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Virtual Reality in Chemical Engineering Education

John T. Bell
H. Scott Fogler

Department of Chemical Engineering
University of Michigan, Ann Arbor, 48109-2136

Virtual reality is an emerging computer visualization technology which will allow educators to place their students into instructional environments heretofore difficult or impossible to achieve. In order to take full advantage of this new technology, a virtual reality based simulator, Vicher, is currently being developed at the University of Michigan Chemical Engineering Department, in order to aid in the instruction of chemical reactor engineering. While virtual reality has been recently employed in a few educational applications, (grade school and high school levels), and for advanced operator training, (virtual surgery, flight simulation), the program presented here is the first known application of virtual reality to chemical engineering education.

Background

Virtual reality, (VR), is a newly emerging computer interface, designed to make the user believe that they are actually inside of the computer generated environment, as opposed to being an external observer looking in. An effective virtual environment must also be highly interactive, giving the user as much control as possible over their surroundings. High degrees of immersion are accomplished via fast, high-resolution graphics, three dimensional audio and video interfaces, head-mounted display devices, wired gloves and other clothing, tactile feedback, and numerous psychological techniques.

Although the concept of virtual reality has been around for almost thirty years, until recently its use has been limited to specialized research labs and those with large computing budgets, such as the military. Within the past few years, however, a number of inexpensive hardware and software VR products have been developed, which has brought virtual reality within reach of the average researcher and even home hobbyist. Furthermore, as virtual reality grows in popularity, the economy of scale will bring new and more powerful features within the reach of educational users. Although high-quality solutions are not yet affordable, and affordable solutions are not yet high-quality, we feel it prudent to begin developing virtual reality based educational applications today, so that we will be prepared for the equipment which will be available tomorrow.

Overview of Vicher

Vicher, (**Vi**rtual **Che**mical **R**eaction module), is an educational application of virtual reality designed to aid in the instruction of undergraduate chemical reaction engineering. The goals in producing Vicher are to 1) provide an educational environment in which chemical reactor design students can explore first-hand the concepts which they have studied in class, 2) provide in-depth reactor design and computer programming training to the students who are helping to develop Vicher, and 3) develop a knowledge base concerning the application of virtual reality techniques to educational applications. This knowledge base may be the strongest benefit of the project, as it can then be applied to more complex applications and more advanced hardware in future developments.

Vicher is being developed using two 90MHz Pentium based personal computers. The two machines are configured with different sets of peripheral hardware, in order to address current as well as future audiences. The first machine uses no special hardware, other than a fast video board and a joystick, and is based on the Microsoft Windows environment. This class of hardware is already in the hands of many students and undergraduate laboratories, and should become common within the next year or so. The second machine contains a specialized ultra-high-speed video board and a 3-D spatialized sound audio card, and is further equipped with a head-mounted display unit, 3-D goggles, and other VR devices. This class of hardware will not be common for several years, but it allows us to deliver a much higher quality product, and we will be prepared for the day when computer capabilities increase. These hardware choices were made as a compromise between delivering the best performance possible and developing a product which can be placed into the hands of as many students as possible as quickly as possible. Vicher will run on either platform and can be easily ported to higher quality equipment, such as Silicon Graphics workstations at a later date.

The virtual environment being modeled in Vicher consists of a small portion of a modern chemical plant, plus two microscopic exploration areas. The rooms consist of a welcome center, in which users learn how to use the program and receive other pertinent information, a reactor room, where users can control and observe an operating reactor, and a debriefing room, designed to test student's mastery of the concepts presented. The microscopic areas are the inside and the outside of a catalyst pellet.

Users interface with Vicher using a joystick for movement, a mouse for activating objects and requesting information, and a keyboard for various other tasks. Users can receive information on any object or area, by using the right mouse button. In the Windows environment this brings up a separate window with the appropriate help text. This help is also linked to other help screens, via a hypertext interface. Work is currently underway to implement a similar feature in the DOS version. The left mouse button is used to activate objects, such as the television or reactor controls, where "activate" takes on a meaning appropriate to the object. The pictures on the walls can be activated, which provides a teleport to the location pictured. A variation of this is to fly through the pictures, which also provides a teleport. We have found the teleports to be a very effective navigational technique and intend to incorporate them in all future areas. When using the head-mounted display, a head tracking device allows the user to simply look where they want to go and push the stick forward to move in that direction. This has been found to be the simplest and most effective navigation technique. Another strong benefit of the head-mounted display is the sensory-deprivation effect - When users are unable to see the "real" world, they become much more immersed in the virtual one.

The Welcome Center

The first room which users encounter is the welcome center, containing tables, chairs, a desk, pictures, books, and a working television set. The purposes of the welcome center are twofold. The first is to overcome the disorientation problems which some users experience when first encountering virtual reality. The welcome center is designed to be a simple, familiar environment in which users can become comfortable with the virtual reality hardware and software before moving on to more complex and possibly abstract environments.

Secondly, the welcome center is designed to be an information center, in which students can get educational input from the pictures, books, and television. This latter goal has been reached to a greater extent in the Windows version of Vicher than in the DOS version, due to various technical considerations. We have also discovered that the welcome center makes a good base of operations from which to explore other areas. Future expansions of Vicher will therefore all branch out from the welcome center. Some of the features of the welcome center will be expanded to other rooms as Vicher grows.

The Reactor Room

The primary engineering area is currently the reactor room, which contains a vertical straight-through transport reactor and its associated catalyst regenerator and control panel. The engineering principles being illustrated in the reactor room are: 1) What does an industrial reactor really look like, and how does it operate, 2) The effects of flowrates on coking and decoking of catalyst pellets, and the subsequent effect on reaction rate, yield, fractional conversion, and other reaction properties, and 3) the shrinking-core model of catalyst decay and regeneration.

In the reactor room students can operate various controls, and observe the effects on reactor performance. Students can enter inside of the equipment, travel through the pipes, etc. in order to observe the activity inside the equipment, or they can simply turn the equipment "transparent", via the control panel. In transparent mode the students can see into the interior from any viewpoint, but cannot see out the other side, as if the equipment were fabricated from one-way glass. In general we have found this to be more effective than entering the equipment, as it provides the students with a wider field of view.

The reactor contains catalyst pellets, which rise faster or slower according to the (user controllable) reactant flowrate. As the pellets rise, they become darker as a result of coke deposits, which are a byproduct of the reaction taking place. The longer the pellets take to travel through the reactor, the dirtier they become. When the catalyst pellets reach the top of the reactor, they enter into the catalyst regeneration unit, where they are cleaned by counter-current steam. Again, the steam flowrate is controllable, which affects the catalyst pellets speed of travel and thereby de-coking rate. Operating the controls outside of a proper range can result in pellets building up in either the reactor or regenerator, or else getting successively dirtier due to inefficient regeneration activity.

Microscopic Areas

The two microscopic exploration areas are the outside and inside of the catalyst pellets. The educational goal of these two areas is to present the mechanism of catalytic reaction, whereby reactants must diffuse into the catalyst pores and absorb onto the catalyst surface before reaction can occur, followed by the desorption and exiting diffusion of the product molecules. In addition, the current implementation also includes an undesired competing reaction and coke formation.

A student on the outside of the catalyst pellets can observe the diffusion of reactants and products into and out of the pellet. This area also serves as a transition from the large scale world into the microscopic scale catalyst pore. Inside the pores of the catalyst pellets, the students can observe the mechanism for catalyzed reaction as outlined above, as well as diffusion effects. The catalyst pellet continues to move from the reactor to the regenerator and back while the user is inside, thereby allowing observation of the entire reaction-regeneration cycle.

The Debriefing Room

The purpose in developing the debriefing room was to question the students, in order to test their mastery of the concepts, to produce a "grade" for running the simulation, and to inspire them to go back to the engineering areas and further explore issues which they didn't grasp the first time through. To date this room has not delivered its full potential, due to difficulties in presenting text in a graphical environment. Recent developments, however, promise to make this a much more functional area in the near future.

Preliminary Results

Two of the three stated goals of producing Vicher have been met - The students developing the programs have learned a great deal from the experience, and a considerable base of techniques has been developed which will be valuable in future applications and in expanding the coverage of Vicher to new areas. As for the third stated goal, teaching reaction engineering, the first test of the program's effectiveness will occur just after the submission of this paper, but will be covered in the oral presentation. An additional unplanned benefit has been a greater understanding of the human factors and psychological issues pertaining to virtual reality.

The students who have been helping to produce Vicher have not only gained a much better understanding of the underlying reaction engineering principles, but have also gained valuable skills in C programming, computer graphics, three dimensional modeling, systems management, project management, and other computer techniques related to virtual reality. Several dozen other students and practicing engineers have tested Vicher, and their feedback has been instrumental in guiding the development of the program. (Although Vicher incorporates logging and videotaping of user actions, the most effective data collection technique to date has been direct observation.) User response to Vicher has been highly favorable.

Much of the knowledge gained in developing Vicher is technical in nature, such as how to move multiple complex objects in a realistic manner at reasonable speeds. (For virtual reality to be effective, the graphics images must be re-calculated and re-displayed several times per second, ideally 20 to 30 frames per second.) This technique has been implemented both in moving the catalyst pellets through the reaction equipment and also in moving the molecules within the catalyst pores. Note that in both these situations the objects in question also change form as the chemical reactions progress. Other features which have been developed and will be incorporated in future expansions include the implementation of a functional television set with both pictures and sound, and the control panel with functional buttons and gauges.

Another area in which knowledge has been gained involves human factors issues. Recall that the essence of virtual reality is to make the user believe that they are actually within the computer generated environment, and that said environment is "real". It is therefore vitally important to understand what features of a virtual world most enhance the believability and realism of the overall experience. For example, the original navigation technique for moving from room to room involved walking down a hallway. The purpose of the hallway was to provide a smooth logical transition from area to area, in order to minimize the disorientation sometimes associated with virtual reality. Our experience has shown that many users had difficulty navigating the hallways, and that the hallways do not add significantly to the experience. On the contrary, once the teleporting pictures were implemented, most users preferred to use the teleports, and have experienced very few disorientation problems with this interface. Accordingly, all hallways are currently being replaced with teleports.

Developing the proper computer-human interface is also crucial to an effective virtual world. In order to be most effective, a virtual reality implementation should have an interface which is as intuitive as possible, so that the user may more easily forget they are using a computer. The best interface found for Vicher is a combination of the joystick and the mouse. The keyboard has been found to be a poor interface for virtual worlds. This is especially true when using the head mounted display unit, as the user is unable to see the keyboard easily. The joystick, on the other hand, is especially effective in conjunction with the head-mounted display, as the user merely looks in the desired direction and pushes the stick forward. The only drawback to the joystick as an interface device, is that not all potential users have joysticks attached to their computers, and some environments (such as undergraduate computing labs) perceive them as toys and will therefore resist their implementation.

Current and Planned Developments

One area in which Vicher is currently weak is in the presentation of text-based material, such as formulas, equations, and definitions, as opposed to presenting situations and objects. This is due to the fact that Vicher is primarily graphical, i.e. pictures as opposed to text. The problem is particularly severe when using the head-mounted display, as text output is displayed on an alternate display not visible from within the HMD. The problem is further complicated by the desire to provide both DOS and Windows solutions. New techniques have recently been developed, however, for presenting textual information in a graphical format, specifically new methods for displaying "pictures of text". One of the major development goals for the next three months is to utilize these new techniques to greatly improve the informational capabilities of Vicher, using wall-sized virtual televisions for the presentation of educational materials.

Another major development effort is to convert the navigational interface from hallways to teleports. This will allow the rooms to be easily reorganized into areas of educational study, and several new rooms and new areas to be added. The new structure will incorporate "studies" or "libraries" between the welcome center and the engineering exploration areas. These study rooms will be where the students are presented with the background engineering information corresponding to each area. One option to be explored is whether or not students should be forced to review the background information before proceeding on the engineering areas. Likewise examination rooms will be added after the engineering areas, to test students mastery of the material being presented. A new engineering area to be added will provide for the study of heat effects (non isothermal operation) in chemical reaction engineering.

Conclusion

A virtual reality based computer simulation program is currently under development, to aid in the instruction of undergraduate chemical reaction engineering. At this time the primary engineering topics covered include the operation of a straight-through transport reactor and associated catalyst regenerator, the effects of varying flowrates on catalyst coking and reactor performance, the shrinking-core model of catalyst decay and regeneration, and the mechanism of catalytic reaction, including diffusion, absorption, and desorption processes. The major benefits gathered at this stage of development are the knowledge base of virtual reality techniques and how best to apply them to educational applications, and the training and experience of the students who are helping to develop the programs.

Additional informational interfaces are being added at the time of this writing, and should be in place by the time this paper is presented. Also within the next few months, new areas will be added to the simulator, including an area for the study of heat effects, (non isothermal operation), in chemical reactor engineering, and additional rooms for the presentation of engineering information and for testing of students' performance. The first reaction engineering class will soon have a chance to experience the simulator, and their feedback will be used to guide the further development of Vicher.