THE VIRTUAL NUCLEAR LABORATORY

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ABSTRACT

In a world where people are overwhelmed by visual information, from television and billboard ads to computer video games, it should come as no surprise that industries are increasingly relying on advanced visualization technology to better handle the increased flow of information. Advanced visualization tools are also being used to improve human-machine interface by providing much more realistic simulated environments for design, training, planning and "practice" purposes. For nuclear engineers, technology to simulate everything from simple half-life measurement experiments to complete control rooms, is readily available and can be used on platforms as accessible as personal computers – or as sophisticated as three-dimensional virtual reality systems. Presented herein is what to an outside observer might look like a typical computer video game, yet to a nuclear engineer it would more closely resemble a simulated nuclear environment, such as a radiation lab, or a control room of a research reactor. It is hoped that modeling tools developed in this project will help large-scale exploitation of virtual reality technology by nuclear engineers.

1. INTRODUCTION

Virtual reality (VR) is an excellent tool for education, outreach, training, planning and research (Sherman 2003). Its use by nuclear scientists and engineers is also on the rise. Reviews of visualization technology and applications in the field of nuclear engineering have recently appeared (Rizwan-uddin, 2003; Karancevic 2003; Whisker 2003a and 2003b). Research groups in France, Korea, Japan and Scandinavian countries are actively pursuing the use of VR in the field of nuclear engineering. In these proceedings, Hanes and Naser (2004) review various visualization tools, including VR, and their use in medicine and different branches of engineering, including nuclear. For a more detailed review of visualization tools available as well as for recent applications in nuclear engineering, reader should refer to these references.

We are developing basic tools to facilitate the use of virtual reality in the field of nuclear engineering. Intended applications range from simple virtual tour of nuclear facilities for outreach purposes, conducting virtual radiation related experiments, virtual facilities for improved human-machine interfacing, virtual facilities for optimum design to minimize maintenance and replacement time for parts, virtual dose calculations, etc. We are also working on a virtual model of a next generation research reactor that will become a test case for the tools being developed by our group. We here report recent progress made towards creation of virtual nuclear facilities including simple radiation experiments and a reactor control room. We have added enhanced capabilities to the basic computer code. These include standard graphics routines, hierarchical and organizational data structures, as well as an increased level of realism and more sophisticated models than reported earlier.

2. HARDWARE AND SOFTWARE

As with most other applications, it is quite likely that PCs will eventually be the computing platform of choice for this application as well. Display technology is likely to grow independently, most likely influenced by the flat panel technology, and eventually moving toward wider use of large size curved displays. Consumer-level graphics cards are capable of supporting dual monitor displays, which can be creatively exploited to display stereoscopic images on one monitor instead. 3D display monitors have already been developed, and are likely to become economically feasible over the next several years. Software to display 3D virtual systems will most likely be influenced by the video game industry. Hardware and software currently being used in this project are briefly discussed below.

2.1 Hardware

The CAVE (so named after the "Allegory of the CAVE" in Plato's Republic) was first developed at the Electronic Visualization Laboratory (EVL) at the University of Illinois in Chicago. A CAVE has now been operational at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign for many years. The CAVE (CAVE Automatic Virtual Environment) is a projection-based VR system that surrounds the viewer with 4 (or more) screens. The screens in NCSA CAVE are arranged in a cube made up of three rear-projection screens for walls, and a down-projection screen for the floor (a projector points to a mirror overhead, which reflects the images onto the floor). Four basic components that comprise the CAVE are: the computers; the graphics systems; the tracking system; and the sound system (NCSA CAVE website).

In addition to its extraordinary graphics capabilities, the CAVE also provides superb audio facilities. It has an eight channel audio system with state-of-the-art digital audio support that is controlled by an advanced sound mixing board. Details can be found at the CAVE website.

Fig. 1. A Picture of the UIUC CAVE.

Developed by some members of the CAVE user group at the NCSA, VISBOX (Fig. 2) is a poor-man's CAVE. It is a single wall system at a fraction of the cost of a CAVE. However, some of the features, such as the head tracking system, are superior to those available in the more expensive CAVE. VISBOX user cannot turn her face by 90 degrees and still find immersed in the same environment, as is the case in the CAVE. However, applications are fully compatible with CAVE. Hence, development can be carried out on VISBOX, and then fine-tuned in the fully immersive environment of the CAVE. VISBOX runs on a single LINUX machine. A VISBOX will soon be operational in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign.

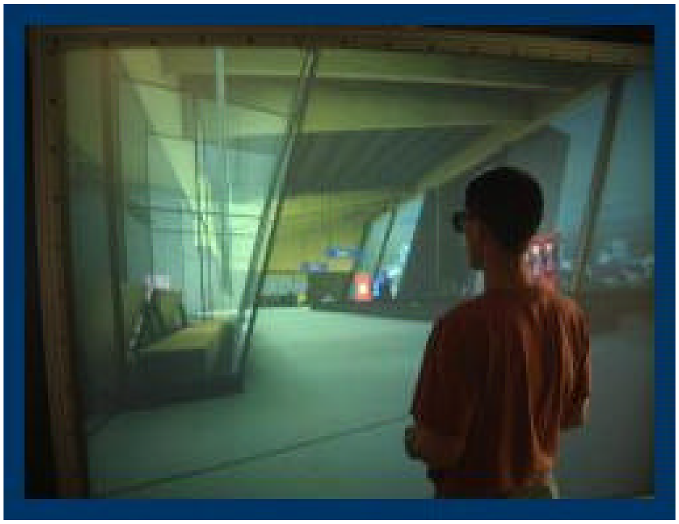

Fig. 2. A picture of a VISBOX and a user.

2.2 Software

Even though several different choices for a graphics library are available, OpenGL (OpenGL website), seems to be the most widely supported one across different computer platforms and graphics cards, in addition to being one of the most advanced sets of routines for rendering graphics. OpenGL provides ample control of detail, and the ability to re-use code. In terms of the language for the actual computer code, or the source code, the most widely used languages for OpenGL are C and C++, both of which have been standardized and very popular. Since C++ is a superset of C, and its object-oriented structure can be very useful in implementing the hierarchical nature of the program, this is an ideal choice. The simplicity and versatility of OpenGL with C and C++ allow for complete flexibility, great power, and the ability to easily incorporate any needs specific to nuclear simulations.

However, it is realized that not all developments will start from scratch. Hence, from the development of 3D CAD models to displaying them in the virtual environment, we are also taking advantage of other languages that are supported by CAD packages. Currently there are relatively few standards. Virtual Reality Modeling Language (VRML) seems to provide a good starting point (VRML website at web3d.org). Some CAD packages do allow the users to save their models in *vrml* format, which can then be easily ported to the CAVE (Rizwan-uddin 2003).

In addition to modeling and representation of the physical systems, standards must also be developed to display the results of numerical simulations (like system variables such as temperature, neutron flux, heat generation rate, etc.) as part of the 3D CAD model. In this regard, past work carried out at NCSA toward the development of standards for file formats will be very useful. Specifically, we plan to rely on Hierarchical Data Format (HDF) project of NCSA (HDF website at NCSA). HDF project provides a standard for the development and support of software and file formats for scientific data management.

3. THE CODE AND GUIs

A general-purpose program is being developed in C++/OpenGL to create virtual models of interest. The program is modular and allows development of components and their assembly. For example, models of meters, gauges, levers, etc., can be assembled on a control panel; several control panels and furniture can be assembled into a control room; and several rooms can be assembled to form a building. Models can be divided into four categories: static; dynamic; interactive; and interactive/simulators. Static models are the simplest with no moving parts. One can walk or fly through these static virtual models. Dynamic models have moving parts, with predetermined motion that cannot be altered by the viewer. Interactive models allow the viewer to move (some or all) components, such as a chair, by "grabbing" them. Interactive/simulator models are the most detailed, and allow the user to interact with the environment and then observe the result or consequence of her action. A simple example would be a worker in a radiation field with a Geiger counter. As the worker walks around the radiation field, the counter displays the exposure/dose, based on a pre-calculated radiation field or as determined in real time. A more complicated example is that of a control room in which the operator can press buttons and turn knobs, and the meters and dials then, based on pre-calculated responses or real time simulations, display the reactor response.

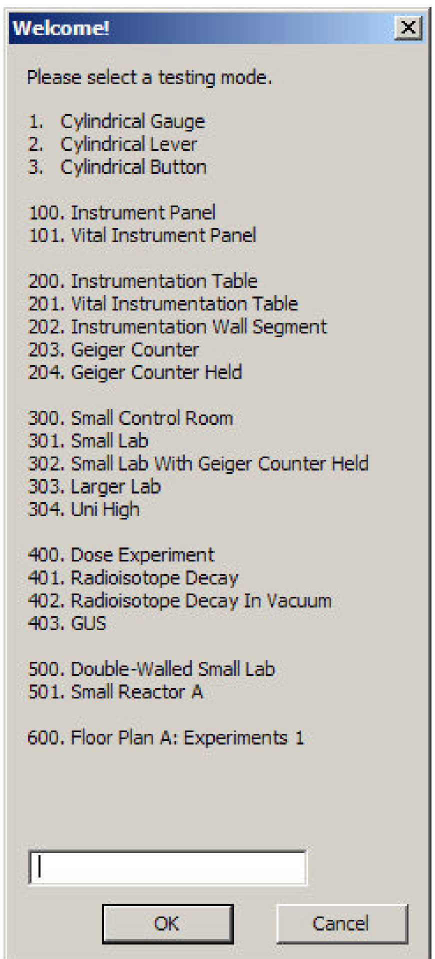

Fig. 3 Startup dialog box

The importance of hiding intricate details of programming is as crucial in the development of these virtual models as with any engineering process. An interactive capability, utilizing standard Windows dialog boxes, has thus been developed to shield the last layer of model developers from the "messy" details. Three dialog boxes of this "developer's tool" are shown in Figs. 3-5. Figure 3 shows various models developed thus far, and allows the user to select one by entering the corresponding code. The dialog box shown in Fig. 4 allows for on-the-fly changes to any component of the simulation, as well as for saving and loading any particular model. The dialog box shown in Fig. 5 contains various options and debugging parameters, including the use of a 3D anaglyphic display.

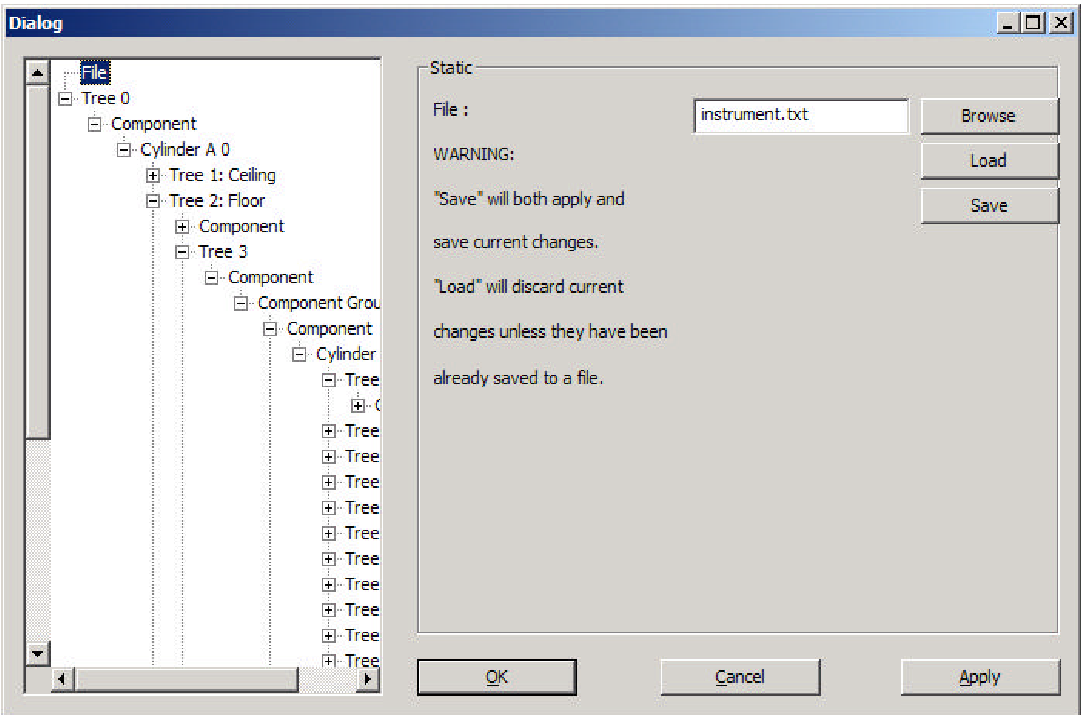

Fig. 4 VR model editor

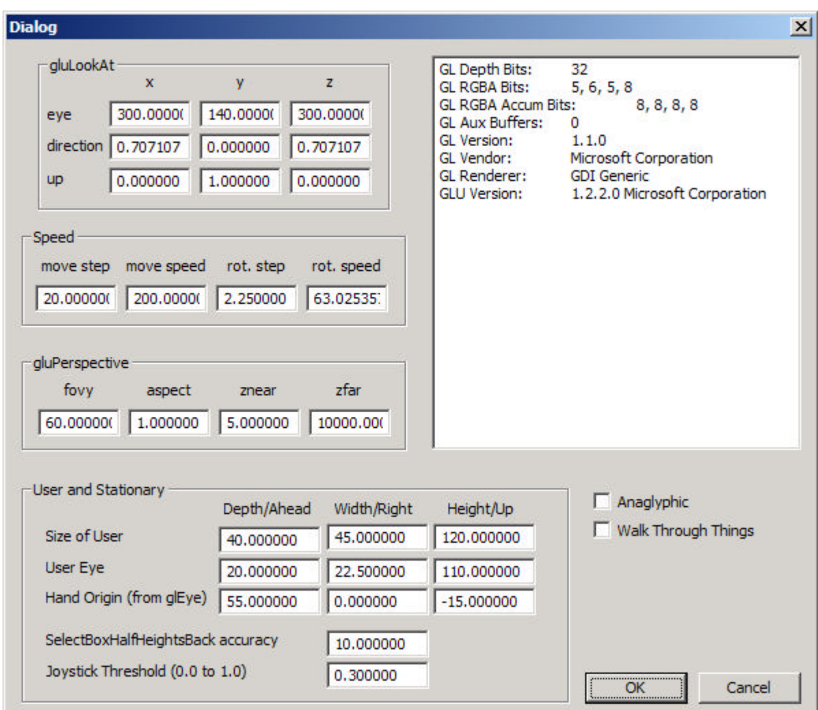

Fig. 5
Various options for model editing

Briefly, the data structure revolves around a tree structure. Each "tree node" contains a "root component" and an arbitrary number of branches. Each branch is no more than another tree node. The data structure allows great flexibility in modeling. Any item to be modeled can be the aforementioned "component." One particular component is named a "cylinder" because it is composed of a floor, a ceiling, and an arbitrary number of walls, each of which is represented by a tree node. As an example, the entire scene of Fig. 6 starts with a "cylinder." This "cylinder" contains four tree nodes with quadrilaterals and their properties (walls), a tree node containing a polygon for the ceiling, and a tree node for the floor. The tree node for the floor contains a polygon describing the floor surface, and several branches, each of which represents a component, or group of components placed on the floor. For example, one of the branches contains a "cylinder" representing the brick wall. The end user will however be able to *click* through the GUI, and see descriptive labels and options. Hence, these "messy" details will not be very important.

4. VIRTUAL MODELS DEVELOPED

Several components, such as gauges, meters, levers, and more detailed models have been developed. Four of these models are described here.

The first, and simplest, of these is a virtual experiment to measure the half-life of a radioactive substance. As the shield between the radioactive substance and counter is removed, the virtual detector displays the number of counts over short time intervals. These counts are automatically updated. The data displayed by the detector can be either pre-computed and stored in a database, or calculated in real-time (Fig. 7).

The second of these models is a virtual laboratory for radiation related experiments. It consists of a room, a shielding wall, and a workbench. It also includes some virtual instruments like a Geiger counter. The radiation field is due to a point source placed behind the wall shown in Fig. 6. The user, holding the virtual Geiger counter in her hand, can move around the room, either by using the joystick or a keyboard on a PC, or by physically walking around in the CAVE. The Geiger counter displays the radiation level (from a pre-calculated database) at the current location of the user. Model is currently being extended to calculate the total dose received by the worker from the time she enters the room till her exit (Whisker 2003b).

The third interactive simulation is a model of the GUS (graphite uranium sub-critical [assembly]) facility at the University of Illinois. Driven by a source, this sub-critical assembly is used for undergraduate laboratories involving measurements of flux distribution, buckling, neutron leakage, and so on. A virtual model of this facility provides a tour of the laboratory, and will have the capability to conduct simple virtual experiments in the future (Fig. 8). The GUS assembly is modeled by "pasting" digital pictures of GUS on a cube. Figure 9 shows a picture of the virtual radiation lab with some control panels, multi-channel analyzers, and the GUS assembly in the back. Certain components, like chairs, in this model can be "grabbed" and moved by the user.

Figure 6 Shielding experiment

Figure 7 Decay experiment

Figure 8 GUS Facility

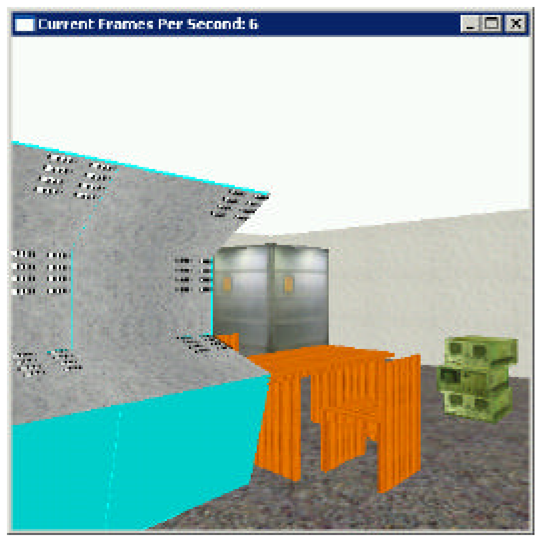

Figure 9 A laboratory, with control panels, a desk and some chairs, GUS, and some multi-channel analyzers

The last, and the most detailed, model is that of a research reactor (Figs. 10 and 11). Components in this model include desks and chairs, generic control panels, and a workbench, displaying reactor power (%) and bulk temperature (°C). Also modeled is the emergency "scram" switch. Once again, power and temperature, after an operator's virtual intervention, can be displayed on the virtual gauges, either from a pre-calculated database or from real time simulations.

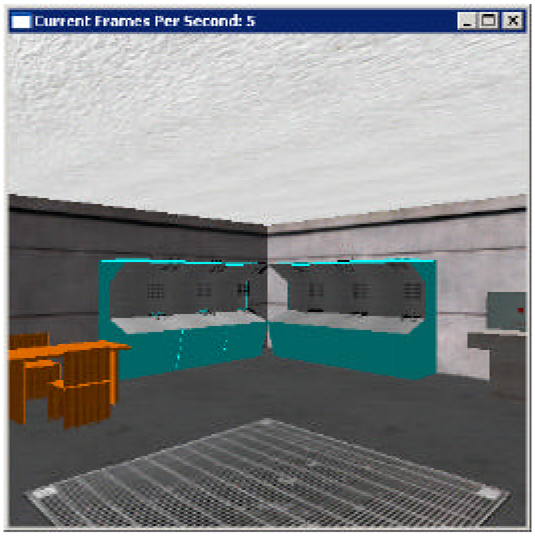

Fig. 10 Prototype research reactor

Fig. 11 Details of a control panel

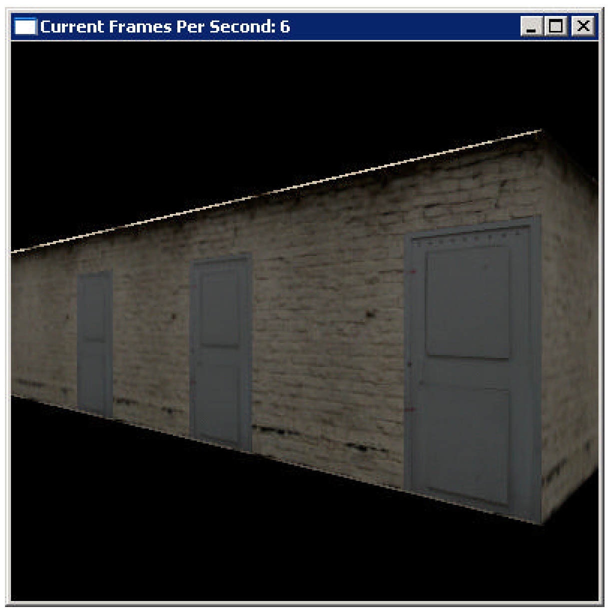

Fig. 12 Several models assembled in a building

Finally, to demonstrate the ability to assemble "components" into larger models, models 2-4 are assembled into a building with three rooms, each housing one model. One can walk through a door in Fig. 12 and find himself in either Fig. 6, 9 or 10. The potential of this approach is only limited by a designer's imagination. Tools developed here can be easily expanded to develop the model of a complete commercial power reactor site.

5. CONCLUSIONS

Safety and ability to minimize cost and exposure risk will inevitably remain two of the goals of any nuclear enterprise. Several recent technological innovations, including virtual reality, can be helpful in achieving these goals. Virtual reality cannot only be used to improve human-machine interfacing and operator training; it may also be very useful in achieving educational and outreach goals of the discipline. Nuclear engineers have only recently started to exploit the potential of virtual reality. While only a few simple models have been presented here, several more detailed and complex models, ranging from more sophisticated experiments, to parts of nuclear power sites, are currently being developed, and will be presented elsewhere.

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