XMegaWall: A Super High-Resolution Tiled Display using a PC Cluster

Yong-Bin Kang[1], **Ki-Joon Chae**[2]

[1] Institute for Graphic Interfaces
Ewha-SK Telecom Bldg. 11-1, Daehyun-dong, Seodaemun-gu, Seoul, Korea
e-mail: ybkang@igi.re.kr

[2] Institute for Graphic Interfaces
Ewha-SK Telecom Bldg. 11-1, Daehyun-dong, Seodaemun-gu, Seoul, Korea
e-mail: kjchae@igi.re.kr

Received: December 21, 2006 / Revised version: March 30, 2007

Abstract This paper presents design criteria for making a super high-resolution tiled display, and describes our experience in building and utilizing that display. In particular, we emphasize on how our tiled display framework is designed, and how we derive high-performance visualization capabilities using a commodity PC cluster integrated into our display framework. Further, we show how our display can be effectively used as a powerful display technology by demonstrating four applications, such as High-Resolution 2D Viewer, 3D Graphics Renderer, Movie Player, and Windows Application Viewer.

1 Introduction

Recently, there has been a significant increase in demands for the interactive visualization of high-resolution life-sizing images and the rendering of complex models in various domains, such as scientific visualizations, virtual reality environments and visual simulation applications. Typical desktop-based display systems have intrinsic restrictions to meet those demands, because of their limited display capabilities and low graphics processing performance. Thus, recent research for meeting the needs of such a visualization community has been primarily focused on the development of large-scale high-resolution tiled display systems[1–5].

The main challenges for building a tiled display system are to support the needs for (1) driving a scalable high-resolution display; (2) scaling graphics performance; and (3) leveraging the potential benefits of commodity technologies. Much work has investigated and continues to happen on developing tiled display technologies and their use in the visualization community. Our primary concern here is how to construct such a tiled display system that can fulfill all those challenges with super high-resolution nearly better than those of previously accomplished similar work.

In this article, we present our experience in building and utilizing a super high-resolution tiled display system (XMegaWall) arranged in a 7 x 4 array projectors, producing a display of 6592 x 2784 pixels across a 5.6m x 2.4m size screen. More specifically, we focus on how the XMegaWall can meet the research challenges noted above by describing (1) its scalable framework; (2) its high-performance cluster-based visualizing architecture. Further, we describe how it can be effectively used as a powerful display technology by showing four applications, such as High-Resolution 2D Viewer(HIV), 3D Graphic Renderer (3GR), Movie Player(MP), Windows Application Viewer (WAV).

The main contribution of this work are: (1) proposing an useful strategy for setting up a practical and relatively cheap wall-sized high resolution display with a cluster of commodity PCs; (2) presenting a tiled display system for rendering or streaming 2D/3D/Video data with high resolution and high performance, as well as how the system was implemented in deep; and (3) demonstrating a number of applications that represent state of the art attention to important challenges that this area poses.

This article is organized as follows. In the next section, we discuss how the XMegaWall is designed. Section 3 presents the XMegaWall's clustering structure. The applications integrated into the XMegaWall are demonstrated in Section 4.

2 XMegaWall Design

First and foremost, in order to help understand how the XMegaWall is structured, we describe its main specification. The XMegaWall is a super high-resolution rear-projected display system, consisting of a unit of 7 x 4 projectors with a resolution of more than 20 million pixels. We configured it to be driven by a cluster of PCs to provide a more affordable, scalable architecture. The main specification is as follows:

– Arrangement: 7 x 4 XGA Tiles (28 DLP Projector driven by commodity PCs to a gigabit switch)
– Size: 5.6m x 2.4m
– Resolution: 6592 x 2784 pixels (28M pixels, dot pitch 0.78mm)

As shown in Fig.1, the XMegaWall is built with multiple low-cost commodity components and composed of three main parts: (1) a hybrid screen for rear-projection; (2) a projector frame and stages to correctly position the projectors; and (3) a cluster of PCs.

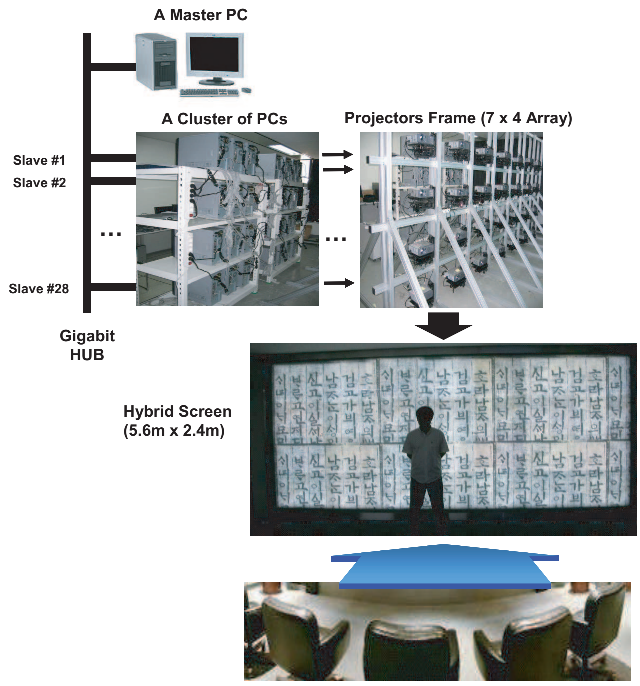

Fig. 1 The XMegaWall's schematic representation

We have designed and manufactured the XMegaWall finding ways to solve the problems inherent from its structure and functional usages or operations. We now describe how the XMegaWall's three main parts are designed and featured in detail after presenting its major characteristics as follows:

– *High-resolution, High-quality representation*
  The XMegaWall achieves seamless imaging and rendering by deriving an effective coordination on a clustered PCs environment.
– *High-performance visualization capability*
  The XMegaWall is designed to enable low-latency, high-bandwidth mechanisms to deliver high-performance visualization based on distributed volume visualization techniques.
– *Scalable, Portable, and Cost-Effectiveness*
  Unlike most traditional display wall systems using very expensive graphics systems and high-end projectors, the XMegaWall drives a powerfully scalable high-resolution display by (1) leveraging the cost of advantages of commodity PCs; (2) designing an assembled projector frame structure; and (3) deriving low-cost, high-precision stages and a high-resolution flat-panel screen.

2.1 Hybrid Screen

The most popular and frequently used methods for building a large display are using the composition of LCD panels[6, 7] and acrylic rigid screens[8]. In the former method, a screen is constructed by assembling a set of small-sized LCD panels. Such a screen of this kind generally gives high surface brightness. Since, however, it yields too many straight-line borders between adjacent tiles, it is inferior in the aspect of visualization effects[9]. Besides, this screen can be easily fragile due to its thin surface. In the latter method, a large acrylic screen can be built by composing several units of small-sized acrylic displays. This screen is rigid, but, it has an intrinsic limitation to expand its size (e.g., max-size is 340 inch[2]) in current manufacturing technology. In addition to this, it gradually tends to be getting bent according to the lapse of time.

For that reason, we designed a new rear projection screen, called a *hybrid screen* that can meet the shortcomings of those two approaches as shown in Fig.2(a). This screen is constructed by attaching a very high-quality non-rigid, white-colored screen to a large-sized transparent tempered glass (5.6m x 2.4m size). Its main features are brightness, white uniformity, wide viewing angle (gain 1.0), seamlessness, and firmness against vibration.

2.2 XMegaWall Projector Frame

When constructing a tiled display framework, one of the important problems is how to uniformly and accurately align the accumulated projectors not to distort the overall geometry of those projectors arrangement. In order to meet the issue with effective ways, we designed and implemented H/W frame which consists of two major elements: (1) a projector frame that can stably resist the weight of multiple projectors; and (2) high-precision but small-sized stages designed to position the projectors.

2.2.1 Projector Frame: Most conventional approach for building multiple projectors frame has been centered on a common method based on the *box-styled design*, assembled by many horizontal and vertical profiles as seen in the left of Fig.2(b). One drawback of this method is that it hinders the operators from accessing to the projectors, thus making it difficult to tune the process of projector arrangement. Therefore, we designed our frame to have a planar body with commodity aluminum profiles as shown in the right of Fig.2(b). This frame can allow the operators to easily access the projectors and help to minimize the tuning time for the arrangement task. Besides, our frame can be easily extended its volumetric size by simply adding a few aluminum profiles on the side of the main frame. Moreover, in order to increase its stability, we added footholds to both sides of each column pole to make a triangular structure being regarded as the most stable form for such a construction.

2.2.2 Projector Stages: We developed a very stable, high-precision 6 degree of freedom (DOF) stage that provides easier ways to adjust the position and orientation of the projector being mounted on the top of this positioning device. Some of earlier designs[2] have mainly two intrinsic problems from the aspects of positioning a heavy-weighted object and operating ranges: (1) it is sensitive to even a light touch, so that it requires frequent re-adjustment task manually; (2) the operation ranges are too narrow especially to the z-direction. To reduce these problems, we separated the z-axis from the other transformation axes in the main body of our stage. Then, we located such a separated z-axis control part to be attached to the project frame (see the left of Fig.2(c)). This method also made it possibly to have a relatively thin structure compared to the former design methods. The right of Fig.2(c) even shows how our stage can be easily extended to the situation where it is used for generating stereo visualization effects.

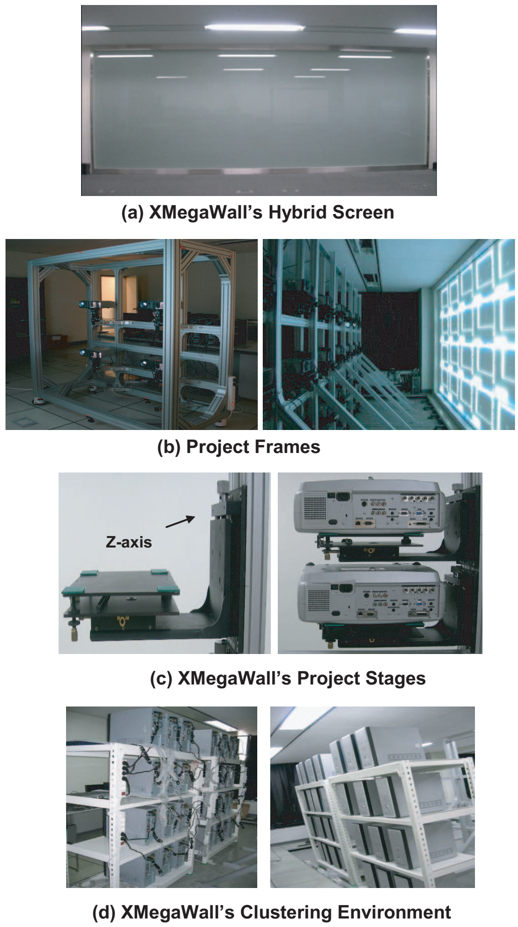

Fig. 2 (a) XMegaWall's hybrid screen (5.6m x 2.4m size). (b) A typical projector frame having a box-styled design (left); The XMegaWall's frame: scalable, stable, easy-to-move, easy-to-use, and low-cost design (right). (c) The XMegaWall's projector stage with 6 DOF: A side view of our stage (left); When the stage is used for a stereo tiled display (right). (d) The XMegaWall's clustering environment for high-performance visualization using rich-featured graphics cards.

2.3 XMegaWall's cluster of PCs

For several years now, high-performance and rich-feature PC graphics interfaces have been increasingly popular and available at relatively lower cost. This trend enabled us to build a clustered tiled display environment at a reasonable cost. The main purpose of the XMegaWall's clustering is to enable the real-time visualization of 3D graphics images or video streams with high-performance in a tiled display environment. Its main characteristic is to have *master-slave model*[10] in which all of the visualization applications are executed in collaboration with all the *clustered slave PCs* (shortly slaves). Such executions can be synchronized to insure consistency among those slaves. Fig.2(d) shows the XMegaWall's clustering structure in which 28 PCs harnessed with high-end graphics card (i.e., NVdia GT6800) are interconnected via a gigabit network.

3 XMegaWall's Rendering Cluster

This section describes how the XMegaWall supports a powerful visualizing capability on its environment. Tiled display systems must have the abilities to display images at very high-resolution, as well as provide a large field-of-view about these images with high-performance. The traditional approach to support these requirements is to use high-performance computers, such as SGI Onyx2 with multiple InfiniteReality graphics pipelines. For example, Argonne[11], Livermore[3] were using multiple pipes of SGI Onyx2 visualization servers to drive tiled displays. Unfortunately, this approach requires (1) very expensive cost, sometimes costing millions of dollars; (2) limits the number of projectors that can support; and (3) is difficult to set up, such that its application areas have been limited to a small number of organizations or users[11].

An attractive alternative to the traditional solution is using a clustered-based approach that uses of a cluster of commodity PCs interconnected via a low-cost, high-speed network for rendering purpose. The major advantages of this approach are economical to build; scalable in performance and resolution; and easy to use and to maintain. The main issues for developing this cluster system is to develop promising rendering strategies, i.e., (1) how to partition and distribute data; (2) how to share and manage data; (3) how to synchronize the output among distributed renderings performed by the multiple clustered PCs. The main purpose of our work here focuses on the development of such a clustered-based rendering system in the XMegaWall, resolving these issues.

3.1 Clustering Model

Before identifying the main features of the XMegaWall's cluster system, we first introduce its data distribution model to help understand how it distributes data and synchronizes its execution. In general, the most popular approaches to setup a cluster-based tiled display can be classified into these two categories. These are client-server approach and master-slave approach[10].

The former approach stores the dataset at one central server and it is usually fairly transparent to the programmer. The program can be implemented as if it runs on a single machine and the system will handle the rest[12]. As described earlier, the XMegaWall's cluster system is based on the master-slave approach that usually requires the least amount of bandwidth. In this approach, the results of user interactions and other state changes are sporadic and relatively simple to transmit over a network[4, 10]. Multiple instances of an application run on all of the slave nodes. A master node sends and handles all user interactions and synchronizes state changes among these slaves. Fig.3 shows a conceptual overview of the XMegaWall's cluster system.

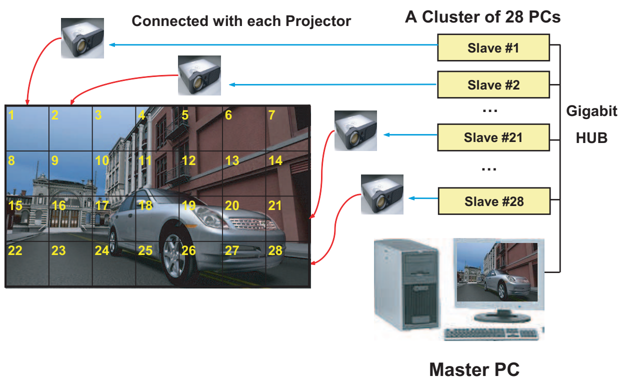

Fig. 3 A conceptual overview of the XMegaWall's cluster system: its display is logically divided into uniformed 28 segments and the splitting images are synchronously displayed by using a set of 28 slaves controlled by the master.

Once the master receives a certain instruction from a user interface, it broadcasts the instruction to all the slaves for interactive execution. For this, we developed two different forms of rendering strategies that effectively work on the different types of applications. In the following subsection, we describe how these work in more detail.

3.2 Main Features of the XMegaWall's Cluster System

The popular visualization applications that are commonly required to be displayed on the large display include high-resolution 2D images, complex 3D graphics primitives, and video streams. In order to maximize visualizing capability on each of these applications, we developed two types of rendering strategies depending on what form of data is distributed between the master and slaves. These are *control data distribution* and *stream distribution*. Here we explain how these are characterized based on major four aspects, such as dataset location, working process, data distribution, and rendering pipeline.

3.2.1 Control Data Distribution: In this strategy, the same datasets need to be located in the master and be duplicated ahead across all the slaves before rendering. The master deals with user events and broadcasts only the control data (e.g., the image resolution size to be rendered, the size of overlapping region to be blended, the synchronization signal, and the viewport frustum change) according to a user interaction. The multiple instances of the same application are run on all the slaves, and all these instances assume identical working process. In addition, all these executions are synchronized by the control data.

The master does not need to be seen in a completely rendered form, because its main role is acting as an intelligent interface to control the slaves. Thus, we implemented a specialized master-side application in which a simple bounding box that completely covers the rendering object as seen in Fig.4. In our demonstration, this technique effectively performs in the situations where the size of the dataset is very high. The distribution of the control data and its synchronization overhead were also efficient, less than 100 bytes per frame. Moreover, with the new feature of the master rendering module, we significantly reduced data loading time (nearly 70%). This effect also played an important role in minimizing the extra latencies caused by the memory overhead and CPU usage for maintaining a whole rendered scene, and thus brought an overall performance improvement (nearly 50%) in our clustered rendering process.

3.2.2 Stream Distribution: This strategy is a particularly useful method for the rendering of high-resolution video streams at high-speed performance. The main challenges are (1) how to transmit an input stream to slaves; (2) how and when to decode it; (3) how and when each

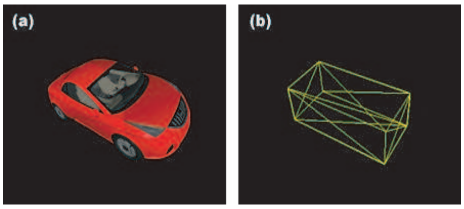

Fig. 4 To obtain a better performance, the master application is made to render the simple bounding box (b) of the corresponding the image (a).

slave clip it appropriately to the partial region that must be displayed by each slave; (4) and how to synchronize all the execution performed on our cluster system. In this strategy, first, the master concurrently multicasts an input stream to all slaves based on its bitrate. Second, each slave decodes the stream, and transmits the decoded audio stream (+ timestamp) and video stream (+ timestamp) to our audio render and video render working on each slave respectively. Particularly, the decoded video stream passes *overlay filter* which performs clipping, stretching, blending, and playing statistics operations. For synchronizing all the audio and video renders, we synchronized *relative H/W system clocks* of all the slaves. Comparing to the former distribution strategy, the main feature of this approach is that it simplifies necessary operations required to each slave. Besides, it does not need additional storage spaces for holding the duplicated datasets to all the slaves.

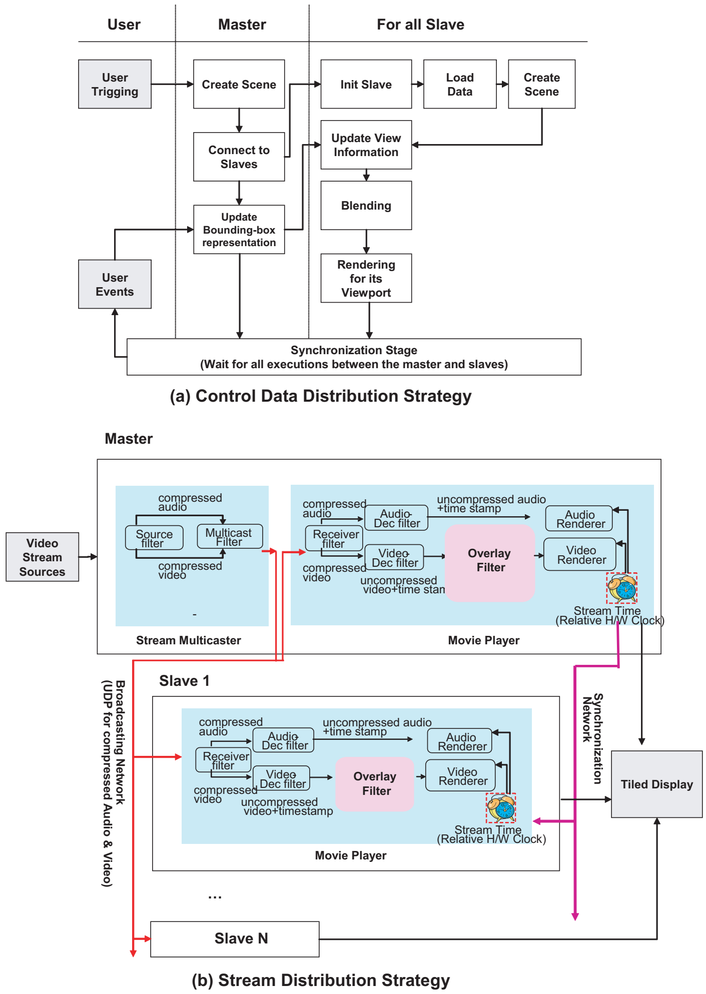

Fig. 5 The rendering pipeline of our two clustering strategies.

4 Applications

In this section, we show our demonstrations. The goal is to answer the question of whether the XMegaWall is appropriately enough as a powerful display technology for high-resolution graphics applications consisting of massive datasets. We briefly describe four applications which have been integrated into this environment.

4.1 High-resolution 2D Image Viewer (HIV)

As our basic application, we developed the HIV that can display high-resolution life-sizing images. Previous work on high-resolution cameras has led to the availability of very large and accurate images of fine art acquired from various areas, such as VR environments, manufacturing industries, entertainment/advertisement industries, and GIS areas. The HIV is executed by adopting the 'control data distribution' strategy as our cluster model. Some examples are shown from Fig.6(a1)-(a3). For the control data, the size of portion that each HIV must display and the size of overlapped region to be blended between adjacent tiles were considered. By this demonstration, we found that the XMegaWall presents an ideal medium for visualizing the image that itself is quite rich at high resolution.

4.2 3D Graphics Renderer (3GR)

Originally, our work is motivated to support *Virtual Reviewing System* which allows designers to review and simulate designs created during manufactural real processes in a more efficient way. With regard to this motivation, our 3GR was made not only to provide better 3D immersion effects, but also to help reduce manufactured cost, explore creativity, and lead to a better final product quality. It can let many off-the-shelf 3D graphics formats run and simulate according to the triggering events of user interactions in real time. Like the HIV, the 3GR's rendering process is performed mainly based on the 'control data distribution' approach. In more detail, the master controls the rendering process of all the slaves, distributes only control data (e.g., view frustums), and has a responsible for synchronizing that process. Each slave renders its own partial scene region when receiving the control data from the master. Fig.6(b1) shows a complex 3D automobile model created by our virtual manufacturing process. As shown in Fig.6(b2), we can manipulate this design and even have a feeling how the inner leathers

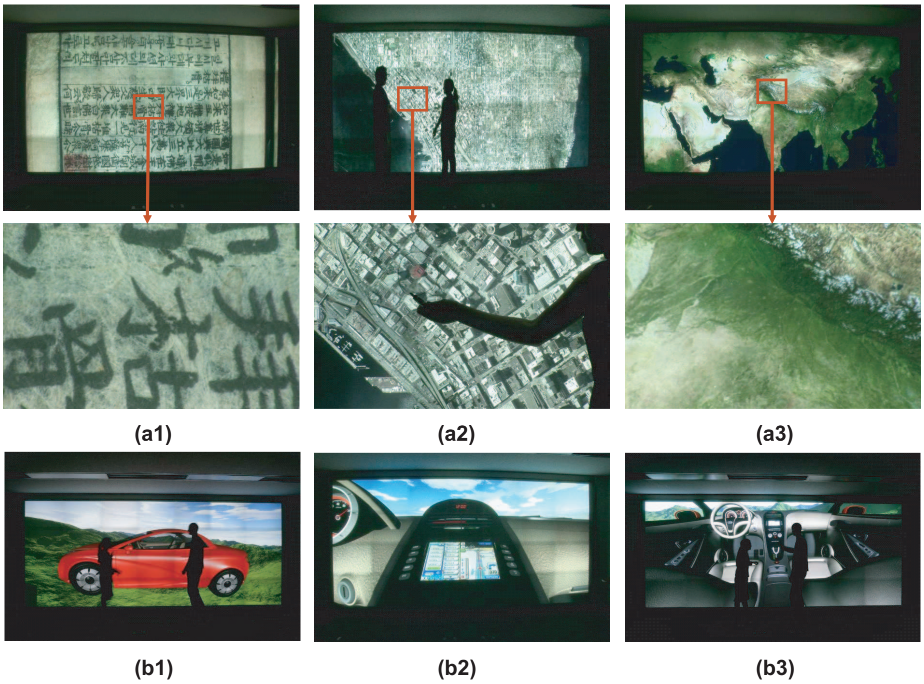

Fig. 6 (a1) A high-resolution picture having ancient Korean characters written in an ancient paper. We can see even the pattern of the delicate weaves of the paper. (a2) A high-resolution picture taken from a satellite displayed on the XMegaWall. We can look into it in depth, even identify the shape of a fingernail-size object in the image. (a3) A picture taken from a satellite. We can get a view of whole map at a look in detail. (b1) A 3D rendered graphics model composed of about 3 millions polygons with background. (b2) A snapshot of the certain region of the inner body of the automobile model seen in (b1). (b3) This application is effectively applied in the situation when reviewing and simulating designed objects.

of the car are characterized in detail. Through the renderer, we were able to enhance the sense of immersion like shown in Fig.6(b3).

4.3 Movie Player (MR)

We developed the MR for playing high-resolution frames of digital movies and for scientific data on our tiled display. Currently, high-resolution digital movies having abundant high-quality of effects have been increasingly created through various off-line cinematic techniques. Those kinds of movies exceed the resolution that a single desktop video player can achieve in general. Moreover, in order to improve the sense of immersion and the feeling of reality on those movies, we certainly believe that a high-resolution movie player is required. The objective here was to produce the MR that can meet these demands and plays the movies at the greatest possible resolution, capable of adapting the frames for playback with any arbitrary resolution. Fig.7(a) shows the snapshots of a 3555 x 2000 resolution movies with 30 FPS on the XMegaWall.

In addition to this, we applied this technique to HDTV displaying. The HDTV signal (ATSC aerial signal) is captured via UHF antenna and it is converted into a MPEG-2 stream by HDTV card on the master. The master then separates the signal into two parts (i.e., video and audio) and multicasts it to slaves. Remaining process is the same with the above. Fig.7(b) shows some snapshots of real-time domestic HD News broadcastings in Korea.

4.4 Windows Application Viewer (WAV)

We developed a Windows Application Viewer (WAV) to run existing Windows applications that can achieve enough performance in the context of the XMegaWall without changes. Here, our goal is to improve usability of our tiled display system by bringing Windows environment to it. The rendering process of the WAV is accomplished by the 'stream distribution' strategy. First, a multi-thread based image capturer running on the master captures consecutive images being displayed in real-time Windows environment. The remaining procedures are same with the case of the Movie Player. Fig.7(c) shows the snapshots of Windows desktop, Microsoft PowerPoint, Internet Explore through the WAV. The WAV's major advantage is that it can display any of Windows applications without modification, as if the user is working on a desktop, on a large high-resolution display.

Fig. 7 Some snapshots being displayed on the XMegawall: (a) Movie Player (High-resolution movie); (b) HDTV News Broadcasting); (c) Windows Application Viewer (Desktop, Internet Explorer, PowerPoint).

5 Conclusion

In this paper, we presented our experience in building and utilizing a scalable, super high-resolution tiled display system. Particularly, we described how our overall system is designed and what its main characteristics are in more detail. Then, we discussed our cluster-based approach that can effectively support the high-performance visualization using a cluster of commodity PCs. More specifically, we presented two types of rendering strategies that can maximize visualizing capabilities of those visualization applications popularly demanded in various visualization domains. Finally, we demonstrated how our tiled system can be appropriately enough as a powerful display technology by showing four popular visualization datasets integrated into our display. Future work will include building a completely immersive display system that could support multi-modal interaction functionalities by deriving intelligent hybrid tracking mechanisms in our display space.

Acknowledgement

This work is supported by Ministry of Information and Communication Republic of Korea. We should also like to express our gratitude to our all the members working in Tiled Display Team at "Institute for Graphic Interfaces (IGI)" for their cooperation and support in building our tiled display system.

References

1. Czerwinski, M., Robertson, G., Meyers, B., Smith, G., Robbins, D., Tan, D.: Large display research overview, ACM Press (2006)
2. Hereld, M., Judson, I., Stevens, R.: Introduction to building projection-based tiled display systems. IEEE Computer Graphics and Applications **20** (2000) 22–28
3. Schikore, D., Fischer, R., Frank, R., Gaunt, R., Hobson, J., Whitlock, B.: High-resolution multiprojector display walls. IEEE Computer Graphics and Applications **20** (2000) 38–44
4. Ni, T., Schmidt, G.S., Staadt, O.G., A, M.: A survey of high-resolution display technologies, techniques, and applications, IEEE Press (2006)
5. Li, K., Chen, H., Chen, Y., Clark, D., Cook, P., Damianakis, S., Essl, G., Finkelstein, A., unkhouser, T., Klein, A., Liu, Z., Praun, E., Samanta, R., Shedd, B., Singh, J., Tzanetakis, G., J, Z.: Building and using a scalable display wall system. IEEE Computer Graphics and Applications **20** (2000) 29–37

6. Jeong, B., Jagodic, R., Renambot, L., Singh, R., Johnson, A., Leigh, J.: Scalable graphics architecture for high-resolution displays, IEEE Press (2005)
7. VisWall: (High resolution display wall, http://www.visbox.com/viswall.html)
8. Bordes, N., Bleha., W.P., Pailthorpe, B.: Compact tiled display with uniform illumination. Journal of Electronic Imaging **12** (2003) 682–688
9. Krumbholz, C., Leigh, J., Johnson, A., Renambot, L., Kooima, R.: Lambda table: High resolution tiled display table for interacting with large visualizations, ACM Press (2005)
10. Staadt, O.G., Walker, J., Nuber, C., Hamann, B.: A survey and performance analysis of software platforms for interactive cluster-based multi-screen rendering, ACM Press (2003) 261–270
11. Hereld, M., Judson, I., Paris, J., Stevens, R.L.: Developing tiled projection display systems. (2000)
12. Renambot, L., Jeong, B., Jagodic, R., Johnson, A., Leigh, J., Aguilera, J.: Collaborative visualization using high-resolution tiled displays. (2006)

Yong-Bin Kang is the team leader of Tiled Display Team at Institute for Graphic Interfaces (IGI), Korea. He has been working over 10 years as a senior researcher, technical consultant, and software architect in the filed of Computer Graphics, Virtual Reality, and EAI. He received MSc degree in Computer Science in Pusan National University in 1998. The major focus area of his research is to develop high resolution tiled display and its multi-modal interaction technologies with stat-of-the-art hybrid tracking techniques.

Ki-Joon Chae is the president and CEO of Institute for Graphic Interfaces (IGI) and a professor in Department of Computer Science and Engineering at Ewha Womans University, Korea. He received MS degree in Computer Science from Syracuse University and Ph.D. degree in Computer Engineering from North Carolina State University, U.S.A. His research interests include network security, network protocol design and performance evaluation, and computer graphics area.