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THE APPLICATION OF VIRTUAL REALITY TO CHEMICAL ENGINEERING EDUCATION

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ABSTRACT

Virtual reality (VR) is an emerging computer interface that has the potential to have tremendous impact on engineering education, by providing students with new insights into their studies and permitting them to explore environments that would be otherwise inaccessible. However before that potential can be fully exploited, engineering educators must first learn not only the mechanics of VR, but also the intricacies of how best to apply this new tool to scientific and technical education. In order to develop techniques for the effective application of VR to engineering education, ongoing research in the department of chemical engineering at the University of Michigan has produced three major and numerous minor VR based educational modules, designed to aid in the instruction of chemical engineering topics. Besides developing effective methodology, another primary goal of this research is to reach as many students as possible on a nationwide basis, which requires the use of relatively inexpensive (student affordable) personal computers as a base platform. Effectively portraying technical information in real time using minimal computing power requires special simulation techniques that are unique to this environment. This paper provides a brief description of the VR modules developed to date, including some of the special simulation techniques that they incorporate, and discusses steps that are currently being taken to reach a wider audience through VRML and other world wide web-based techniques.

BACKGROUND:
Description of VR

Virtual reality (VR) is an emerging computer interface that strives to increase the realism and impact of simulations by placing the user in the center of an interactive three dimensional environment, complete with spatialized sound, haptic feedback, and eventually olfactory and taste feedback as well. Technological devices used to deliver this experience typically include head-mounted displays (HMDs) and wired gloves, however the real critical component to delivering effective VR is a graphics system capable of rendering three dimensional graphics at a reasonable frame rate. Where computing power is limited, compromises must be made in terms of model details, and special techniques must be incorporated to squeeze the most performance from the available equipment.

Benefits of VR to Engineering Education

There are many educational benefits offered by VR, as evidenced by hundreds of papers in the literature (Panteledis) applying VR to K-12 education. For engineering educators, one of the appealing features of VR is the ability to take students to places that are otherwise inaccessible, such as the surface of Mars, the inside of an operating reactor, or between the plates of a capacitor. Another strong benefit is to reach students who have alternate learning styles (Felder), particularly those who are visual, active, and global learners. Three dimensional visualization is yet another strong benefit of VR, as might be useful in CAD classes, mechanical engineering applications, and for viewing atomic crystal structures.

Unique Simulation Problems in Educational Virtual Reality

Most scientific computer simulations require first and foremost an accurate result. While execution speed and robustness are also important criteria, they are subject to the constraint of determining the correct answer to within a tight tolerance, often six digits of precision or better. VR, on the other hand, requires fast screen updates in order to be believable. Rather than asking "How fast can we get the answer?", VR programmers must constantly ask "How much detail and realism can we add and still complete all calculations (including graphics rendering) within a tenth of a second?"

The classic solution to this problem is to use a high powered computer, with a graphics system capable of delivering whatever performance level is required. However an educational simulation will have little impact if students do not have access to the computing power necessary to run it. Therefore educational VR is faced with the difficulty of delivering as much detail and speed as possible on commonly available inexpensive computer platforms.

In addition to the cost of the computing engines, educational VR is also constrained by the limited performance of student affordable peripheral devices. For example, high quality HMDs have recently dropped in price from roughly $70,000 to a mere $20,000, which is still far out of the reach of most students. There are devices available for less than $1000, but their visual resolution is sufficiently poor to render the user legally blind in many cases.

Because of this price-performance tradeoff, the most successful and well-known VR applications currently fall into one of two categories: high budget applications where the benefits justify the high cost of quality equipment (e.g. military flight simulators and medical applications), and the entertainment industry. The latter can tolerate poor visual quality because the user is generally too excited and busy shooting things to notice details or lack thereof. Educational VR is stuck in the middle, attempting to deliver high quality technical instruction, with an absolute minimum of CPU cycles, in an atmosphere where the user cannot read more than a few words (in huge fonts) or discern any meaningful details. The HMD also blocks user access to the keyboard and to supporting documents, in exchange for delivering a high degree of immersion.

DESCRIPTION OF DEVELOPED SIMULATIONS

A number of educational applications have been developed at the department of Chemical Engineering of the University of Michigan to explore the use of VR as an effective educational tool (Bell & Fogler, 1995, 1996a-c). The three most significant applications - Vicher 1, Vicher 2, and Safety - are all simulations of chemical plants. These applications address the topics of catalyst decay, non-isothermal reaction conditions, and chemical plant hazard analysis respectively. Scenes from each of these applications are shown below:

Vicher1

Vicher 1 consists of three different reactor rooms, three microscopic areas, and a welcome center that serves as a central location. The reactor rooms illustrate slow, medium, and fast mechanisms of catalyst decay, (time scales of minutes, hours, and days to weeks) and the industrial methods for handling each case. The three microscopic areas illustrate the mechanism of solid catalyzed reactions within a porous medium, in increasingly stronger magnification. The first microscopic view shows a single pellet the size of a small planet. Flying inside shows the interior of the porous structure where the reaction mechanism is first illustrated, and zooming in further shows a close-up of the pore wall with only a single reacting molecule within view.

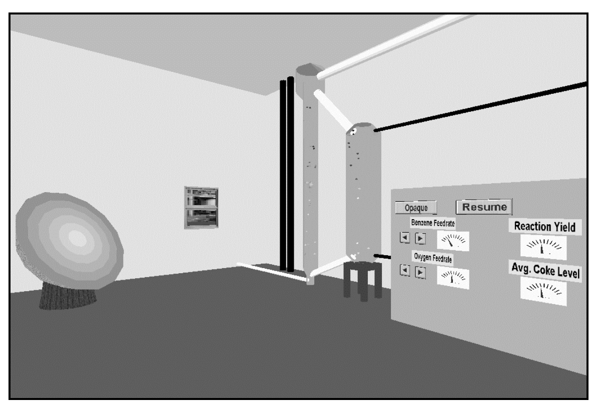

Figure 1: The transport reactor room allows students to view the effects of changing reactor conditions. The cutaway pellet in the corner illustrates the shrinking core model of catalyst decay.

Vicher2

Vicher 2 currently consists of three reaction engineering areas, illustrating different topics in non-isothermal reactor design, and a central welcome center. As in Vicher 1, students can operate most of the virtual reactor equipment, and can observe internal conditions either by turning the reactors transparent, or by stepping inside the equipment.

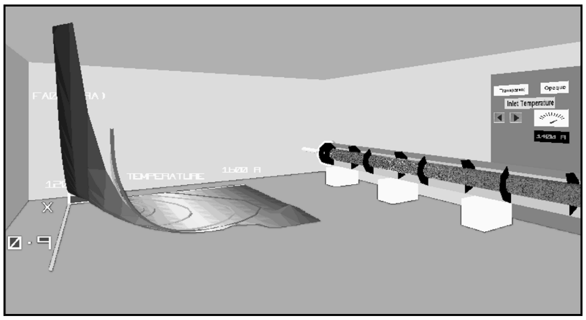

Figure 2: The non-isothermal packed bed reactor room uses color-coded 3-D graphs to illustrate the kinetics associated with a tubular reactor.

Safety

The safety application allows students to explore a chemical plant in order to analyze the hazards present and the safety systems in place to handle those hazards. This simulation has much more realistic detail than that found in the Vicher modules, because it is based upon photographs and observations taken at an actual facility. On the other hand, this is a static world, and the only action that students can take besides visual exploration is to bring up the associated "help" documentation, containing a full description of the items present, MSDS information, and equipment photographs.

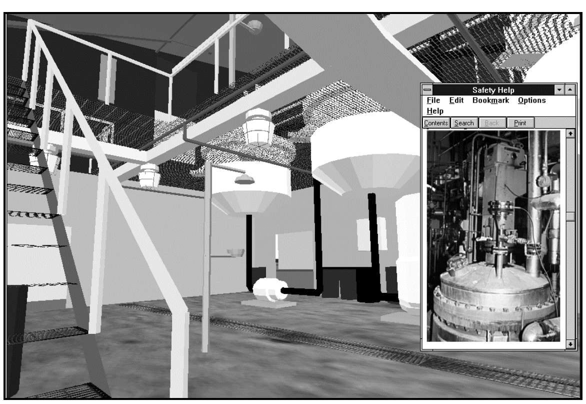

Figure 3: This safety and hazards analysis module includes a help document (inset) containing photographs of the industrial site being modeled.

Exploratory Applications

In addition to the three major applications described above, a number of smaller applications have been developed, in order to explore the capabilities of VR as an educational tool, and to test and illustrate particular techniques. These applications can be categorized roughly into two areas: three dimensional spatial relationships, and the exploration of information space. The former includes visualizations of metallic crystal structures and fluid flows, while the latter includes thermodynamic relationships and azeotropic distillation diagrams. Some views of these smaller exploratory applications are shown here:

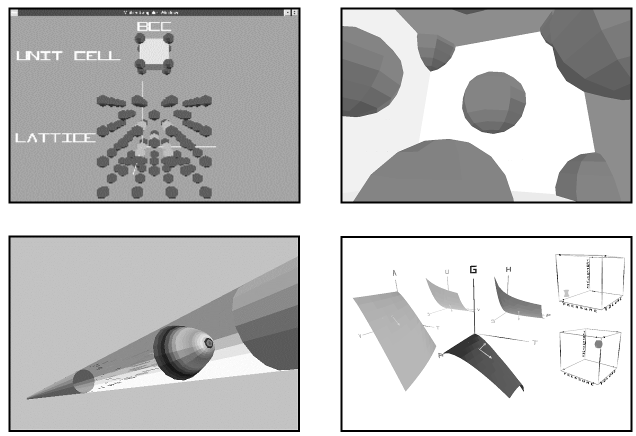

Figure 4: Top row shows body-centered and face-centered crystal structures. Bottom row shows fluid flow and thermodynamic relationships.

Further details regarding all of the applications described above can be found in the cited references, and on the web site http://www.engin.umich.edu/labs/vrichel.

SPECIAL TECHNIQUES DEVELOPED FOR IMPLEMENTING EDUCATIONAL VIRTUAL REALITY

In order to overcome the unique problems associated with delivering educational VR on student affordable equipment a number of special techniques have been developed. These techniques include tricks for displaying scientific concepts as quickly as possible, as well as methods for overcoming the general inability to read text in a student-affordable virtual environment. A few of these special techniques are described here.

Billboarding Molecules

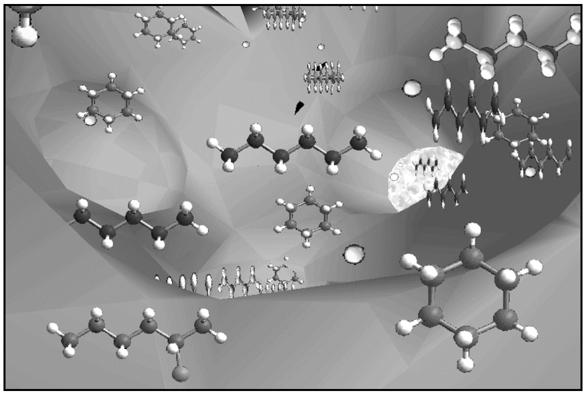

Figure 5: The interior of a microscopic catalyst pore, illustrating reaction mechanisms in Vicher 1.

Within the catalyst pore shown above there are fifty or more molecules, continuously moving, reacting, and bouncing off the walls. If they were to be modeled as ball-and-stick figures, they would require a minimum of 150 polygons each, or 6500 moving polygons that must be tested for collisions and view blockage with each frame update. Instead, each molecule is modeled as a single polygon, on which is applied a picture of a molecule. This technique is known as texture mapping, which is also used for modeling detailed flat objects such as brick walls and bookshelves. In the case of the molecules, the polygons must also be turned to face the viewer, which is called billboarding. The rotation step was optimized by matching the orientation of the molecules to the user's view, rather than making them truly orthogonal to the vector between the user and the molecules. The result is correct in the center of the screen (focus of interest), and sufficiently accurate at the edges not to be noticed. Considering that the execution speed varies with the square of the number of visible polygons, the reduction from 6500 to 50 is significant.

Graph Display

Several different techniques have been developed to display scientific graphs. The first was to produce a 3-D graph using externally calculated data and terrain generation techniques, as shown in Figure 2 above. This surface was then colored polygon by polygon to indicate the temperature coordinate. (red=hot; blue=cold.) By coloring the virtual reactors with the same color scheme, a tangible link was made between the mathematics and the equipment. "Lines" in 3 space were generated as long thin cylinders.

Another technique used to portray 2-D graphs within a virtual world was to first generate the graphs using a popular spreadsheet program, and then apply the captured result as a texture map on a single polygon. When the user changes reactor operating conditions (among pre-determined choices), the texture map is replaced with the image appropriate for the new situation. In order to make the graph "grow" over time in the time-temperature room, the completed graph is displayed partially blocked by a cover slip that is "shrunk" over time to reveal the graph. While these graphical techniques do not provide highly accurate detail or useful run-time calculations, they do illustrate the qualitative trends to within the visual resolution of low-cost HMDs.

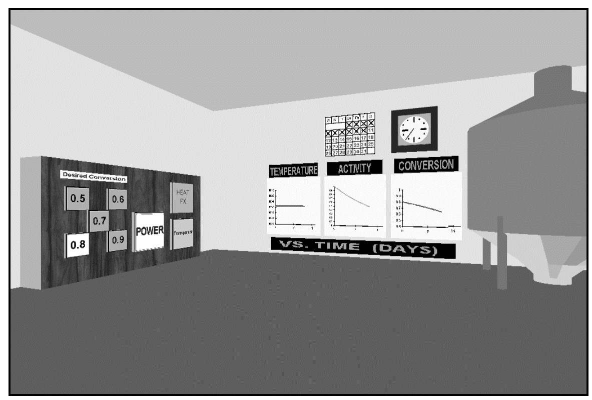

Figure 6: Graphs in the time-temperature reactor room show temperature, catalyst activity, and conversion changing with time.

Displaying Text (or Not)

Traditional educational computer modules present the user with large amounts of text to be read on the screen. (In extreme cases they can amount to little more than a computerized version of the textbook.) Several methods have been explored for displaying text in VR, without yielding a completely satisfactory solution. Very large fonts are sufficient for one or two word labels, but not for lengthier texts. Auditory narration also has its benefits, but is not universally useful. Virtual television sets have proven to be a useful information delivery device, with each "channel" having a different still image (texture map) and auditory component. Finally the MS Windows "Help" facility has been utilized, allowing users to click on a virtual object to bring up a separate window with textual and graphical information. By including photographs in these help files a level of detail can be provided that would not be possible otherwise, as shown in Figure 3. However in general the conclusion has been that VR is not an appropriate medium for delivering textual information, and therefore educational VR applications should strive to avoid text as much as possible.

FUTURE EFFORTS FOR DELIVERING VIRTUAL REALITY TO STUDENTS

Initially it was stated that in order to reach the widest possible student audience, educational applications needed to be designed for commonly available student affordable personal computers. While there is still a strong basis for that argument, a new vehicle has evolved over the past few years for quickly and easily delivering computer-based information to the masses: the world wide web. Now, with the growing popularity of the virtual reality modeling language (VRML), VR can be expected to ride the wave of the ever expanding Internet. Our current efforts in exploring this field involve converting some of our simpler applications to VRML format, and developing new applications using another web-based VR development tool, WorldUp (Sense8). The latter is a GUI based interface for the development of virtual worlds, that is supposed to eventually include a freely available Netscape plug-in for anyone to view and interact with the resulting virtual environment. We have started to make sample worlds in both VRML and WorldUp format available on our web site: http://www.engin.umich.edu/labs/vrichel. However the VRML export is still less than satisfactory, and the WorldUp Netscape plug-in is not yet available.

CONCLUSIONS

In order to effectively apply VR as an educational tool in engineering and other technical areas, a number of unique simulation difficulties must be identified and solved. Key among these is the shift in emphasis from accuracy to speed imposed by the need to maintain high frame rates on student affordable PCs and the low resolution of inexpensive viewing devices. A number of special techniques have been developed in the course of developing three major and numerous minor educational VR applications. Some of the techniques described here include the display of moving (reacting) molecules, the display of 2D and 3D graphs, and a discussion of different methods of presenting textual information in a non text-based environment. Future advances in computer technology will bring ever more powerful graphics to students' desktops, which will relieve some of the current simulation restrictions. The ever burgeoning world wide web will eventually include VR, however the currently implemented solutions are not sufficient for practical educational use.

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His current research work combines his chemical engineering and computer science skills to study the applicability of virtual reality to chemical engineering and education. His other research interests also involve the application of emerging computer technologies to chemical engineering and education.

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In 1980, Professor Fogler was a first recipient of the newly instituted award for Outstanding Research from the University of Michigan College of Engineering, and also in 1980, received the Chemical Engineer of the Year Award from the Detroit section of the American Institute of Chemical Engineers. In 1987, he received the University of Colorado Distinguished Alumnus Award, and in 1988, he was elected President of the Computer Aids for Chemical Engineering (CACHE) Corporation.