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CONSTRUCTION SIMULATION USING VIRTUAL REALITY

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ABSTRACT

Two main simulation methodologies namely, the network-based simulation and the graphical simulation technique are being used in the construction industry. While the network-based simulation technique, which was originally developed for manufacturing processes, is very tedious, complex, and time consuming, the graphical simulation technique is taking many forms and it is gaining more support within the construction industry. The graphical simulation technique, which was originally derived from what is called the Visual Interactive Simulation (VIS).

Tthe Virtual Reality (VR) technology may be used to model, design, and simulate construction operations. There are some attempts in that direction, however, these attempts have either been or are being made within research institutes and large construction companies where expensive computer hardware were purchased and sophisticated software were developed. There is no indication that these attempts were made on non-expensive computer workstations or on the PC platform. This paper describes some state of the art techniques by which construction operations (such as earth removing operations, material handling, manipulating building components.. etc.) can be modeled, visualized, and graphically simulated in real-time 3D environments on the PC. The construction industry will benefit from this study since it introduces new software and hardware technologies that are capable of delivering comparable workstation performance on the PCs at a fraction of the cost.

INTRODUCTION

With the complexity involved in large scale construction operations, the construction industry is in continuous need for a technique that is capable of modeling, visualizing, and simulating construction operations [Oloufa 1992]. Several network-based simulation programs such as Micro-cyclone (Halpin

1973) were introduced to the construction industry for the above noted purpose. Although these programs helped construction managers to simulate equipment operations, they failed to include many factors that influence the construction process. These factors are the construction site itself, the building geometry, and the dynamics involved in operating construction equipment. These factors play an important role in determining many scheduling and safety related decisions during the construction phase. A major disadvantage of using such simulation technique is the complexity and the time required by the user to understand simulation languages and their modeling procedure. Using these simulation techniques, a simple crane or earth-removing operation may be modeled using a very complicated simulation network that is very difficult to interprete.

With the current advances in the computer software and hardware technologies the use of computer generated graphics and visual simulation techniques to model, design, and simulate construction operations is increasing rapidly. One of the main advantages of using the graphical simulation technique is that the site topography, the building components, and the equipment dynamics are all part of the graphical simulation cycle. The utilization of the object-oriented paradigm allows the user to model the entire construction site as 3D objects that interact with each other and with the user. These 3D objects which are typically representing the construction site, construction equipment, and building components are represented in what is called virtual environment. It is called a virtual environment because it represents a real life universe in a 3D computer generated scenes. This type of visualization methodology shares the same graphical characteristics of the Virtual Reality (VR) technology.

Attempts have been made to utilize the VR technology in modeling, visualizing, and simulating construction operations. One of these attempts was introduced at The Georgia Institute of Technology when Opdenbosch (1994) developed the Interactive Visualizer Plus Plus (IV++), a real time object-oriented program for visualizing and simulating construction operations. Although the IV++ opened a new dimension to model and simulate construction operations it was developed on a very expensive computer platform. Most construction and design firms within the US and world wide are depending on non expensive computer workstations to solve their analysis, design, and CAD problems. Even if few design firms have used fast computer workstations (such as SUN, HP, Silicon Graphics.. etc.) to solve their CAD problems they are migrating to the PC platform for major cost effectiveness. The current advances in the computer hardware industry made the difference between a mid-range computer workstation and a very fast PC quite small.

VIRTUAL CONSTRUCTION ENVIRONMENTS

The simplest way to describe a virtual environment is to imagine a set of 3-D objects drawn on a computer screen and the user has some sort of control on the viewing conditions such as location and orientation [Opdenbosch 1994]. Similarly, a virtual construction environment is a 3-D graphical scene where the objects in that scene are representing the construction metaphor. The 3-D objects in such environments may represent building structure, people, terrain, and a construction equipment. With the recent advances in computer software and hardware technologies, the user is able to quickly navigate through that computer generated 3-D environment. In addition, the user can control the viewing point inside the generated environment by using Head Mount Displays (HMD) and tracking devices. The purpose of such hardware devices is to match the users rotation and orientation with the rotation and the orientation within the generated environment when the user wears HMD and tracking devices[Pimentel and Teixeira 1995]. The use of a HMD device provides a closer look to the computer generated environment by the user so as to feel like being inside the environment. This unmatched level of interaction between the user and the generated virtual environment is referred to as immersion. The next section presents the main building blocks that are required for VR technology in modeling, visualizing, and simulating construction operations.

THE VR TECHNOLOGY REQUIREMENTS FOR CONSTRUCTION SIMULATION

With the recent advances in the computer software and hardware technologies, the VR technology is gaining greater recognition day after day since it provides a relatively more economic solution in training and other engineering applications. This section describes the basic building blocks that are required to apply the VR technology in simulating construction operations on non-expensive personal computers without programming. The operating system, the hardware, and the software required to simulate construction operations as a real-time rendered images are suggested herein. These computer generated series of real-time images are referred to as virtual environments [Pimentel and Teixeira 1995].

The Operating System

As previously mentioned, this paper targets the PC based platform to demonstrate some of the techniques by which construction operations can be

simulated in virtual environments. Many software developing companies in the area of computer graphics and graphical simulation started to release what is called Virtual Reality Authoring programs. These VR programs are the software tools which are required to create virtual worlds without programming. Most of these new VR authoring programs are being developed to operate on both the Windows 95, and the Windows NT operating systems (from Microsoft Corp.). Since the cost of both operating systems is relatively negligible, either one may be used. Furthermore, both operating systems have an easy-to-use Graphical User Interface (GUI), and provide many features such as Dynamic Linking (DLL), Object Linking and Embedding (OLE), Dynamic Data Exchange (DDE), and Open Data Base Connectivity (ODBC). These features allow great flexibility in operating any Windows-based application.

The Hardware

The recent advances in the computer hardware technology made the performance of a mid-range computer workstation (such as SUN or Silicon Graphics) available on very fast PC stations (such as the new Pentium Pro or P6) with a fraction of the cost. In addition, several non-expensive HMDs including tracking controls are becoming available in the market for less than $800 (such as the i-glasses from Virtual i O, Inc.). Moreover, several companies are providing special graphics accelerator boards(such as the GLZ5 from Intergraph, Sapphire 2SX from Fujitsu Corp., etc.) which boost the graphics display performance to a level comparable to a mid-range graphics workstations. As prices drop fast, a high performance virtual reality system consisting of a Pentium Pro PC station, a navigation device (similar to a joystick), a HMD with a tracking device, and a graphics accelerator board can cost about $7000 which still non expensive compared to a computer workstation which would cost about $35,000 to $200,000.

The Software

In early 1996 since many software development companies released what is called VR authoring programs (such as VRCreator by VREAM Inc., WorldUp by Sense8 Corp., and Virtus Walkthrough from Virtus Corp.) These VR programs are the software tool by which virtual worlds can be developed and distributed among users and without the hassle of computer programming. Elements of a construction operation can be modeled using existing CAD programs (such as AutoCAD, or MicroStation etc.), imported from a graphics library, or simply created using the VR authoring program itself. Cause and effect relations between objects within the virtual environment can then be

created based on their roles in the construction site. The user has the full control of the displayed objects and the viewing parameters such as shading, color, background, light, orientation, and location. The level of interaction between the user and the generated virtual environment, can be achieved using a head mount display and a tracking device. Thus the user can experience the generated environment as an observer, a truck driver, from an excavator driver side, or even as a crane operator and he/she turns into virtual reality. The illusion of immersion is extremely beneficial if the generated virtual environment is used for training purposes, or safety enhancements.

Another advantage that users can expect from the new VR authoring programs is the ability to have a multiple participant option allowing more than one user to share the same virtual environment at the same time and across the Internet. Therefore, a user in one place can put himself in a crane while another in a truck and observe each other within the virtual environment. This level of multiple interaction is extremely effective in training applications.

The cost of such VR authoring programs ranges between $500 to $3000 depending on the level of features that each program offers. The future competition between VR companies and the increasing popularity of the VR technology will force these prices to decrease sharply. In should be noted that the two VR authoring programs mentioned earlier in this paper (VRCreator and WorldUp) were chosen since they utilize a fast graphics rendering software engines. These two software rendering engines are the RealityLab and OpenGL from Microsoft Corporation. The VRCreator program uses the RealityLab rendering engine. This fast rendering software engine was developed originally by a British company called Render Morphics on the Silicon Graphics workstations and ported to the PC platform by Microsoft. This graphics engine is supported by the Windows 95 operating system. Furthermore, WorldUp uses the OpenGL graphics software rendering engine which was originally developed on the Silicon Graphics and ported to the PC platform by Microsoft. One of the features of using the OpenGL graphics software rendering engine in developing simulation programs is speed and performance gained in the developed application. In addition, the OpenGL graphics engine is supported by many graphics accelerator boards. This graphics engine is supported by the Microsoft's Windows NT operating system as well. The next section provides an illustrative example on creating a virtual environment for a crane operation using the VREAM approach.

Example Using The VREAM Approach

VREAM Inc. is one of many software development companies specialized in developing programs for visual simulation and virtual reality. The company was founded in Chicago, IL. in 1990 to provide virtual reality solutions without programming for PC users. The company's first achievement was the development of the VRCreator program under the DOS operating system which has gained a good reputation among virtual reality users. One of the main features of the VRCreator software was its graphical user interface which includes a modeler and a run-time engine. The company has started to migrate its program to the Windows operating system about two years ago taking the advantages offered by such a graphical user operating system (such OLE, DDE, ODBC, etc.). The following example was created using a pre-release version of the VRCreator program under Windows 95 operating system.

Step-1: The Modeling Process

The first step required in creating any virtual environment which represents any real life operation is to graphically model all the objects participating in that operation. In this case AutoCAD R.12 was used to model the construction site topography, the crane prototype, and the building geometry. The site topography was modeled as a 3-D flat terrain where the building geometry was represented as a set of beams and columns. The crane prototype was imported as a DXF file format using an older graphics library downloaded from the Internet and modified inside AutoCAD. VRCreator offers an integrated intelligent and easy-to-use modeler; however, it was not available with the pre release version.

Step-2: Adding Realism to The Created Models

The next step involved the utilization of the VRCreator program itself in order to add realism to the created drawing models (objects). VRCreator offers many features which can add more realism to the generated virtual environment such as different shading modes, different texture mapping modes, different light sources, colors, sounds, etc. For example, a sand texture (Bitmap file which can be mapped on to the object) has been applied to the 3-D terrain in the virtual environment. In addition, two light sources has been added to the virtual environment. Finally, a background image was added to illustrate the virtual environment as if it has been visualized during the day.

Step-3: Adding Behavior to The Graphical Objects

In this step behavior is attached to objects within the virtual environment in order to simulate the crane operation. The rotations and the horizontal

movements of the crane's boom are assigned in the vertical environment. When the simulation cycle begins the crane object moves each of the building components (such as beams and columns) from the material patch location to the proper location in the building frame. This assembly process has been done according to a script file which can be written by the user or graphically defined within the VRCreator program. Figure 1 represents the crane operation from a viewer point. Figure 2 illustrates the virtual construction environment (construction site, equipment, and the building components) from an elevated camera.

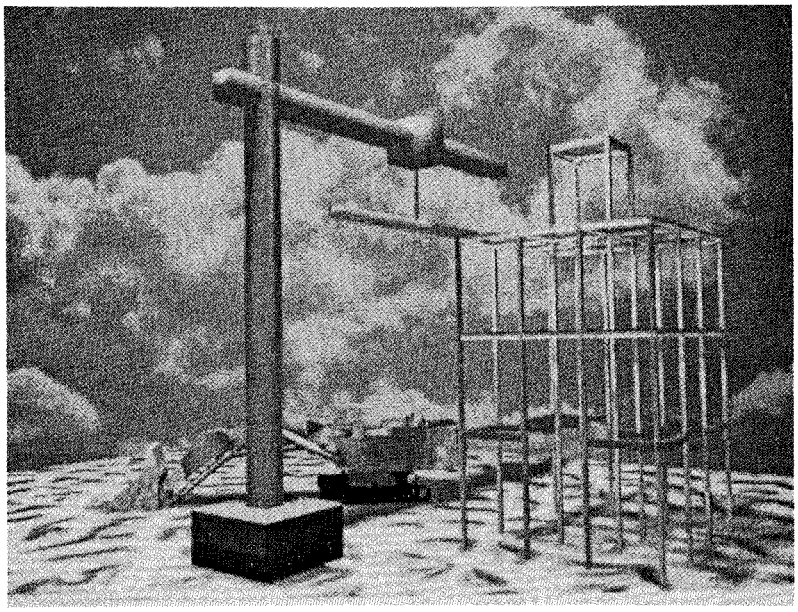

Fig. 1: A virtual environment viewed from the user side

CURRENT RESEARCH

Using the methodology described in this paper for construction simulation a Ph.D. research was initiated in the Civil Engineering Department at The University of Florida. The main objective of the research is to investigate the usability of the VR technology in construction simulation. Many of the construction operations such as material handling operations, crane operations etc., are being simulated in virtual environments. A typical construction project is being used as case study for the research main objective. The research shall

benefit the construction industry since it will introduce a non-expensive, and an easy-to-use methodology for construction simulation. The research utilizes a state-of-the-art VR development system named WorldUp by Sense8 Corporation. This VR system allows the development of VR applications that can be distributed with its graphics engine (WorldUp Player). Several algorithms that describe equipment dynamics and kinematics are under development at this stage of the research. These algorithms are written using a scripting language identical to Microsoft's Visual Basic. One of the main features of the developed application that it can be distributed on the Internet as a VRML application (Virtual Reality Modeling Language). Thus multiple users can experience the same virtual environment, describing a construction operation, from more than one location simultaneously. Another important feature of the developed application that it can include a Graphical User Interface so it can be distributed along with the rendering engine (WorldUp Player) for other users.

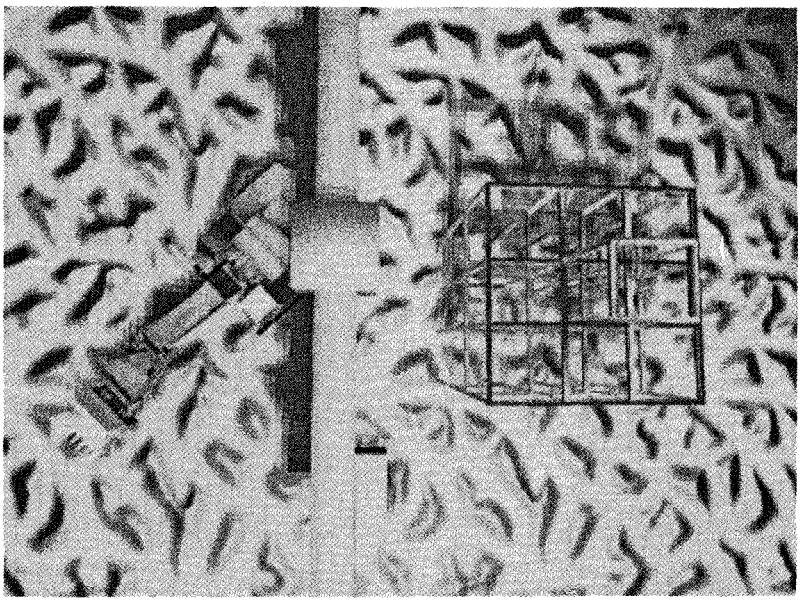

Fig. 2. The virtual construction environment as viewed from an elevated camera

CONCLUSION

This paper introduced a new methodology by which construction operations could be simulated in virtual environments. The methodology presented in this paper allows designers, construction managers and others to have an early view of the construction process. This will benefit the construction phase of any project by predicting what kind of problems might exist and how they could be solved.

It is hoped that the methodology described in this paper will be used as guidelines for future research to utilize the VR technology in simulating construction operations. The flexibility of current visualization, and 3D graphical simulation programs available on the PC platform shall allow researchers to incorporate systems such as scheduling programs and expert systems.

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