonic airplane (Fujita, Kuzuu & Matsumoto, 2001). The visualization system in which the researcher can examine the phenomenon by comparing the numerical simulation data that was calculated in a fixed time step and the video images that recorded the experiment in the wind tunnel was constructed. As a visualization technique for the numerical simulation data, the surface layer rendering method was used to represent the realistic image of the flow phenomenon, and as for the experimental data, the two-dimensional video image was used.

Figure 3 shows the example of visualizing these data in the immersive virtual environment. In this example, the numerical simulation data and the video image could be visualized synchronously by controlling the progress of time in the virtual world, though the frame rates of the original data were different. This synchronization was achieved not only for the normal replay but also for the arbitrary reproduction such as the fast-forward or the slow replay. Then, the researchers were able to examine the phenomenon effectively while looking at the synchronized images in the immersive virtual world.

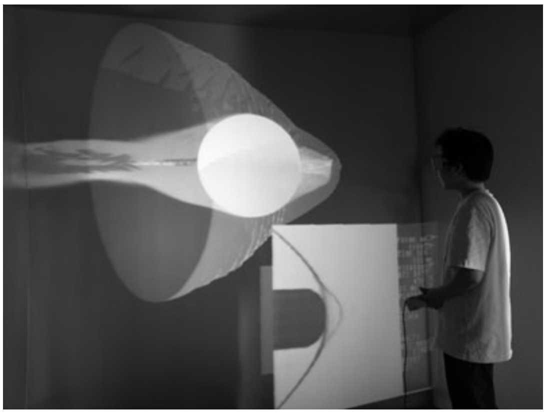

Figure 3: Synchronized visualization between the numerical simulation data and the experimental video in the immersive virtual environment

4 Synchronization between Remote Places

4.1 Clock Adjustment Function

Though the dynamic data can be visualized on the accurate time scale at each site by using the time passage control function, the synchronization between remote sites is also required when the visualization system is used in the networked environment. Namely, it should be guaranteed that the remote users are experiencing the same world at the same time. In order to realize the synchronization between remote sites, it is necessary that the time has no difference between both sites as well as the time progresses correctly at each site. In this study, the method of synchronizing the clocks between remote sites was introduced to share the time in the networked virtual environment.

In this system, one computer is used as an interaction server and it receives all the operation commands from the both sites. These commands are immediately sent from the server to the client, and they are executed at both sites. However, since the transmission of the commands needs some communication time, the execution at the client site might be slightly delayed. Therefore, the average communication time to transmit the command is measured by sending some commands between the server and the client when the program is started, and the command is executed after waiting the average communication time at the server site. Then, the user's operation can be synchronized between remote sites.

Moreover, when the program is started, the clocks at the both sites are adjusted to each other by transmitting the initialize command from the sever site to the client. But when a long time passes, the time difference between both sites is caused by the accumulation of the errors in the built-in clock or the transmission time. In order to realize the synchronized visualization, the clocks must be strictly coincident between both sites. For example, when the operation command such as the "replay" or the "stop" of the animation is input, the frame numbers of the animation data should be identical between each site. Therefore, in this study, the clock adjustment function was implemented. In this method, the time at the server site is sent to the client site attached with the command data, and the clock at the client site is adjusted to the server site. Therefore, even if the errors in the built-in clock or the transmission time are accumulated, the frame numbers between both sites become coincident with each other when the operation commands are executed. Figure 4 shows the time control method using the time passage control and the clock adjustment functions.

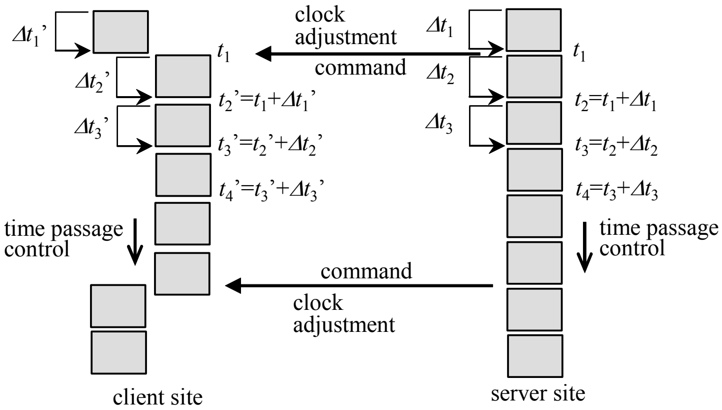

Figure 4: Synchronization control using the time passage control and the clock adjustment functions between remote sites

4.2 Experiment in Networked Environment

In this study, the networked visualization system was constructed by applying the time control method, and the accuracy of the synchronization between remote places was estimated. In this system, the data of the above-mentioned supersonic jet flow was visualized using the several kinds of visualization methods such as streamlining, particle tracing, shading, contour lines, and surface layer rendering. Each visualization method has a large difference in the rendering load. For example, though the rendering performance was over 30Hz when the streamlining or the particle tracing was used, it was less than 10Hz when the surface layer rendering was used. In addition, the rendering load depends on the complexity of the rendered image that is changed according to the movement of the user's viewpoint. Figure 5 illustrates the examples of visualizing the animation images when various visualization methods were used. In these examples, the video avatar technology was used to represent the remote user in the shared virtual world (Ogi, Yamada & Kayahara, 2003).

Figure 5: Examples of visualizing the animation data of the supersonic jet flow using streamlining, particle tracing, shading, contour lines (left) and surface layer rendering (right)

The experiment on sharing the animation data in the networked virtual world was conducted between the CABIN at the University of Tokyo and the COSMOS at the Gifu Techno Plaza. The CABIN and the COSMOS are CAVE-like multi-screen displays. These two sites are 400km away, and they were connected through the JGN (Japan Gigabit Network). In this system, the interaction server at the CABNIN site receives the operation commands from both sites and forwards them to the COSMOS site. Then, the operation command can be shared between two sites. The purpose of this experiment is to examine whether the users at both sites can discuss with each other looking at the same frame of the animation data at the same time by using the time control functions.

The frame number of the displayed image was recorded respectively at each site at the same time, and they were compared. As a standard time for the recording, the telephone time signal service provided by NTT was used. Namely, when the animation image is visualized in the shared virtual world, the time signal and the frame number were recorded in the audio sector and the video sector of the DV tape respectively at each site. These video and audio data were captured by the PC and the gap of frame number was examined. In this method, the measurement accuracy of the synchronization time is about 1/30sec that is equivalent to one frame of the video stream.

Figure 6 shows the appearance of measuring the synchronization of the visualized images. As a result of this experiment, the gap of the frame being rendered at the same time was less than two frames between two sites when the rendering loads are changed variously. This means that the synchronization error in sharing the dynamic data in the networked virtual world was less than 1/15sec. This error is thought to be caused by the variance of the calculation time in the rendering loop and the communication time in the command transmission.

Figure 6: Appearance of measuring the synchronization of the visualized images between remote places

5 Future Work

In the prototype system, the computer simulation data was visualized using the three-dimensional computer graphics images, but the experimental image was reproduced using the ordinary two-dimensional video. In this method, though the user can observe the simulation data from various viewpoints, he can only see the experimental video from the camera position in the three-dimensional virtual world. In the next step of this research, we are planning to develop a method to record and reproduce the three-dimensional image of the experimental data so that the user can examine the physical phenomenon by comparing the computer simulation data and the experimental data as three-dimensional information.

For example, the three-dimensional video technique can be used to reproduce the three-dimensional images of the experiment (Gross et al., 2003). In this technique, the experimental images are captured from various directions by using the multiple cameras that are placed surrounding the experimental equipment, and these images are integrated to generate a three-dimensional video. The authors have developed the communication method that uses the three-dimensional video of the user in the immersive shared virtual world (Ogi, Yamadas & Hirose, 1999). The three-dimensional visualization of the experiment can be realized by applying this technique to record and reproduce the image of the experiment. Figure 7 shows the concept of generating the three-dimensional video of the experiment by using the multiple cameras. In this method, it is expected that the user can analyze and understand the phenomenon effectively by integrating the computer simulation and the experiment in the three-dimensional world.

Moreover, in the experiment, not only the video images but also the measurement data concerning the various kinds of physical quantity are obtained. By integrating the measurement data into the visualization image in the three-dimensional shared virtual world, the MVL environment in which the researchers can examine the phenomenon more effectively would be constructed.

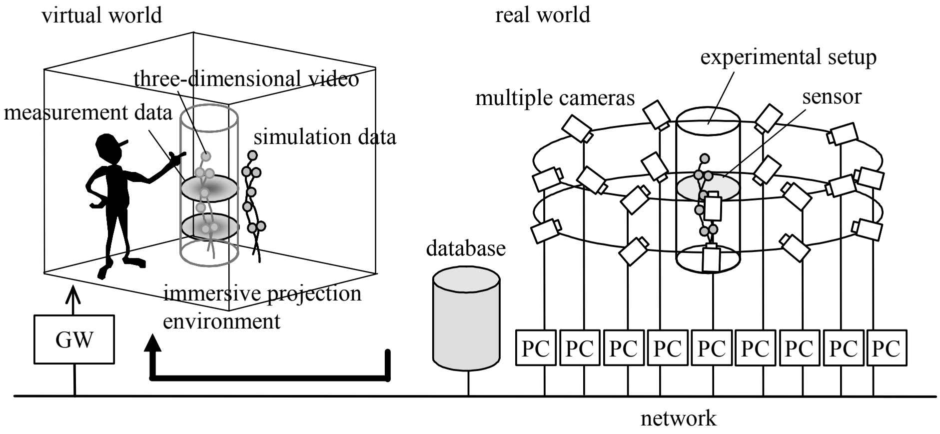

Figure 7: Method of recording and reproducing the three-dimensional video of the experiment

6 Conclusions

In this research, the framework of integrating the computer simulation data and the experiment data in the shared virtual world was constructed. In order to represent the dynamic physical phenomenon, the mechanism of the time control in which the different kinds of data can be visualized on the same time scale is necessary. In particular, this paper discussed the functions of the time passage control and the clock adjustment to realize the synchronized visualization. The experiment on sharing the visualization data of the animation between remote places was conducted by using these functions, and the effectiveness of this method was evaluated. The future work will include developing the method of recording and replaying the experimental images using the three-dimensional video technique to integrate the computer simulation and the experiment as three-dimensional information.

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References

Fujita, M., Kuzuu, K., & Matsumoto, Y. (2001). Visualization of three-dimensional unsteady compressible flow using a volume rendering technique. *Proceedings of CFD 15th Symposium*.

Gross, M., Wurmlin, S., Naef, M., Lamboray, E., Spagno, C., Kunz, A., Killer-Meier, E., Svoboda, T., Van Gool, L., Lang, S., Strehlke, K., Vande Mooere, A., Staadt, O. (2003). Blue-c: A spatially immersive display and 3D video portal for telepresence, *ACM Transactions on Graphics*, 22, 3, 819-827.

Hirose, M., Ogi, T., Ishiwata, S., & Yamada, T. (1999). Development and evaluation of immersive multiscreen display "CABIN". *Systems and Computers in Japan*, 30, 1, 13-22.

Ogi, T., Yamada, T., & Kayahara, T. (2003). Avatar communication: Virtual Instructor in the demonstration exhibit, *Proceedings of HCI International 2003*, 3, 1431-1435.

Van Dam, A., Forsberg, A., Laidlaw, D., LaViola, J., & Simpson, R. (2000). Immersive VR for scientific visualization: A progress report. *IEEE Computer Graphics and Applications*, 20, 6, 26-52.

Yamada, T., Hirose, M., Iida, Y. (1998). Development of complete immersive display: COSMOS. *Proceedings of VSMM98*, 522-527.