RAPID CONSTRUCTION OF MODEL BUILDINGS

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EXECUTIVE SUMMARY

The construction of detailed computer graphics models of urban settings is very labor intensive, yet accurate visual databases are essential. The proposed research will explore how Distributed Virtual Environments (computer graphics systems using 3d stereo viewing devices, many-degree-of-freedom (MDOF) input devices, direct-manipulation "virtual carpenter's tools", and multi-user, distributed, interactive task environments) can be used to rapidly model urban environments, for subsequent use in visual simulators. The project has the following components:

The Virtual Environment Operating System (VEOS) will be extended to accept MDOF input from sources using the MIDI communication protocol. Interactive tools based on the extended VEOS will be used to explore human factors issues concerning the optimum use of CrystalEyes stereographic displays with MDOF input devices to perform simulated building construction tasks such as relocating walls, cutting doors and windows, and applying texture maps. A large rear projection screen will serve as a wide field of view display device.

We will extend VEOS to explore human factors issues concerning multi-user cooperative tasks on distributed simulations, using the Distributed Interactive Simulation (DIS) protocols (with extensions as necessary.)

The graphical database format for the extended "Carpenter's VEOS" will be based on constructive solid geometry (CSG).

The products of this two-year project will be experimental simulated tools, and a working software prototype of an innovative Networked Virtual Environment for 3d Computer Aided Design. This CAD environment will be titled "PolyShop - A Shared Virtual Workshop".

INTRODUCTION

During the recent Gulf War, an extensive SIMNET database of Kuwait City was constructed, with the expectation of its being used with the Odin simulation system [McBride 91] as a planning and after-action review tool. Fortunately, the rapid conclusion of the war obviated the need for door-to-door combat. However, the database development exercise highlighted the extreme expense of simulation database construction.

The essential difficulty of 3d CAD involves the translation of ideas about the 3d world into a 2d screen[McWhorter 90, Yeh 90]. The menus of powerful CAD programs are very complex, and require weeks of training and months of practice before a modeler becomes productive. Even the best CAD modelers take almost as long to build, say, a tank, as a model maker would take to make an equivalently detailed scale foamcore plastic model of the tank.

Experiments have been done that indicate the use of stereoscopic displays instead of monoscopic displays significantly reduces task completion time in remote manipulation tasks [Spain 91]. Remote manipulation (telerobotics) is very similar to modeling of simulated objects. This paper proposes a two year study of the human factors and software engineering aspects of the use of MDOF input devices with stereoscopic displays in innovative approaches to "CAD from the inside". The study would focus on a specific area of modeling: the construction of buildings and furniture.

The following questions will be considered:

-- Is it possible to use stereo viewing and direct-manipulation virtual tools to bypass much of the learning curve and the narrow bandwidth of the 2d CAD interface? To what extent does a 3d interface improve the operators capability to manipulate inherently 3d geometric models?

-- Does the increased control capabilities of MDOF input devices offset the (possibly) increased learning curve needed to train operators? What feedback mechanisms are required for effective operator control of virtual tools using MDOF input devices?

-- Can multiple operators work on the same geometric entities in a Distribute Virtual Environment? How do data and network latencies affect ability to perform cooperative tasks?

PROJECT DESCRIPTION

The problems to be considered in this proposal concern three broad areas of interest in virtual environments: modeling, networking, and input/output technology. Modeling is costly and difficult to automate. Networking has implications for both computation and geographic distribution of simulations. Input/output technology is changing the human user from an observer to a participant. Each of these areas strongly impact the future of training in virtual environments.

Construction of Detailed Urban Models. This project will explore the human factors and software engineering issues involved in the rapid, accurate production of 3d models of buildings and furniture, working within a virtual environment. This will involve the experimental mapping of MDOF input devices to simulated tools for construction of 3d models.

Little work has been done exploring the connection of simulated tools to input devices for construction of entities in the virtual environment. PolyShop will provide a test bed where human factors experiments on component skills and simulated tools for virtual building construction can be accomplished. Experiments will cover topics such as

-- control modalities (on/off, linear, rotary, pressure sensing)

-- optimum assignment of degrees of freedom to keyboard, 3d mouse and other analog input devices

-- easy to use techniques for the incorporation of photo-derived metric information into geometric parameters, and of texture information into surface maps for models of buildings

-- measures of completeness. For instance, a real carpenter cutting a board gets cues from sawdust, bending of materials, etc. In the virtual world, what cues other than the appearance of a cutting line are most effective?

During the project, users will construct two small visual databases, consisting of

(a) a small Middle Eastern village of about six houses on a hillside, and

(b) a small sample of a typical modern large-city downtown area including a curbside sector with parked automobiles, a bank lobby, retail stores and a residential apartment.

The buildings in both databases will be equipped with windows and doors, and typical furniture will be provided.

Distributed Virtual Environments. The benefits of networked simulations for training are already well understood. The present proposal focuses on extending the benefits of networking and virtual environments to the expensive, slow process of preparing a training scenario.

One of the principal payoffs expected from VE is the ability to bring customers, workers, management and data together on a task, regardless of their physical locations.

The manager convenes a three-way Virtual Workshop. The SME looks at the preliminary 3-d model constructed from satellite photos, "walks around" the building, points out that an apparent door is bricked up and the real door is invisible from above. The modeler quickly changes the building. When the SME is satisfied, the manager immediately notifies the planners that the building is ready for rehearsal.

The ability to remotely link virtual environments as a routine operation will support a number of other essential activities that now require travel and severely disrupt schedules, including

-- training of modelers. Specific skills can be demonstrated by a master teacher; trainees can show their technique and be critiqued by the remote master.

-- rapid inspection of libraries of models at other sites. Rather than down-loading a large library (requiring enormous local storage and substantial transmission time), simply visit the library in its current location. Only the portions of the library being examined would actually pass through the network.

-- collaborative design. Several experts may each have a portion of the information needed to solve a problem. A shared virtual work environment would allow a one-hour meeting to replace a two-day trip.

Stereographic Displays. No technology is so strongly associated with virtual environments as is display technology, especially head-mounted displays. Virtually every VE article ever published in the popular media has at least one obligatory photograph of someone wearing an HMD, staring off into virtual space. Studies show that stereo viewing improves user accuracy two to four times, and improve speed of task accomplishment over monoscopic displays.

However, head-mounted displays suffer from several problems for use in a production environment, especially where fine detail work is important. The head-mounted displays currently available weigh several pounds, and become uncomfortable after short-term wear. The resolution of the best color LCD based HMDs will only allow the resolution of 15 arc-minutes - much less than necessary for the CAD work proposed in this project. In order to match the resolving power of the human eye, HMDs would need pixel counts approaching 5,000 x 5,000 (assuming a 120 degree field-of-view).

There is an elegant, lightweight 3d viewing device available today: the StereoGraphics CrystalEyesTM. These glasses have optical shutters and are used with a 120 hz monitor, driven by a Silicon Graphics workstation, which alternates left and right stereo views. The user sees a full stereo frame every 1/60th second. The glasses are coupled to the display via an infrared synchronization link. Several viewers can look at the same scene at once, on a single monitor. These attributes make the Crystal Eyes system a strong candidate for use in experimental CAD environments. The realtime generation of time-multiplexed stereographic images is well-understood [Baker 87, Beaton 90]. The monitors used with Crystal Eyes systems are higher in resolution than the displays in HMDs ... up to 1280 x 1024. The smaller field-of-view means that the Crystal Eyes system can resolve images much closer to the 1/2 arc-minute resolution of the human eye.

PolyShop will be configurable to use monographic displays, time-multiplexed stereographic displays, and HMDs.

MIDI - Input at Greater than 6 DOF. The Musical Instrument Digital Interface (MIDI) is the world wide standard protocol for the interfacing of electronic musical instruments and computers. Initially, MIDI was developed to provide interconnection and communication among electronic instruments. The protocol has grown to support many kinds of data communication. MIDI is a detailed and accurate protocol that allows for high bandwidth transfer of discrete and continuous data. There are three categories of MIDI events: channel status events, system common events, and system real-time events. There are about 24 separate event types in the current MIDI specification.

In addition to electronic instruments, a large variety of sources can be used to generate MIDI data in real-time. Possible sources include sonar data, laser range data, position data, orientation data, gesture data, as well as algorithmically created data. It is possible to select MDOF input devices, such as an electronic keyboard, to provide high bandwidth inclusive and interactive construction and control tools within the PolyShop virtual environment.

Because of the wide variety of sources of MIDI data, the richness of the data structure, and the high bandwidth and data rate associated with MIDI data streams, MIDI has excellent potential as a tool for building and controlling virtual worlds from within.

3D Interaction

The principal missing element in these studies to date, has been any attention to the problem of speeding up the modeling process. Terrain elevation profiles and lineal and areal features (roads, forests, lakes, etc.) constitute the bulk of a visual database outside the target area. The standard modeling environment is simply an off-the-shelf Constructive Solid Geometry modeler named GMS [ICM 1990]. The GMS system is relatively easy to use but contains no special provisions for rapid model production.

In particular, no means are provided in GMS for importing texture data, orthorectifying images, measuring features within rescaled imagery data, or constructing CSG models to correspond to such texture maps. The well-known simulator modeling tool MultiGen [Software Systems 1991] has some of these attributes, but is not a CSG tool.

Research on 3d interactions is a rapidly developing area [Williams 90; Adelson 90], and thus it is possible to intelligently build on others work. PolyShop will provide a practical application environment where evaluation of a number of MDOF input devices can be accomplished.

The input devices to be evaluated will include Spaceballs, VR Wands, and electronic keyboards. These input devices will be evaluated in different combinations and with multiple users.

Task Level Simulation and Stereoscopic Displays. Simulation has always involved a tradeoff between fidelity and cost. SIMNET, for example, is a relatively low fidelity simulator, but was constructed at approximately 1/10th the cost per unit of a high fidelity training simulator. However, often the accomplishment of detailed tasks with visual feedback requires a higher level of fidelity from the visual system.

A related application area where this is true is the construction of 3d models using CAD software. Even where these models will ultimately be viewed through NTSC monitors, model development usually takes place on workstations using monitors with at least twice NTSC resolution.

Modeling of visual databases is analogous to remote manipulation tasks and detailed task simulation, where visual feedback normally takes place through a monitor. The CAD systems used for 3d modeling usually provide perspective and orthographic views of the model in an attempt to provide the user with feedback about modeling operations. Even so, ambiguity in the representation of the model can prevent errors from being perceived until the model is rendered. Other factors, such as interface (menus, icons, cursors) design and input devices, can also affect user performance.

Some existing research indicates that stereoscopic displays provide better user performance at specific 3d visual tasks than monoscopic displays (even where perspective and orthogonal views are provided). However, there is little documented, non-anecdotal evidence about the use of stereoscopic displays for visual tasks. The work that has been done focuses on relatively simple tasks. [Hodges, Spain, Barham]

The development of visual databases is a complex 3d visual task where this research is needed. The development of 3d databases for simulators and virtual environments is normally done off-line, using 2d perspective presentations of the model. While it may be of interest to spend time "inside" 3d visual databases under development, technological limitations (such as the low resolution of HMDs) currently prevents this from providing detailed practical feedback to the modeler.

PolyShop will provide a testbed to evaluate performance issues in complex 3d visual tasks. Factors that will be evaluated for effect on performance will include stereoscopy, interface design, and input devices.

3DM. The only existing, fully operational example of "CAD from the Inside" of a Virtual Environment as of March 1992 is the Three-Dimensional Modeler (3DM) developed by the University of North Carolina, which runs on the PixelPlanes 5 image generator. In essence, the tool is a three dimensional version of the Macintosh "pull-down menu" interface.

In 3DM there is a menu which the user initially finds occupying the visual field when the demo starts up. It is very large, because today's EyePhones have such crude resolution that words must be man-high to make the text readable. The user must learn the menu, then back off a sufficient distance to allow space to construct objects in the space in front of the menu (which is now difficult to read). Objects are manipulated using a hand-held "wand", which also controls the gross motion of the viewpoint.

There is no calibration; one simply draws objects "freehand" using primitive cubes, rectangles and spheres. Objects can be duplicated and moved around, but CSG operations such as set difference or intersection are not possible. It is difficult to determine the elevation of objects because no shadows are cast on the ground plane; and since no constraints are in effect, the user cannot easily place objects at ground level.

3DM is a credible "proof of concept", but it is not yet a serious modeling tool. Indeed, UNC continues to routinely build its 3d models using AutoCAD rather than using 3DM. In the following section, we describe a number of features missing from 3DM which PolyShop will have.

General Plan of Work

Test databases will be constructed and evaluated by subject matter experts. The design cycle will be executed twice - once to build and test a preliminary prototype, and once to build and exercise a robust experimental testbed for ideas about cooperative work in long-haul networked virtual environments.

An integral part of PolyShop is the idea of multiple degrees of freedom (MDOF). A MIDI keyboard (e. g. a portable music synthesizer) will be interfaced to the CAD computer. Such a keyboard supports "chording" - the simultaneous depression of several keys. For instance, if one wants to begin with a standard cube and grow it into a larger cube, one would press and hold the three keys for "make taller", "make longer", and "make deeper" simultaneously. If, however, one wanted a long, thin sheet of material oriented in an east-west direction, one would press the "make longer" key to achieve the right length, and the "make taller" key to achieve the desired height.

Options include the appearance of a metric grid in three dimensions; a "snap-on" mode where growth and motion are constrained to discrete points; and the use of traditional pointing and dragging techniques, extended to 3d. However, a main hypothesis of the research is that a problem with the "point and click" Macintosh style user interface which limits its usefulness in 3d is the severe overloading of a single command concept.

Devices such as back-hoes, which incorporate eight or more control handles, are rapidly mastered, because each control corresponds to one natural degree of freedom. Another example is a helicopter. The pilot has at his disposal four simultaneous degrees of freedom. However, their timely coordination is a highly skilled task, requiring much longer to learn than backhoe operation. Three dimensional CAD is somewhere between these two extremes of difficulty.

It is our hypothesis that in three dimensions, the rich spatial environment will be better managed via multiple simultaneous control, than by the single "thread" of control in a point-and-click interface. Imagine a helicopter pilot trying to achieve all that he must, using a single control handle! Even with joystick, collective control and rudder pedals the task is challenging.

The availability of fifty to eighty keys (with a label template) provides a cheap, off-the-shelf i/o device to test the concept of multiple degrees of freedom. Much of the experimentation in the project concerns determining which graphical and spatial degrees of freedom should always be present (via the keyboard) and their most useful arrangement. The design of Version 1 will necessarily evolve and be improved as the project proceeds.

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