WEB-BASED VR-FORM VIRTUAL LABORATORY

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Recent technological advances on the Internet have enable2d a multitude of applications to operate via the World Wide Web. E-Learning is one such application. To this end, various institutions and universities are now offering online courses that students from all over the world can subscribe to and attend. Various teaching methods and tools have appeared, such as Web Courseware, On-Line Answer Machine, Web Classroom, etc.

Virtual experiments have also been developed. Some recent articles describe the design of virtual experiment systems and their uses in academe.[1-4] Another important simulation technology, virtual reality (VR), was introduced by John Bell and Scott Fogler as a powerful new tool in engineering education.[5]

We have developed an infrastructure for a Web-Based VR-Form Virtual Laboratory (WBVL) to aid in the undergraduate laboratory. We have successfully implemented several virtual chemical engineering experiments, such as "Measurement of Water's Degree of Hardness." In the following paragraphs, we will describe the four basic features of WBVL, give technical details, describe the set-up, introduce the virtual experiment operational model, and list the benefits to be gained from WBVL.

FEATURES OF WBVL

Educating students in engineering and related scientific fields is made difficult by the complex ideas and phenomena that are hard to demonstrate by conventional methods. For example, it is hard to get students to understand the structure of molecules through the use of 2-D graphics, and a virtual experiment faces the same problem. In order to help the students understand and master virtual experiments, they must be presented in **3-D form**, where they can observe any object from any point of view and any angle. This important feature of WBVL not only helps the student accomplish their objectives, but it also aids in holding their interest.

When performing experiments, students run the apparatus, observe phenomena, record data, and complete a report of the experiment. This means that they must interact with the experiment at every stage. For this reason, **interactivity** is another important feature of WBVL. Each virtual experiment is capable of presenting different reactions to differing input by the students. This interactivity helps the student feel that they were actually doing the experiment.

At times the students cannot access a laboratory and the only way they can conduct an experiment is through the Internet, so **network basing** is also important. With network-based virtual experiments, experiments are not limited to the laboratory environment.

Virtuality, another feature of WBVL, is a kind of virtual experiment based on simulation and is called Simulation Experiment (E). In some of the articles mentioned previously, another kind of virtual experiment, called the Remote Control Experiment (RCE), is described in which the students control actual experimental instruments via the Internet. This

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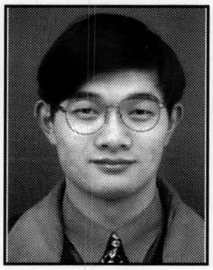

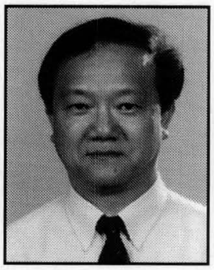

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is not feasible in all cases, however, since some experiments use apparatus that cannot be remotely controlled, or they take a long time to complete, or they are too expensive. RCE also limits the number of students who can participate. SE has no such limitations and is a more realistic form for virtual experiments.

TECHNICAL REALIZATION AND SYSTEM STRUCTURE

A server/client model is used in WBVL, with the server side being based on a web server (see Figure 1). All the virtual experiments are kept on the server side, and when the students want to load one they send a request to the server and it delivers the corresponding experimental data. The benefit of this approach is that updates and revisions are done centrally on the server and the latest version is always available to the clients (students).

The architecture of the client side is shown in Figure 2. Microsoft Internet Explorer is the user interface and all the experimental material is interpreted and represented in 3-D form. The 3-D scenes of the virtual laboratory and experiments are described by VRML,[6] the most common standard for describing interactive 3-D objects on the web. A VRML plug-in is needed on the client side to interpret the 3-D scenes. The following paragraphs describe all the components of this system.

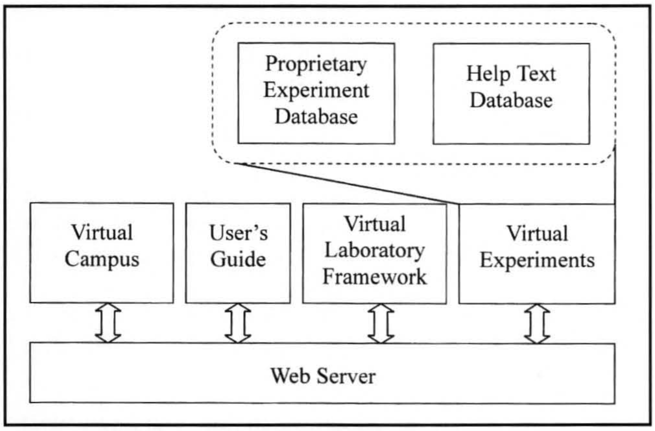

Figure 1. *Server-side system architecture.*

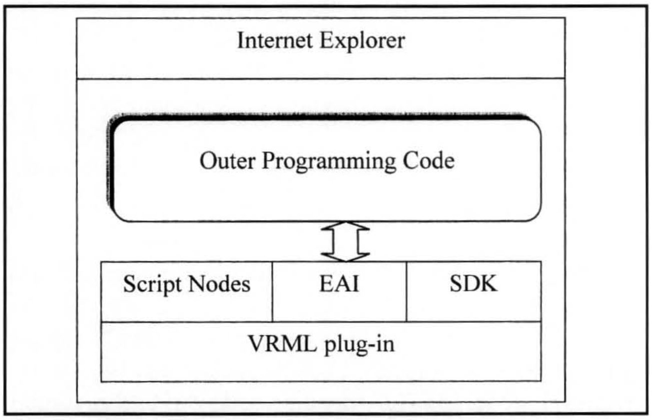

Figure 2. *Client-side system architecture.*

Web Server • The Web server is used on the server side to deliver virtual experiment curricula to the client side.

Virtual Campus • The virtual campus is a 3-D university environment where the students can go to different virtual laboratories to perform different experiments. In this virtual campus there are buildings and laboratories; the laboratories have hyperlinks directing the students to the experiments.

User's Guide • A user's guide teaches the students how to use WBVL and includes information on the virtual experiments (explained more thoroughly later in this paper).

Virtual Laboratory Framework • The virtual laboratory framework is the common framework of most virtual experiments. Just as in the real world, many virtual experiments are performed in the same laboratory and thus share a common virtual laboratory framework, including a 3-D laboratory scene and an interface to other parts of WBVL, etc. This approach has three benefits: it can reduce the design complexity of the experiment (the designer need only concentrate on the experimental contents, models, and private 3-D scenes of each experiment); updates of the laboratory scene and function are much easier; and the shared laboratory framework makes the graphics interface of all the experiments uniform. This helps students master the use of WBVL quickly.

Proprietary Experiment Database • Although WBVL has a uniform laboratory framework, each experiment should have its own proprietary characteristics. The experimental scenes must be different because different experiments use different apparatus and devices. Experiments' contents and models are also different from each other. These private properties of each experiment are stored in the proprietary experiment database.

Help Text Database • The help text database contains the text of online help for the experiments.

Internet Explorer and VRML Plug-In • In order to use WBVL, a general web browser on the client side is required. We use Microsoft Internet Explorer (see Figure 3). ActiveX is used to organize and gather several parts of WBVL together and Internet Explorer acts as an ActiveX container. Internet Explorer is also the uniform graphics user interface (GUI) for WBVL.

Realistic 3-D models of the laboratory and the experimental proprietary scenes are developed using VRML. The Virtual Reality Modeling Language (VRML) is a file format for describing interactive 3-D objects and worlds. VRML, used on the intenet, intranets, and local systems, is also intended to be a universal interchange format for integrated 3-D graphics and multimedia, so it fits WBVL's features well.

Although VRML is designed to describe the interactive 3-D objects, to a certain extent its interactive features and 3-D modeling ability are still limited. For example, standard VRML can only receive some simple mouse actions, such as clicking, touching, and dragging. Also, it doesn't support curved surface modeling. Such simple interactive and modeling abilities are insufficient for WBVL, but fortunately, some extensions have been developed that extend the VRML functions, including keyboard-input node, drag-and-drop node, geometric NURBS node, and geometric spline nodes that can model more complex and higher quality shapes with fewer surfaces and less file size. With the VRML extensions, we can manipulate WBVL easily and more efficiently.

Figure 3. *One WBVL experiment: "Measurement of Water's Degree of Hardness."*

A VRML plug-in is necessary to interpret the 3-D Virtual Experimental Environment (VEE). There are currently many VRML plug-ins available, but not all of them support VRML extensions or provide a Software Development Kit (SDK), so the selection of a VRML plug-in is very important.

In VEE, students can operate all kinds of virtual devices (detailed later in this paper), such as beakers and test tubes, which are shaped as 3-D objects by VRML. Through these operations, the students can control the experiment's progress, observe phenomena, and record data. Because a VEE consists of many virtual devices and other 3-D objects, the 3-D scene can be very complex, and a good VRML plug-in can improve the system performance.

Considering all the above criteria, we have chosen Cortona VRML Client,[7,8] one of the best free VRML plug-ins, to implement WBVL.

Script Nodes • The Script node is an important VRML node used to program behavior in a scene. Each Script node has associated programming language code that is executed to carry out the node's function. Using the Script node in WBVL has four purposes:

1. *Communication with objects outside VEE* • In order to make WBVL work, cooperation between it and other elements of WBVL is necessary. For example, VEE should communicate with Online Help to change the help text as the experiment progresses. Such communication ability is achieved by the programming language code in the Script node, together with EAI or SDK technology, mentioned below.
2. *Animation generation* • Many actions in WBVL, such as object moving, coloring, shaping, etc., use animation. Most animation is generated with the Script nodes, which manipulate the attributes of objects to generate their animation.
3. *Receiving students' commands* • In most cases, students' commands are received by sensor nodes, which is the standard way VRML interacts with the user. In a 3-D experimental scene many sensor nodes may be used, such as TouchSensor, CylinderSensor, PlaneSensor, etc.—all are able to receive the mouse actions and send one or more events to the Script nodes. The Script nodes then interpret the students' orders and carry out the corresponding action (typically, sending some events to other nodes).
4. *Simulation in WBVL* • The Script nodes, which have simple computational ability, are used to carry out uncomplicated simulations. Although the computational ability is somewhat limited, the simulation results can be used directly to change the representation of VEE, so simulations that have low computational complexity and large data input/output can be easily performed using the Script nodes.

EAI • External Authoring Interface (EAI), designed to allow an external environment to access nodes in a VRML scene, is part of VRML97 standard. Using EAI, we can extend the interactive and computational abilities of VRML. VEE, together with another important and powerful element, Java Applets, is embedded in the same web page. Most of the numerical/symbolical computations, analyses, and simulations of the virtual experiments are the responsibility of Applets. EAI enables Applets and VEE to communicate with eact other. Applets can exchange events with VEE and be notified when the node fields in VEE are changed. By means of EAI, WBVL can obtain extensible interactivity. The students can interact with experimental environments via the normal controls on a web page. For example, students can adjust an experimental parameter by inputting data in a textbox or by changing the viewpoint using an Applet button.

SDK • Although EAI can extend the interactive and communicative abilities of VRML, these features are still quite limited. For example, EAI is incapable of creating some advanced interactive objects, such as popup menus, or of accessing all nodes in a 3-D scene. In addition, EAI is complicated to use. SDK (Software Development Kit) is a better solution because it is easier to use and much more powerful. It is more frequently used in the design of WBVL.

SDK provides an Application Programming Interface (API) that enables the developers to integrate 3-D technology and VRML into a web page. A 3-D scene is treated as an ActiveX control, and outer VBScript, JavaScript, and Java Applet codes use SDK to access and manipulate any object in it or use the VRML event model to exchange events with it. At the same time, some low-level functions provided by SDK are necessary in building advanced interactive means, such as popup menus, hints, toolbars, etc., which are very useful in building a user-friendly interface. For example, when a student clicks on a test tube, a popup menu will appear to allow selection of what to do with it, *i.e.,* dump it or move it.

Outer Programming Code • An outer programming code is requisite when using the Script node, EAI, and SDK. Cooperation of each part of WBVL is also achieved by using it. Java and Script languages are used for outer programming codes and are transferred to and run on the client side.

The Script nodes of VRML can use Java classes as their associated programming codes. Generally, Java Applets use EAI to communicate with VEE, but SDK can also be used by Java Applets and JavaScript/VBScript codes to collaborate with VEE. For example, the on-line help system is handled in this way.

WBVL SET-UP

Similar to the traditional experiment set-up, WBVL is also composed of four parts: the user's guide, laboratory experiments, on-line help, and experiment reports. The user's guide tells the students the basic rules about the virtual experiments. After mastering the necessary learning, students can perform the experiment. The on-line help system provides information to the student at any stage of the experiment. After finishing, students are required to fill out an experiment report, which will be graded immediately by WBVL.

User's Guide • Setting up the user's guide has two main goals. First, students can get basic information about the experiment they will perform. The user's guide is intended to be an extension of the traditional curriculum held by teachers. Second, through the user's guide students can become familiar with WBVL. Although WBVL is designed to simulate the true world of experiment as much as it can, it is still not easy for a novice to run the experiment. The user's guide gives the students enough information to use WBVL.

The user's guide is divided into three parts:

1. *Introduction to WBVL* • This part describes the basic use of WBVL. Students can read this part and become familiar with the whole system.
2. *Virtual Devices Library* • Virtual devices are those devices used in the experiments that have special functions and that students can interact with, *e.g.,* beakers, tubes, etc. The virtual devices library contains a basic introduction to them and describes their uses. Because of the differences between the virtual and the real worlds, without learning about how these devices look and how to use them, students would not be able to conduct the experiment.
3. *Specifications of Virtual Experiments* • This part gives the details of each experiment on WBVL, including the experiment's goals, principles, contents, methodologies, and emphases. It contributes greatly to the students' understanding of the experiments.

Laboratory Experiment • In WBVL, one virtual laboratory environment and several proprietary environments have been implemented so a variety of experiments can be performed. Figure 3 illustrates an experiment ("The Measurement of Water's Degree of Hardness") where students can operate beakers, graduated cylinders, pipettes, burettes, etc., to measure the degree of hardness of a water sample. In the process of experiment, they observe the phenomena and record the necessary data. The original data of this experiment is given randomly to make the experiment more authentic.

Online Help • In performing experiments, students (especially novices) are sometimes confused by the numerous experimental steps and data and need a help mechanism that can give them instruction whenever they need it. Online help is an important feature of WBVL. Along with the experiment's process, the online help loads help text from the database and displays it in a help frame, as shown in the right side of Figure 3. The help text tells the students what to do and how to do the next step. Relative knowledge about the experiments is also provided in the help text.

Experimental Report • In conventional curricula, students submit a report on the experiment as their last step. The report includes the design of the experiment, phenomena record, data record, analysis, and conclusions. It sums up what the students learned, whether they reached their goals, and how well they did. The report also allows the teacher to discern the level of the students' knowledge.

Because of the importance of the report, it is also a part of WBVL. Once the students finish their experiment, a report that was prepared beforehand is presented for them to fill out. WBVL then grades their experiment according to records made during the experiment combined with their final report. For computer grading, templates of the experiment reports are compiled in a standardized form (*i.e.,* the templates are composed of groups of multiple-choice tests or blank quizzes) that are carefully designed by the instructors. Because the standardized forms enable computers to check the reports automatically, a teacher's workload is greatly reduced. Using this method, however, gives the students little opportunity to write a complete experimental report, so written reports are also required in order to give the student training in report writing.

VIRTUAL EXPERIMENT OPERATIONAL MODEL

Virtual experiment operational models control the operational sequences of the experiments and can greatly affect the difficulty or ease of performing the experiment. The choice of this model should be carefully considered in the systematic analysis. Generally, the operational models can be divided into three categories: concurrent models, serial models, and combined models.

Concurrent Model • In the concurrent model, all virtual devices in the experimental scene can be operated concurrently, *i.e.,* the students can choose an arbitrary device to operate at any time. Figure 4 shows the architectural structure of this model. Skilled students usually prefer this model because of its unrestricted nature. Real-world experiments can be best simulated with this model, but it also has the following disadvantages:

1. *The students get no information about what they should do next since there are no restrictions for their operation. Some inherent restrictions in the real-world experiments are not noted, leaving so many choices for them that they sometimes become bewildered.*
2. *Because actions are arbitrarily chosen, abnormal results—even illegal operations—are inevitable. For example, an experiment that requires reagent A to be mixed with B, then with C, may have that sequence altered in a virtual experiment, with uncertain results. Under the concurrent model, the system has to cope with all the extra operations and give appropriate responses. If numerous virtual devices are used, there may be too many extra operations and combinations to be dealt with. This is a key problem in using the concurrent model. Because of this disadvantage, the concurrent model is seldom used alone in WBVL. Only those virtual experiments that don't restrict the sequence of each step use this model.*

Serial Model • An alternative is the serial model, in which the student must obey a predetermined operational sequence. In this model, the students can operate only one device at a time, and which device they can operate is determined by the sequence database. After they finish one stage of the operation, another device becomes operable while the other devices remain "blind," *i.e.,* cannot be operated. The students are thus forced to perform the experiment in a predetermined correct sequence.

Compared to the architectural structure of the concurrent model, the serial model inserts a valve between the user interface unit and the virtual device (see Figure 5). An opened valve enables the students to control the corresponding device, while a closed valve makes the corresponding device inoperable. The open and closed sequences are predetermined and stored in the operational sequence database at the time of the experiment's design.

Benefits of the serial model are

1. *The experiment's process is clear to the students. They are guided step-by-step through the experiment and can finish it easily and more efficiently. At the same time, this model focuses the student's concentration on the experimental phenomena and data, and not just on how to finish the experiment. This feature is especially useful for novices who are not familiar with either WBVL or the experiment.*
2. *By limiting the student's operation to a single device, the serial model avoids the possibility of illegal operations, so the design complexity of WBVL is greatly simplified. This can greatly shorten the development period of WBVL as well as reducing its cost.*

The drawbacks of the serial model are obvious. They are

1. *A reduction of reality sensation. The students cannot choose which virtual devices they control. This limits the independent students.*
2. *It disables the experiment's variability. By making the*

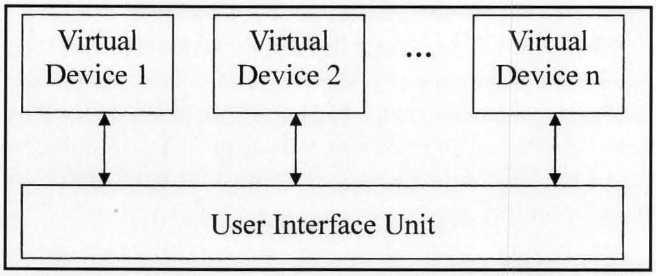

Figure 4. *Architectural structure of concurrent model.*

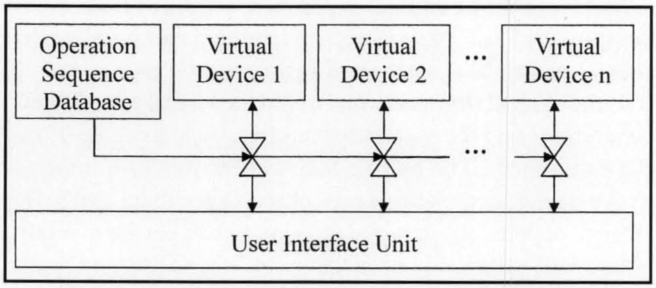

Figure 5. *Architectural structure of serial model.*

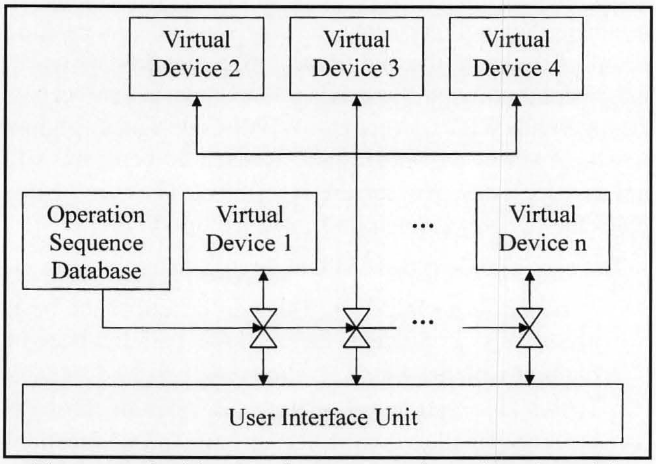

Figure 6. *Architectural structure of combined model.*

students strictly follow a predetermined experimental step, slight changes are impossible. Student initiative becomes restricted.

Since the virtual experiments using the serial model are subject to the risk of being treated as mere television shows, it is only used in exhibitive experiments.

COMBINED MODEL

The pure concurrent and serial models are rarely used in the design of WBVL because of their disadvantages. An alternative is the combined model, which combines features of both the concurrent and serial models.

The concurrent model has no predetermined operational sequence, while the serial model defines a straightforward operational sequence without any branches. The operational sequence defined in the combined model is much more complicated than either of them.

The number of controllable virtual devices in the combined model can be larger than one, as illustrated in Figure 6. It can be seen that although the global structure is serial, the concurrent model is also sometimes presented. The global serial operation model insures that the experiment can reach a certain end, while the partial concurrent model enables students to select the best way to accomplish the experiment. The student's selection and operation will affect the final score.

This model is suitable for most virtual experiments. For instance, the experiment "Usage of Analytical Balance" uses such a model. Opening the sliding door should occur before placing the object on the pan. The serial model is used to determine the operational sequence of these steps, but since the selection of the poises is arbitrary, the concurrent model is also used.

APPLICATION OF WBVL

Based on its four basic features, WBVL has a number of benefits for engineering education. First, it is valuable for simulating some special experiments, *e.g.,* dangerous experiments, very large or small experiments, expensive experiments, or experiments that cannot be done in a traditional laboratory. Second, WBVL can be used as pre-lab preparation. Before students perform a real experiment, they can become familiar with it through WBVL, thus improving the efficiency and avoiding potential damage of some vulnerable apparatus. Third, WBVL may be a way to solve the experimental education problem of distance education. In distance education, students from geographically distinct locations can no longer go to a laboratory to perform an experiment. Online virtual experiments are more realistic in this case.

In order to aid E-Learning of the basic chemistry course, a set of virtual experiments has been realized in WBVL, including "Measurement of Water's Degree of Hardness," "Usage of Analytical Balance," "Electrolytic Polishing," and "Ionic Equilibrium of Electrolyte in Water." Some students use this sytem as a pre-lab preparation and feel that after study on the WBVL, they can better master the basic concepts and operations of the experiments.

A demo of WBVL is available at

http://networking.zju.edu.cn/wlxk/VLabs/index.htm

It is a Chinese web site where a virtual campus and four virtual experiments are provided. We recommend the following minimum configuration for running WBVL: Windows PC, PII 450 or higher, 128M RAM, TNT2 or better display card (16 bits color), 1024x768 screen, MS Windows 98/2000, Internet Explorer 5.0 or higher, Cortona VRML Client 3.1.[7]

CONCLUSION

WBVL should be considered as a supplement rather than as a replacement for conventional experiments. With its four important features (3-D form, interactivity, networking basing, and virtuality), WBVL makes the students feel they are performing a real-world experiment. WBVL is structured in Client/Server architecture, with the experiment curriculum material held on the server side. Because the only requirement on the client side is a general web browser and a VRML plug-in, WBVL is easy to use. The set-up is similar to conventional curricula, so students can quickly master it. The operational model used in most of the virtual experiments is the combined model, which can achieve a better compromise between the virtuality and the system complexity.

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