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Augmented Virtuality Space: Enriching Virtual Design Environments with Reality

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Abstract. As compared with Virtual and Augmented Reality, Augmented Virtuality (AV) has rarely been explored for design applications. Augmented Virtuality refers to a predominantly virtual environment enhanced by the addition of real contents. AV technology provides a means to merge a richly layered, multi-modal, 3D real experience into a virtual environment. This paper presents the creation of an Augmented Virtuality prototype that could enhance the intuitive objective of design and collaboration effectiveness by seamlessly inserting real context and experience into a virtual design alternative. An application scenario of this prototype is also presented. The AV system allows a designer equipped with an immersive head mounted display (HMD) to either "step into" the design space or in some similar fashion to have his or her view of a virtual building augmented with a projection of real images/video registered to the virtual world coordinate system. This paper also presents the proposed experimentation and relevant human-computer interaction issues in AV applications in design and collaboration.

Keywords: Augmented Virtuality, virtual space, architectural design, collaboration

1 Introduction

Virtual Reality (VR) technology was originally embraced by architecture visionaries for design concept presentations during the last decade, as computing advances have supported more sophisticated graphics capabilities [5]. Augmented Virtuality [7], a more expansive form of Virtual Reality and the augmentation of a virtual setting with real objects, provides a means to merge richly layered, multi-modal, 3D real context and experience into a virtual environment. Design industry such as architecture opens the door for more innovations in Augmented Virtuality. Despite its potential, Augmented Virtuality has not received nearly the amount of attention paid to Virtual Reality and Augmented Reality. AV has only been applied in very limited domains: as display on unmanned air vehicles [10], 3D videoconferencing system [11], and scientific center [1]. There is no recognized research effort towards AV applications in architecture domain. The novelty of the work presented in this paper is supported by the paucity of published research that investigates AV applications in design and collaboration.

This paper presents our creation of an Augmented Virtuality prototype that could enhance the intuitive objective of architectural design and collaboration effectiveness by seamlessly inserting real context and experience into a virtual design alternative. The system was developed with an interactive computer graphics approach. The AV system allows an architect equipped with an immersive head mounted display (HMD) to either "step into" the design space or in some similar fashion to have his or her view of a virtual building augmented with a projection of real images/video registered to the virtual world coordinate system. Real entities like image/video acquired from the real world by camera could be mapped or registered into the virtual world to essentially "decorate" it with much of the richness of the real world. The system also provides a mean for design collaboration by provide a two way video and audio conference channels. The user is able to see and talk with the coworker as if he is in the real environment. This paper also presents the potential research solution in AV environments to enhance design comprehension, collaboration, and the interface mechanisms/technologies that should be incorporated in AV environments to facilitate interactions with design models.

In order to pre-clarify our system, a simple user scenario could be developed as following: The completion of a construction/interior decoration project has been declared by the construction company, and the original designer is involved in the final inspection. By employing our system, a virtual model of the building has been created and maintained according to the real situation. The building model is decorated with up to date images as well as live video stream from the construction site, which shows the detailed condition of the building as well as the outlook view from the window. By using a HMD or normal projection screen, the designer is able to inspect the building model from a remote location. During the virtual inspection process, the designer is also able to have live audio/video conference with a coworker and obtain assistance regarding the inspection task.

2. Augmented Virtuality System

The AV prototype system developed in this paper consists of four major components working in collaboration: AV User Interface; Remote Collaborator Interface; Modeling/Rendering Unit and Model Object Inventory. Supporting hardware devices such as head-mounted display (HMD) and a number of cameras are used to enhance the user's environmental awareness as well as provide input and output data. Figure 1 shows the architecture and the components of the system.

The system employs a modular architecture during implementation. Each of the four sections serves a particular functionality and is self-retainable. The system can be upgraded by redeveloping individual section without affecting others by providing the same data transmission socket. For instance, new HMD with higher resolution or advanced orientation/movement control devices (motion tracker) can be added into the system by implementing minor changes into the AV User Interface.

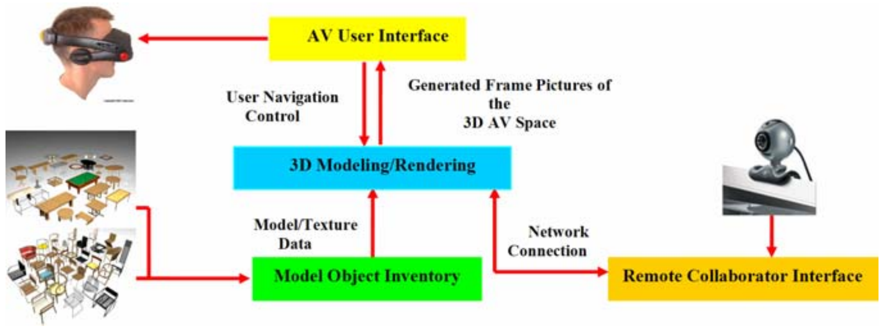

Fig. 1. System structure of various functional components.

2.1 System Architecture

The current setup employs two desktop computers under a Master – Client network architecture. The master node represents the major user and the client node represents a coworker at a remote location. The master node stores the entire Model Object Inventory and performs the Modeling/Rendering calculation. All necessary information for the visual/audio update is collected from client node and transferred to the master node. The master node then performs a real-time production of 3D models as well as the video input stream and delivers the generated frame pictures to the user. These two nodes communicate with each other via a gigabit LAN network under TCP/IP protocol. The system is capable of adopting multi-Client Nodes which enable the user to communicate with multi-coworkers at the same time.

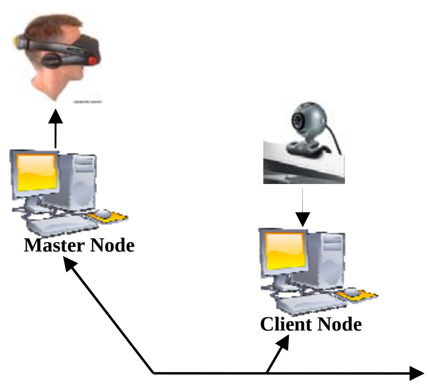

Fig. 2. Network architecture.

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2.2 Software layer

Since the major motivation of this paper is to create a realistic and immersive Augmented Virtuality space, the goal of technical implementation is to develop a virtual environment which is richly layered, multi-modal, 3D real context and be able to map entities from the real world into a virtual design environment. The realization of such AV space demands intensive 3D model construction and high flexibility of live video stream manipulation. After testing several software setups, the programming application of Max/Msp with extension of Jitter has been chosen to serve this purpose.

MaxMsp is a graphical programming environment for audio and multimedia. Jitter is an extended collection of video, matrix, and 3D Graphics objects which cooperate with Max/Msp. Jitter can provide extensive support to OpenGL Application Programming Interface (API). It also provides supports to 3D modeling, texture, rendering, live video input and manipulation. Some major advantages of using Max/Msp/Jitter [12] are summarized as follows:

1. It can superimpose 3D-graphics on a video backdrop
2. It offers a number of 3D primitives
3. It has import functions for 3D-models
4. It offers real-time manipulation of Quicktime video, 3D-models and sound parameters

Max/Msp/Jitter also supports the purpose of creating AV space in the following way:

1. It has a graphic interface for rapid development of the scenarios
2. It provides scripting programming capabilities as an addition to the graphical interface for complicated tasks
3. The virtual camera parameters can be easily adjusted according to keyboard input or sensor input (later version)

2.3 AV User Interface

Users can interact with the system through the input and output devices provided by the AV User Interface. The AV User Interface takes in information of the user input such as rotation and reposition, and presents the user with a real-time rendered 3D view displayed on the HMD. The user input is mapped to the four arrow keys of a standard keyboard. A hi-Res800 HMD is used for the visual feedback to the user. This HMD has two separate displays which provide 28 -24 degrees diagonal field of view in horizontal and vertical respectively. It also has integrated stereo earphones and integral microphone, which would be employed for the audio conferencing in the AV space.

View Changes. The concept of virtual camera is used to represent the perspective in virtual world. The direction of virtual perspective changes by manipulating two sets of 3D spatial coordinates of *Camera Position* (X,Y,Z) and *LookAt Position* (X,Y,Z) (see Figure 3). In this AV system, a virtual camera is used to simulate the user:

1. Simulate the user's first-person view with the camera view;
2. Simulate the user's forward/backward movement by moving the virtual camera forward and backward;

3. Simulate the user's turning of direction by rotate the *LookAt* position of the camera according to the camera position.

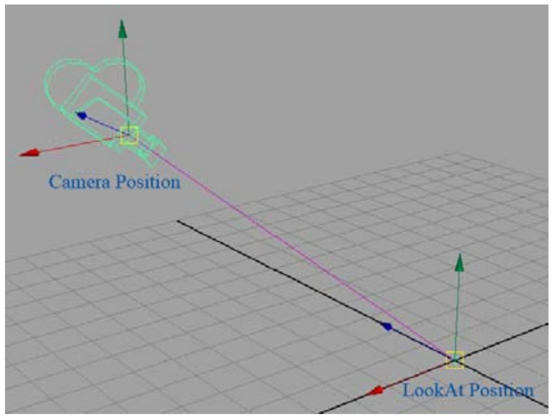

Fig. 3. Direction of camera view.

Rotation. The AV system employs a pre-calculated lookup matrix to cooperate with directional navigation. The matrix consists of 360 elements which implement a one-one mapping of 360 degrees with one degree interval. Every element consists of a set of (X, Y) value which corresponds to a point on a circle which center at the origin and 1000 units in radius (see Figure 4). Every single click of left/right arrow key would turn the view point by one degree, while holding down the keys would trigger the turning of 1 degree every 25 ms until the release of the keys. This lookup (X, Y) value set is then added to the current position of the user in order to obtain the up-to-date LookAt position (see Figure 5).

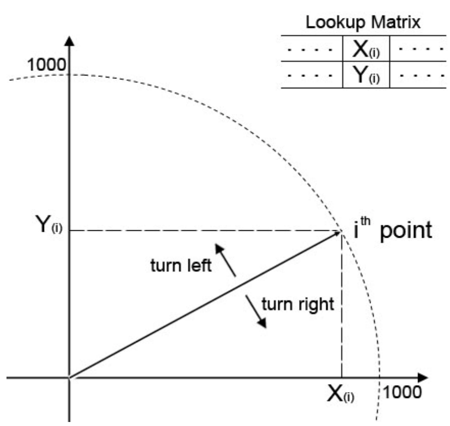

Fig. 4. Camera direction mapping.

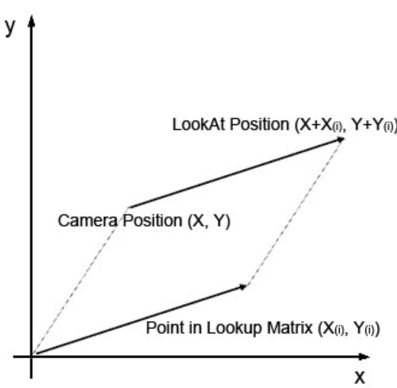

Fig. 5. Camera direction transfer.

Forward/Backward Movements. The forward and backward movement is set to the value of 10 units in the current direction of the user. It is calculated by dividing the lookup matrix value set (X, Y) with 100, and adding the result back to the current position of the camera. Similar to the turning control, holding down the forward/backward keys would trigger the movement once every 25ms.

2.4 Remote Collaborator Interface

The Remote Collaborator Interface provides a mean for participants at remote locations to meet each other in virtual worlds. It runs on a Client Node computer and is connected to the Master Node via internet. It captures live video stream of a collaborator from the real environment using video input devices. The video stream is then transferred to the Master Node and displayed in the AV space. The remote collaborator would also be able to see and talk to the AV user from the Client Node computer in the manner of video conferencing. Indeed, it is a simulation of daily face-to-face communication with one party in real world and the other in virtual world. It provides a mean for distant collaboration/communication work in AV space.

During the design phase of the AV prototype system, we take into consideration of the collaborative work between multi-participants (3 or over). The system is capable of conducting several video conferences in the AV environment at the same time, provided that sufficient virtual image planes are placed in the AV space. This functionality is designed to simulate the real working environment which involves communication with multi-users. However, we restrict that only the Master Node will display the video of all collaborators. On any Client Node, only the video of the AV user will be displayed. It is simply because the collaborators' experience is out of the scope of this paper. For the current prototype system, we examine the case of two participants (one Master Node and one Client Node).

Another usage of the Remote Collaborator Interface is to capture live video stream as textures to be used in the AV space. The camera can be setup to capture the outlook view from a window (or alternatives). The video stream is then transferred to the Master Node, and be texture mapped to a virtual window in the AV space.

2.5 Object Inventory

The Object Inventory is a collection of realistic 3D model representation of real objects (see Figure 6). The Object Inventory keeps track of the 3D special information (such as 3D translation, 3D rotation, 3D scale parameters, etc.) of every object inside the constructed AV space. The inventory also stores user specified parameters of texture (e.g. texture plane value set of t and s) and rendering (e.g. local lighting and shading). This information is bind to individual objects and preloaded into the memory once the program is initiated.

The inventory also provides a high level of extendibility by reading in 3D model files (extension of .obj). This file format is widely used by many modeling applications. We employ the modeling application software of Google SketchUp Pro 6 to serve our purpose of obtaining object models. SketchUp features a well constructed online library which includes a rich collection of existing models. The collection covers a wide range of objects such as furniture, electrical equipment, bathroom equipment, etc. Many of these models are developed by the manufacturers in regarding to their products. Employing existing models accelerates the implementation of the system and increases the realty of the AV environment.

2.6 3D Modeling/Rendering

Reality of the virtual space has always been an issue in most virtual reality application. The computational power of current PCs is simply far from sufficiency to generate photorealistic picture frames in a real-time manner. For the user to obtain immersive and realistic feeling of the virtual space, the system can texture-map real photos taken in the real environment onto the corresponding virtual elements. An individual is able to take photo of particular objects (e.g. walls) with digital camera and then use it as texture. In which case, the quality of the photo (e.g. resolution) is crucial regarding the resulting quality of virtual model.

Currently, we use a video plate as a mean to cooperate with the communication between participants (see Figure 7). The video plates hang on virtual walls in the AV space. Due to the limitation of the screen size of the HMD, we scale the video plate relatively large in its dimension. When the user is navigating the AV space, he/she is able to stand in front of the video plate and talk with the remote participant appearing on the wall.

Fig. 6. Object inventory.

Fig. 7. Video as texture.

We also extend the texturing by converting real video stream as environment texture. For instance, a camera on a Client Node is setup in a way to capture a live outlook view from a window. The video stream is then transferred to the Master Node and used as texture of a virtual window in the AV space. When the user is navigating in the AV space, he/she would be able to “see through the window” as if he/she is in the remote location.

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2.7 User View and User Scenario

Figure 8 and Figure 9 displays the view of real photo texture mapped on virtual wall. The quality of the AV model is greatly relying on the quality of the photo used. In real situation, the quality of photo would largely depend on the camera used, lighting condition, position/angle and etc. As it has been presented in Figure 9, although these two photos are taken at similar position, under similar lighting condition with the same camera, the bright/dark dividing line lies between two pictures. However, the overall quality of texture mapped photo presents good level of reality.

Fig. 8. Photo as texture (information board).

Fig. 9. Combining two photo as texture.

Figure 10 shows the setup situation when a user is interacting with the system. He is equipped with the HMD as displaying device and controlling the orientation through keyboard input/output. The projection screen displays his first person view from the AV environment.

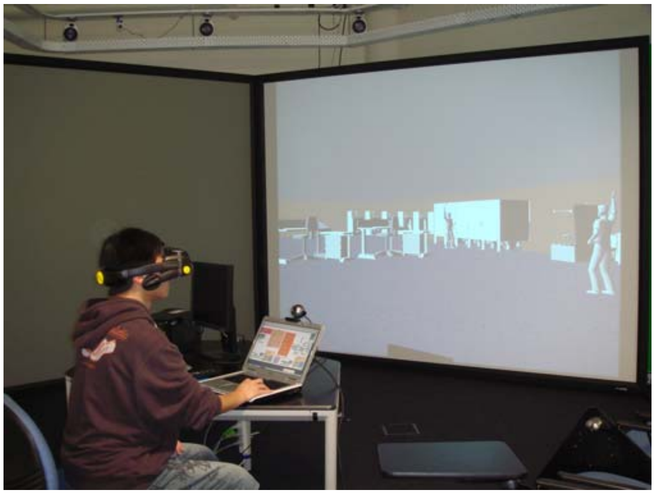

Fig. 10. System setup.

Figure 11 and 12 shows two sample images which would be displayed by the HMD. The AV environment employs both virtual model as well as photos as texture of walls. It clearly shows the detailed environmental view. Corresponding to the user scenario described in Section 1, the designer is able to perform the inspection activities based on this virtual view.

Fig. 11. AV design environment 1.

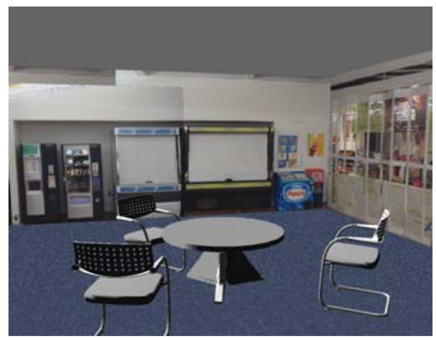

Fig. 12. AV design environment 2.

3 Research Issues and Proposed Experimentation

The current stage of the research is mainly focused on the development of setup of the AV space. We focus on developing an interface which enables the user with virtual design activities. It also provides a mean for distant design collaboration as well as an improved presentation of the AV space. The proposed experimentation stage will involve controlled user experiments to validate the concept of AV as an intuitive interface paradigm capable of supporting design by an individual and from collaborative work. The customized AV experimental facility created in this paper will be used as the vehicle for experimentation. Since the pattern of individual work is quite different with collaborative work [2], it is necessary to have the two separate avenues for experimentation, which map onto the above research aim.

3.1 Experimentation on the Effectiveness of AV Space for Individual Design

For the individual design scheme, the authors will investigate how AV space might provide perceptual and cognitive support and augmentation, for an individual designer interacting within a virtual design which contains real entities that can be potentially exploited in useful ways. One experiment would be conducted to study the effects of the merging of real entities into a virtual environment on the nature of a person's perceptual and cognitive performance as compared with a purely virtual (VR) environment and a purely real environment. Human subjects will be recruited to attend the experiment to perform tester task(s) in the above three environments. The test task(s) would be specifically designed to address issues of designer's comprehension and retention of design information as well as the effectiveness of design information presentation. Users' performances will be measured by subjective metric — the NASA Task Load Index [4] as well as objective metrics — task performance accuracy, time, and distance traveled. Furthermore, usability engineering approaches would be adopted to perform meaningful usability evaluation of the AV spaces. For example, special usability questionnaires and associated data collection strategies would be developed in order to assess certain features of AV space, such as extent of presence. The authors will base the development of the questionnaires on the authors' previous work [14] and widely accepted theoretical models such as the model of presence [13] that can be easily generalized to the AV case. Statistical model will also be developed to arrange the experimental sessions and collect data. Statistical analysis tool (SAS) will be used to test inter-factor correlations for reliable results. The authors will focus experimentation design and results interpretation on understanding the following specific questions to some extent:

- Is human's capability of comprehending the design and effecting desired actions based on the resulting mental model constructed from perceiving the AV space improved compared with completely virtual and real environments?
- What are the potential patterns of actions projected from the AV space and memory [3] that human mentally combine in order to perceive and understand the AV space?
- What are included in human's experience (e.g., the sense of presence) that results from the interpretation of the mental model constructed within the AV space?

3.2 Experimentation on the Effectiveness of AV Space for Collaborative Work

For the collaborative work scheme, the authors will experimentally investigate how spatial knowledge acquired from the merging of real entities (e.g., image of real landmark) into the virtual space combined with the real-time communication channel by configuring collaborators' faces as real video streams into the virtual design space could help designers to employ effective conventional spatial reference strategies for carrying out collaborative navigation tasks in complex surroundings, especially a large-scale design project. An example would be facilitating the process of transforming landmark knowledge into route knowledge and further into survey knowledge. The authors propose to address this issue through tests of spatial cognition benefits and effectiveness of communication [6]. Spatial cognition includes acquisition, organization, use, and revision of knowledge about spatial environments. The processes that occur in spatial cognition are complex and not fully understood, but differences in performance under different circumstances (various environments) can be measured through controlled experimentation [8]. One experiment is planned for comparing AV with a purely virtual environment and/or a real environment. Likewise, human subjects will be recruited to attend the experiment to perform tester task(s) in the alternative testing environments. The tester task(s) would be designed to address issues of shared understanding/experience and social interaction. For example, the tester task could involve a collaborative virtual built environment search where two users try to collaboratively find ways to a common target (e.g., location of a suspicious design/construction defect). Shared understanding could be reflected through users' performances which could be measured by objective metrics — task performance accuracy, time, and distance traveled. Special questionnaires and associated data collection strategies would be developed in order to assess certain features of collaboration enabled within the AV space, such as social-presence. The approach of protocol analysis will also be used to supplement the lab experiments to closely examine design collaboration (e.g., assessment of social interaction) by capturing episodes of collaboration activity. Protocol analysis undertaken in real time provides a means for eliciting persons' thoughts while they are performing a task [15]. A special protocol coding scheme will be developed to accommodate the testing features, and the structure of it would be derived in the combined way of data generated structure and theory derived structure [9]. Likewise, statistical methods will be incorporated into the experimental design and data analysis. The authors will focus experimentation design and results interpretation on understanding the following specific questions to certain extent:

- What conventional spatial reference strategies (e.g., spatial memory) could be maintained with critical spatial information that is represented by entities from the real world and is presented in a familiar way within the AV-based collaborative navigation environment?
- What types of new communication strategies would arise in the AV space as compared with completely virtual environment?

4. Conclusion and Future Directions

This paper presents the creation of an Augmented Virtuality prototype that could enhance the intuitive objective of architectural design and collaboration effectiveness by seamlessly inserting real context and experience into a virtual design alternative. Real entities like image/video acquired from the real world by camera could be mapped or registered into the virtual world to essentially "decorate" it with much of the richness of the real world. This paper also presents the potential research issue and challenges in AV applications in design and collaboration. The power of the AV concept is found in the opportunities that are presented for a user to interact with only the most important real and virtual contents in AV environments.

One future research direction is an advanced version of AV User Interface. The purpose is to improve user's environmental cognition by employing a CAVE-like multi-displays AV environment. The system would provide the user with a wide obverse visual angle capability. It is believed that the degree of immersion would have significant impact over the user's environmental cognition, and hence affect on their design activities.

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