Audience Interaction for Virtual Reality Theater and Its Implementation

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ABSTRACT
Recently we have built a VR(Virtual Reality) theater in Kyongju, Korea. It combines the advantages of VR and IMAX theater. The VR theater can be characterized by a single shared screen and by multiple inputs from several hundreds of people. In this case, multi-user interaction is different from that of networked VR systems and must be reconsidered. This paper defines the multi-user interaction in such a VR theater as *Audience Interaction*, and discusses key issues for the implementation of the Audience Interaction. This paper also presents a real implementation example in the Kyongju VR theater.

Keywords
Virtual Reality, Theater, Multi-user interaction, Audience Interaction.

1. INTRODUCTION
Recently we have built a VR(Virtual Reality) theater in the city of Kyongju, Korea. The theater features a large cylindrical screen, surround 3D sound and a fragrance control system, and is designed to provide a visual, aural and olfactory immersive system for a large audience. It also allows a large audience (over 600 people) to interact with a single screen through individual interaction devices located at each seat. Its goal was to provide brand new interests for people by combining the attractions of an IMAX theater (a large audience enjoying a shared experience) with the attractions of VR (the ability to interact with environment). The theater is distinguished from IMAX theater with the addition of multi-user interaction. In the technical view point there is another big difference between the two theaters in rendering methods. The VR theater needs real-time rendering to change the images according to the result of user interaction. However, it is hard to implement in the film-based IMAX theater where the story of the movie is fixed. The theater is also distinguished from distributed collaborative VR by the co-presence of the audience. While the distributed collaborative VR or networked VR connects users with a network, the VR theater is a tightly coupled VR system where several hundreds of people interact with a single screen at the same place. In this case the multi-user interaction in the theater must be reconsidered.

There are only a few researches on the single screen interaction in VR systems. Among them is the research on eMUSE (electronic Multi User Stage Environment) system[4]. It was one of the researches in eRENA project that have been testing various possibilities of multi-user VR. The eMUSE was the multi-user shared environment for culture, performance, art and entertainment. They used virtual space as a stage setting, and studied the behaviors and interactions of people within it. However, they tried only the case of a small number of people. Another related research was Inhabited TV[1]. Inhabited TV had a similar goal to ours, which was to combine multi-user virtual environments with television. Inhabited TV used collaborative virtual environments so that on-line audiences can participate in TV shows within shared virtual worlds. Inhabited TV also introduced the concept of layered participation, where each layer defined different possibility for interaction. In their concept, audience in the outermost 'viewers' layer, has only very limited possibilities for interaction.

Researches on multi-user interaction with a single screen can be found in the field of CSCW (Computer Supported Cooperative Work). Recently a few research groups have studied a similar kind of interaction to the VR theater, single output screen and multiple input devices. Stewart et al. [3] defined it as Single Display Groupware (SDG) and described the benefits and negative effects of the SDG, comparing to traditional remote collaboration. They also gave some possible scenarios of the SDG application. Zanella et al. [5] investigated interference problem among user interactions in SDG. However, they focused only on single PC environments and still a small number of people.

In this paper, we consider design issues of the multi-user interaction system in the VR theater when the audience is very large. The design issues to discuss include interaction devices for each seat, mapping of audience to virtual objects, and interaction function design. This paper also presents an implementation example of the Kyongju VR theater.

2. AUDIENCE INTERACTION
The multi-user interaction in a VR theater can be understood as multi-user collaboration in a virtual environment. In that point, it is related with the research on the collaborative work in the field of CVE (Collaborative Virtual Environment) and CSCW.

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However, the researches in the CVE and CSCW field have been focusing on the multi-user collaboration in distributed environments, which is different from that in the VR theater. Thus, in order to distinguish them, we define the multi-user interaction in the VR theater as *Audience Interaction*. Then, the Audience Interaction is characterized by co-location and simultaneousness of multi-user interaction.

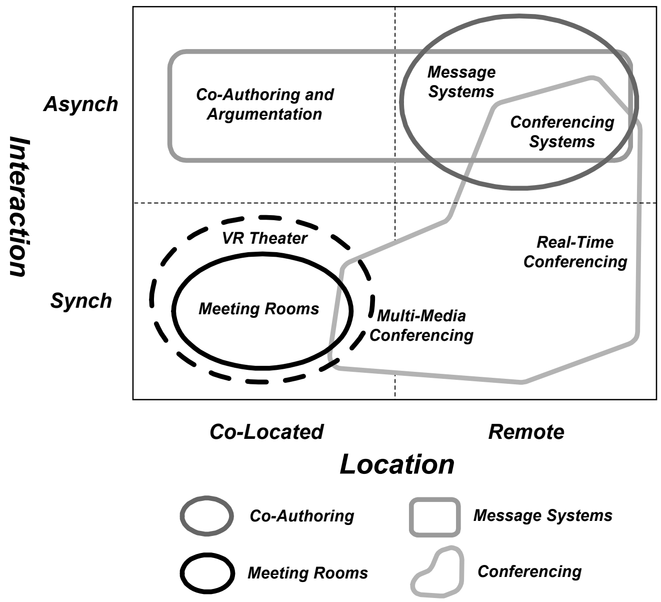
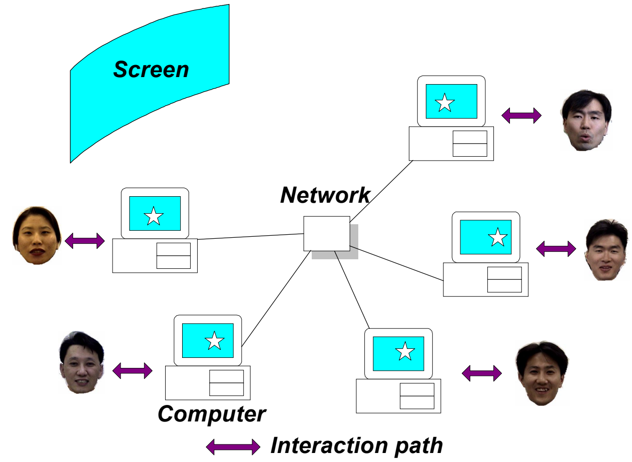


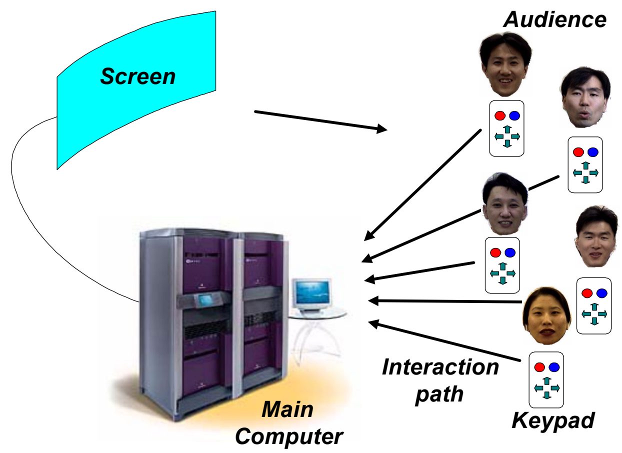
Figure 1. Classification of the CSCW systems.

Actually this kind of classification was already made in the CSCW field. In his early research T. Rodden[2] classified CSCW systems along the two axes of interaction and location as shown in Figure 1. In this classification, the VR theater may be categorized into the *Meeting Room* class since users are co-located in the theater and their interaction is synchronous (nearby exist in time). However, the typical Meeting Room configuration stated in [2] may not be appropriate for the VR theater especially that accommodates several hundreds of people. Figure 2(a) shows the configuration of the typical Meeting Room where a large projection screen is located in front of users and every user has his/her own video terminal. This may be appropriate for a VR theater for a small number of people. In the VR theater for several hundreds of people, however, it is hard to install individual video terminals for every seats because of the space and cost. Thus the VR theater is a larger concept to contain the Meeting Room class as shown in Figure 1. Actually the VR theater in Kyongju, Korea, has the configuration of Figure 2(b) in which only individual input devices are provided for each seat.

In the Audience Interaction, input device is the first design issue. There is no existing design guideline, but the least rule is that it should be designed to fit to the contents to be displayed. One possible solution is to mimic the currently used mouse device to generalize input capability. If a VR theater has the Meeting Room configuration, there is no mapping problem. However, if individual video terminal is removed, it raises a mapping problem between audience and virtual objects to control. It is because



(a) Typical Meeting Room



(b) Kyongju VR theater

Figure 2. Comparison of interaction systems of the typical Meeting Room in the CSCW systems and the Kyongju VR theater.

removal of individual video terminal results in removal of individual cursor. That means it is hard for audience to identify the objects to control by interaction, though the single screen in the VR theater implements the concept of WYSIWIS (What You See Is What I See) of the CSCW [2]. The interaction between multi-user and a virtual environment can be classified as shown in Table 1 according to the number of interactive objects that are affected by interaction. When the number of interactive object is only one, there is no mapping problem because every people share a single screen. However, if the number of interactive object is increasing, assignment of the objects to audience is needed. The solutions to this mapping problem are tagging names or giving specific features (shape, color, etc) to the objects. In this case, we need to previously notify audience of the names or features of the objects that they can control. If the number of interactive object is increased and reached to N:N or N:L (L>N>>1) relation (Table 1), this mapping may become infeasible because of the limited number of features to be used to distinguish. Thus, in the VR theater for large audience, N:1 or N:M (M<<N) relation is reasonable and feasible.

Table 1. Classification of multi-user virtual environment systems according to the number of interactive objects.

Number of Users	Number of Interactive Objects	Comments
N	1	Every user controls one interactive object
N	M (< N)	N users are divided into M groups, and each group control one interactive object
N	N	Similar to 1:1 relation. Each user controls one interactive object
N	L (> N)	Each user controls 1 or more interactive objects

Once the mapping strategy is determined, there remains the functionality design of the Audience Interaction. The functionality design is to define the actual function of interaction for multiple user inputs. When we use N:M (N>M>1) relation in the Audience Interaction, the audience is first divided into M groups. Within the M groups, in turn, N:1 relation is applied. As a result, we can design the interaction function only for the N:1 relation regardless of N:1 or N:M relation. So, the interaction function has the form of

$$y = f_I(x_1, x_2, \cdots, x_N), \quad (1)$$

where $f_I(.)$ represents interaction processing, and x_i's are user inputs. Various interactions can be implemented by changing this interaction function $f_I(.)$. Though the interaction function should be designed according to the contents, it can be classified into two classes, cooperative and competitive. In the VR theater, competitive interaction can be used as a key factor to give a n interest to the audience as in most computer games. A proper combination of cooperative and competitive interaction may be the most important design issue in the Audience Interaction. For instance, the competitiveness can be introduced among groups, not within a group, when the audience is divided into multiple groups.

3. IMPLEMENTATION OF AUDIENCE INTERACTION

The VR theater in Kyongju, Korea, was built to accommodate 651 people at a time. Since it is hard to use a large number of interactive objects for a large audience, we divided the audience basically into 3 groups so that 651:3 (= N:M) relation could be easily implemented. The seats in the theater were grouped into 3 parts: left, center and right. The audience was divided into 3 groups according to the seat groups. We used color feature to make people easily identify their group. Red, yellow and blue colors were assigned to the 3 groups respectively. These colors were not applied to the seats directly, but to interaction keypads attached to every seat. The interaction keypad is a specially designed user input device for the Audience Interaction. The interaction keypad was designed to have 6 keys – 4 directional keys and 2 selection keys, which mimic the functionality of the mouse. Figure 3 shows the samples of red, yellow and blue keypads.

Figure 3. Interaction keypads used for the Audience Interaction

In order to receive user inputs from 651 interaction keypads, we also designed a data gathering device called keypad controller. The keypad controller was designed to control 30 keypads max. In the VR theater, total 24 keypad controllers were installed. Then 10~30 keypads were connected to each keypad controller. The keypad controllers were connected through Ethernet to a monitoring server that monitored total user interaction inputs. The main functions of the keypad controller were to read the status of keypad switches, to make packets out of it, and to send the packets to the monitoring server. The keypad controller scanned keypad switches every 30msec so that it can monitor user inputs in realtime. Figure 4 represents the configuration of the interaction system.

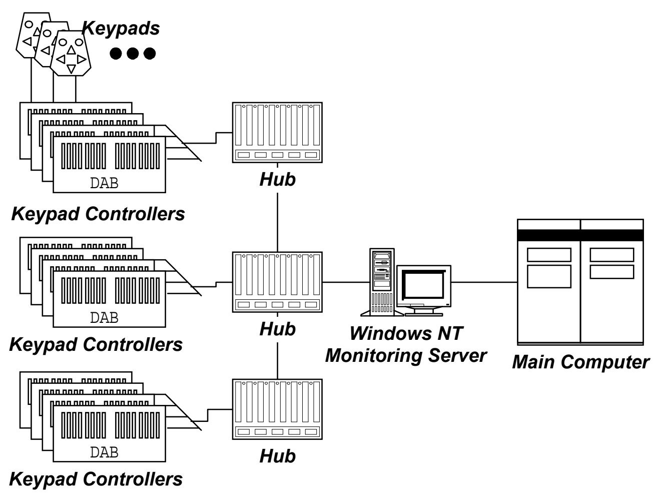


Figure 4. The configuration of the interaction system

The monitoring server interprets the packets coming from the 24 keypad controllers, and displays the status of the 651 keypads on the computer monitor. The monitoring server also applies various interaction functions to user inputs, and sends the result to the main computer. The specific interaction function $f_I(.)$ is selected by the commands from the main computer. The interaction functions $f_I(.)$ implemented in the monitoring server are categorized into 3 classes as shown in Table 2. The first one is the statistical processing. It provides the statistics of pressed keys for whole audience or for each group. The function can be used in cooperative action, for instance, to select a direction to move by majority rule. The second function provides first-come-first-served services. This class is a competitive one. In this case, the system receives the inputs from a specific number of people. The system ignores the inputs after the limit is reached. On the other way, the time-limited service is also available. The system ignores the inputs after the time limit. In either case, we can specify by the commands the number of people to select or the time to cut off the service. These services can be applied to whole audience or to each group, too. The last function is to read the switch status of a specific seat. This class is elementary, and can be used in both of cooperative and competitive interactions. The Kyongju VR theater provides these three interaction function classes, and their usage depends on the VR contents.

Table 2. The interaction functions that implemented in the Kyongju VR theater.

Function Class	Detailed Service
Statistics	- Total/Group statistics
First-come-first-served	- Total/Group first-come-first-served service - Limit the number of people / Time limit
Individual status	- Key status of a specific seat

4. PRESENTATION

The VR theater in Kyongju, Korea, was built to provide audience with immersive and interactive virtual experience environments. Besides the interaction system, the VR theater facilitates an immersive environment by a large screen that displays stereo images of high resolution. The VR theater uses a large cylindrical screen of the size of 27m x 8m. The images to be projected on this screen have high quality of the resolution of 3780 x 1024 pixels with the brightness of 4000 ANSI lumens. Six projectors are used to make the passive type stereo images that produce visually immersive feeling. The sound system contains 24 speakers that enable 8 channel surround 3D sound. In the sound system, the platform under the seats is used as a large woofer so that audience can feel the sound by the body. Another facility to provide immersive feeling is a fragrance control system. It controls the type and amount of fragrance, and time to release. As a whole, the Kyongju VR theater provides immersive environment by automatically controlled visual, aural and olfactory rendering. Figure 5 shows the system configuration of the Kyongju VR theater, in which the visual and sound interaction are the next research issues to probe further.

The Kyongju VR theater had presented about 15 min-long VR movie of the name of "Into the breath of Seorabol" from the 1st of Sept. to 25th of Nov. in year 2000. It was the theme movie of the Kyongju World Culture Expo2000, which was seen by almost one million people during the period. In the VR movie, we provided the user interaction using statistics because it was easy and intuitive enough for people to learn fast for the short waiting and running time. Only 4 directional keys were used, and the inputs

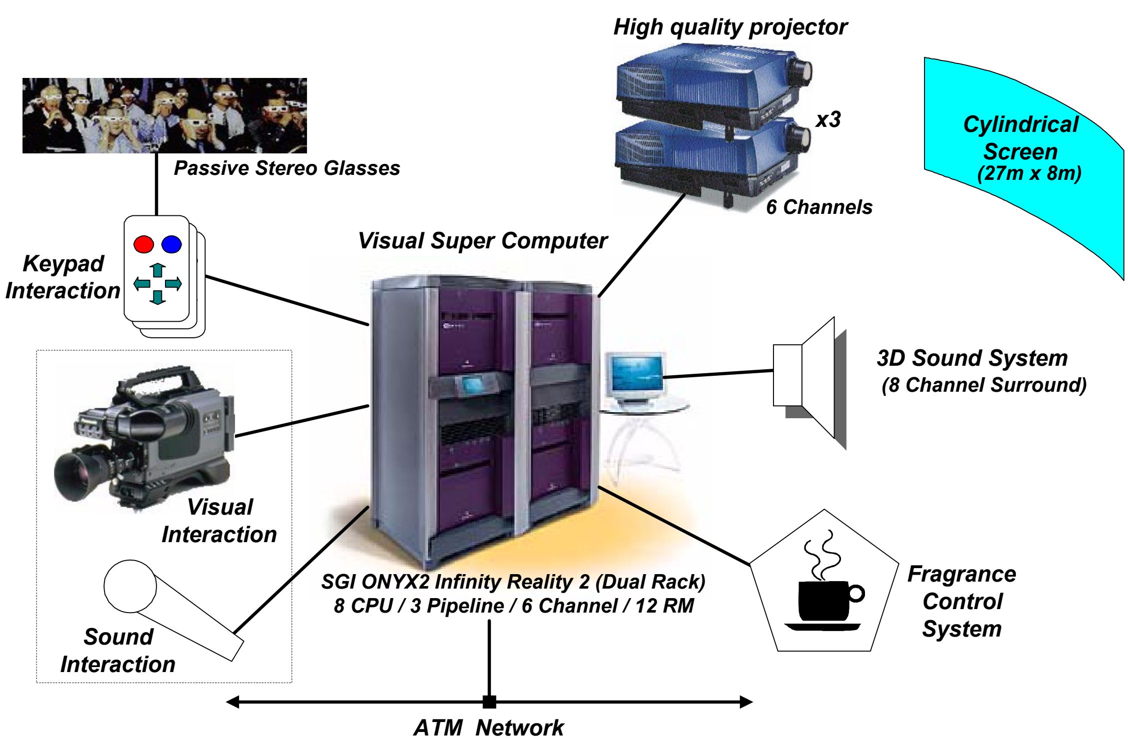


Figure 5. System configuration of the Kyongju VR theater.

from the other 2 selection keys were ignored in the keypad interaction. The purpose of the implemented Audience Interaction was to move a flock of butterflies on the screen. Left and right key inputs were programmed to move the flock to the left and right, respectively. Up and down key inputs were used to move the flock far from and close to the audience, respectively. The final direction was selected by majority rule. This interaction was enabled only in small periods of running time. When the interaction was enabled, arrow marks were displayed on both sides of the screen so that people could recognize it started. The arrow marks was programmed to become solid white as the number of corresponding directional input was increased. The arrow marks played a role of a feedback signal to the audience so that they could recognize the intention of the other people. As a result, the arrow marks provided an awareness method of the intention of the other people. Figure 6 shows a screen shot when the interaction was enabled.

Figure 6. A screen shot when the interaction is enabled.

The interaction was enabled 3 times during the running time, in the introductory part, in the halfway part and in the last credit scene. We could notice that the audience couldn't move well the flock of butterflies in the introductory part. But, they became quickly habituated to the interface and could move butterflies across the screen in the last interaction period. This showed that the implemented interaction was intuitive. When we implemented the interaction using statistics, we were worrying that butterflies might not move at all since the average of key inputs was just 'don't move'. However, people recognized the motion of butterflies was bounded by the screen boundary and tried to move them to the other directions at the boundaries. From this we could see that the visual feedback removed the averaging influence.

5. CONCLUSION

The VR theater concept is rather new for the research field, and it can include the Meeting Room class in the classification of the CSCW systems. The VR theater combines the advantages of VR and IMAX theater, but provides new challenges. In this paper, we defined the multi-user interaction in a VR theater as *Audience Interaction,* and discussed the design and implementation issues of the Audience Interaction. The design issues for the Audience Interaction can be summarized into three items such as interaction devices, mapping problem between audience and virtual objects, and interaction function design. The mapping problem between audience and virtual objects is new and becomes important for the Audience Interaction because it is a single screen application. The mapping is likely to be N:1 between audience and virtual object in the implementation phase because of the limited number of features to identify virtual objects. This paper presented the implementation example of the world's largest VR theater in Kyongju, Korea (http://www.sgi.com/features/2001/feb/kyongju/). However, more research on the Audience Interaction is needed along with the VR contents developments.

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