

REMOTE EXPERIMENT LABORATORIES USING VIRTUAL REALITY TECHNOLOGIES: THE VRLAB PROJECT

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ABSTRACT. This paper presents the “Remote Experiment Laboratories Using Virtual Reality” (VRLab) project. VRLab promotes the coordinated use of Virtual Reality technologies along with video streaming and remote control combined through a web interface in order to provide a new approach to multi-user remote experimentation for educational purposes.

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1. INTRODUCTION

Throughout the educational curriculum, students are called to master various topics on physics, chemistry, informatics, etc, that require a practical understanding of certain processes. Such practical training can be achieved by performing experiments in laboratories. However, not all institutions have the means to provide the equipment, maintenance and/or the expertise required to carry out such experiments in-house. Reasons for this include financial restrictions, small student audiences, safety regulations or remote location of such educational institutions.

All these problems can be solved by using the Internet and the modern computer technology. Nowadays most of the schools in developed countries have Internet access and the adaptation of new technologies in education opens new horizons for the development of new technological infrastructures. However, educational applications are still limited, mainly multimedia material, simulations and Internet articles. The new pedagogical approach requires creation of educational material, which should stimulate the interest of students and support their direct and active participation in the educational process.

Recently, many research [1,2,3,4,5,6,7,13,8,9,10]and commercial [11, 12] systems have already been developed to offer off-line (simulations) and online (real-time) laboratory experiments through the Internet. Important challenges in the design and development of such systems is to provide to the user realistic visualization of the experiment and its results as well as increased interactivity options.

VRLab is a project, funded by the Greek Secretariat for Research and Technology (GSRT), conceived to offer an e-learning solution to this end. Its aim is to provide users (teachers or students at different educational levels) with a system accessible via the Internet to remotely conduct experiments, which are located in a remote laboratory, with safety and no financial or time restrictions. In the same time the students will be able to observe the real experiment through a camera, as well as a 3-D representation of the experiment progress in real time. The same 3-D representation can be used in an off-line mode (without using the Internet) in order to perform a simulation of the experiment according to the applicable physical laws. The system will be able to support specific virtual reality devices, such as a head-mounted display, if available, in order to immerse the user into the experiment or the simulation so as to offer new and more natural ways of interaction with the experiment. The main objectives of the VRLab project are summarized below:

- 1) Research on alternative ways of using the Internet and novel 3-D graphics and Virtual Reality technologies in education aiming at maximizing learning effectiveness.
- 2) Introduction of users in the online laboratory with expensive / specialized equipment from any-where in the world and anytime of the day, familiarization with tele-education.
- 3) Safe, remote execution of hazardous experiments and/or experiments that demand special precautions.
- 4) Development of tele-education projects for lecturers, teachers and students located in distant isolated areas.
- 5) Stimulation of discussion and exchange of know-how and experience during the experimental courses.
- 6) Stimulation of participation and cooperation of persons with special needs.

- 7) Evaluation and direct commercial promotion of the educational product to be produced.
- 8) Experimental Cooperative educational methods
- 9) Parameterisation and reusability of the project results

To this end, the VRLab consortium ¹ proposed, designed and are currently developing an integrated novel application for conducting real experiments as well as simulations for educational purposes through a 3-D Virtual Reality environment.

2.SYSTEM ARCHITECTURE

The VRLab system consists of the following sub-systems:

1. The systems server station, which consists of one PC for each experimental setup that will be supported and an additional central server,
2. The client system, which includes a user interface based on 3-D graphics and virtual reality technologies and
3. The Web portal, which provides the user with additional information and functionalities and acts as an integration platform for the entire system

2.1.THE SERVER STATION

The Server station, which composes the heart of the system, consists of three *Experiment Servers*(one per each supported experiment), each containing:

- A PC with specialized software to control the experiment and collect measurements from it,
- A digital camera for visual inspection mounted on a mechanism that allows camera control from the PC,

¹The VRLab partners are “HYPERTECH S.A.” and “GNOMON” (two major software companies), “ITI-CERTH” (a research institute), “HTEI” (the Thessaloniki Higher Technological Educational Institute) and the “Hellenic College” high school

- An online data logger using appropriate sensors, which is needed to record measurements from the experiment and store them in the server PC,
- A specialized control board necessary for controlling the experimental setup
- The required experimental setup with standard laboratory equipment.

The three experimental stations are connected to a local network (LAN) and communicate with a central server(PC), which acts as the Internet gateway of the server, handling requests from the users connected to the system (Figure 1). Normally, this PC also hosts the Web portal.

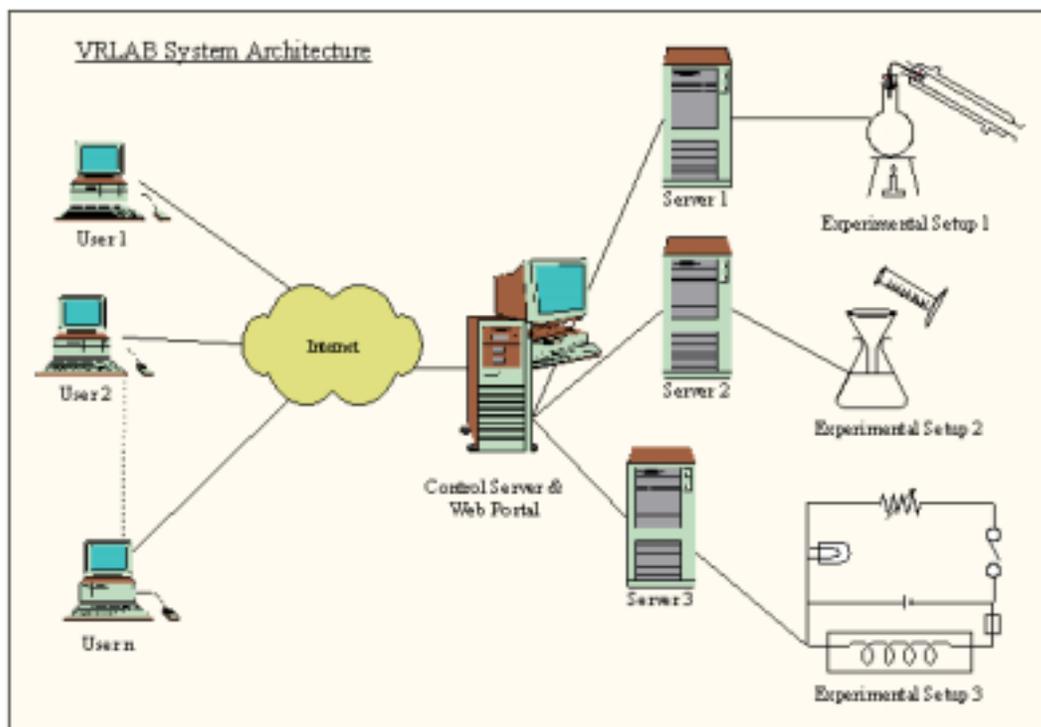


Figure 1: VRLab System Architecture

THE CLIENT SYSTEM

Each remote user uses a web-based client application developed as a set of Java applets, in order to access the server station. From his workstation, he is able to select an experimental setup to work with, to watch real-time video during the performance of the experiment and to remotely control the camera. The user interface also displays a 3-D representation of the experiment progress in VRML, which helps the user understand the experiment better and allows him to set-up the parameters of the experimental setup and sensors, as well as to control the flow of the experiment and the measurement collection, by activating certain “*hot-spots*” For example, the movement of a piston inside a gas chamber is performed naturally by “dragging” a 3-D model of the piston with the mouse. The movement is activated by “mouse-clicking” on the corresponding hot-spot. Afterwards, the 3-D representation of the pressure sensor will display in real time the sampled measurements along with the theoretical pressure values, so that the user can directly watch the progress of the experiment and compare with the theoretical values based on gas laws formulas. Thus, an impressive “complete” picture of the experiment is provided to the user, which cannot be obtained solely by watching the video stream of the experiment.

The 3-D representation can activate and represent the real experiment in real-time, as described above, but also permits the user to run an (off-line) simulation of the experiment, without actually conducting it. In the latter case, the simulation is based on the theoretical laws, using parameters that can be defined by the user. Thus the user can produce, present and compare results of the theoretical analysis, by superimposing the theoretical and experiment results in the same window, which is usually very useful to draw conclusions about the experiment.

The system is able to receive measurement values from the experiment in nearly real time and to display them in corresponding graphs through the same web-based interface. The experiment progress can be observed simultaneously by all users connected to the system, however at each time instant only one user has the permission to control the experimental setup. Nevertheless, the control of the experiment may be passed from one user to the other, according to the time-scheduling for the experiment, which is controlled by the Web portal. In addition to that, a user chat option is available, for exchange of information, comments, questions and guidelines. The Graphical User Interface (GUI) is illustrated in Figure 2.

Furthermore, virtual reality equipment, such as a Head Mounted Display

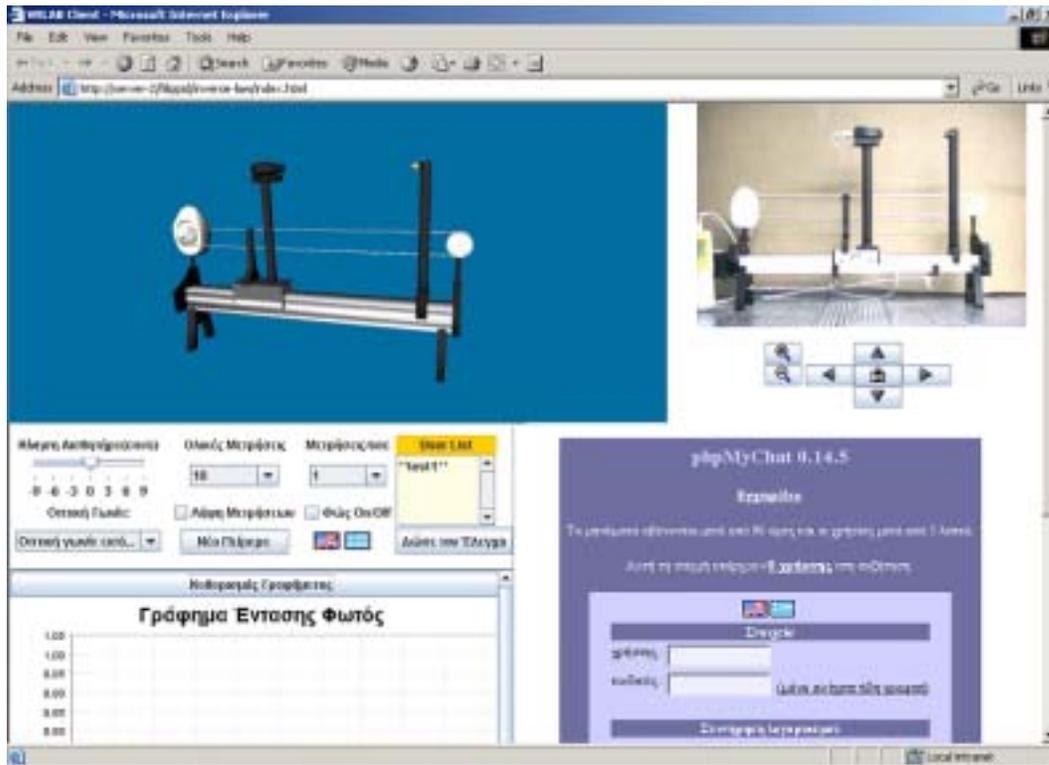


Figure 2: VRlab User Interface

are also supported and used, if available, in order to immerse the user into this virtual experiment environment, aiming at providing the user with a more “vivid” display of the experiment progress. Finally, a virtual guide system is currently under development to provide help for the user. This system will consist of a speech synthesis module using a text-to-speech synthesis system that supports the Greek and the English language and a facial animation reproduction module, which is based on the synthesized speech. After the user has activated the virtual guide, help can be provided (e.g. when the user clicks at an object or the mouse is over a hot-spot).

The use of the 3-D representation, as also confirmed by the first reactions of the students to the system, has significant advantages:

- allows observing the experiment from different angles,

- provides user-friendly access to additional information and data about the experiment and all instruments that are used. Furthermore, hyper-links to Web pages that offer additional related information can be also defined.
- permits automatic notice for bad manipulations or about important results, when conducting the experiment.
- leads to easy and user-friendly interaction with the experiment.
- is very impressive and thus stimulates the interest of the students.

2.3. THE WEB PORTAL

The Web portal, designed and developed so as to support and integrate the basic client-server system, consists of the following subsystems:

a) *Subsystem for user account management*

This system allows the user to safely log-in to the system and access a number of functionalities such as:

- Access to running simulations and reading the available multimedia information content (videos, presentations, hyper-links etc).
- Participation in user forums for exchange of information and questions related to the experiments,
- Access to the time-scheduling sub-system for conducting experiments

b) *Time-scheduling sub-system for conducting experiments*

A time-scheduling sub-system was designed and implemented that controls when and for how long each user can conduct or observe an experiment. More specifically, the following functionalities are supported:

- View of the experiment performance schedule, so that a user can find a convenient time slot to perform a specific experiment,
- Submission of request for performing an experiment at a specific time slot

- Receipt of the special password that allows conducting the experiment at a specific time slot.

c) *Implementation of experiment simulations*

Although, as discussed above, the client software will allow the user to perform off-line simulations of the experiments, to obtain theoretical results, the Web portal can store some of these simulations to be used as a demonstration and introduction of the system to new users.

d) *Implementation and maintenance of User Forum, provision of theoretical and scientific support material (e.g. images, video, spreadsheets, etc.)*

A User Forum system was implemented to allow off-line communication between users and exchange of views and questions about the experiments. In addition, rich material about the experiments will be made available (theoretical textbooks, user manuals, related videos, hyperlinks etc.) to the portal users.

3. THE SUPPORTED EXPERIMENTS

The experiments and simulations have been selected from heterogeneous fields (physics, personal computers), so as to investigate the usability of the system in different knowledge fields. The selection of the experiments that were implemented within the proposed project has been done according to the following criteria:

- significant technical and methodological degree of difficulty
- potential health risk
- required expensive equipment
- are included in the detailed educational program of the Greek secondary education
- use sensors and on-line measurements that can be used to create graphs
- the transmission of video from the camera is useful and necessary

- the performance time of the experiment is neither extremely small, and thus it can be well adapted within a laboratory course, nor extremely large, in order not to increase significantly the required network bandwidth.

Based on the aforementioned criteria, the following four experiments have been selected to be implemented, for the system's trials within this project:

3.1.GAS LAWS

The experimental setup of the server contains a container with a piston, relaxation valve, heat source and temperature, pressure and distance sensors. The remote controller can modify the volume, pressure or temperature of the air inside the container and record the corresponding measurement values. The experiment cannot be easily conducted at the school, since a complex setup is required with calibration adjustments that are critical to the outcome of the measurements.

3.2.INVERSE LAW OF LIGHT INTENSITY

The setup includes a light source, a light intensity sensor and a distance sensor. The remote controller can vary the distance of the light source to the sensor and measure the intensity of the light versus the distance from the sensor.

3.3.STUDY OF THE MAGNETIC FIELD OF A COIL

The setup includes a tubular coil or a Helmholtz coil with the necessary power source (AC or DC) and a Hall sensor or another small (induction) coil. The remote controller can move the sensor to various locations in the magnetic field and record its intensity with respect to the distance and the intensity of the current that runs in the coil. The experiment cannot be easily conducted in schools, due to the the required high-cost equipment used.

3.4.DIGITAL DESIGN SIMULATION

Along with the aforementioned real-time remote experiments and in order to demonstrate the use of Virtual Reality technologies in e-learning applications, CERTH/ITI developed a Digital Design simulation in collaboration with

the Information Technology Department of the Higher Technological Institute of Thessaloniki. The scenario includes a set of VLSIs, and a matrix for their integration. The user has to interconnect chips together, to implement specific logical functions. The system provides continuous feedback while the user makes the necessary connections.

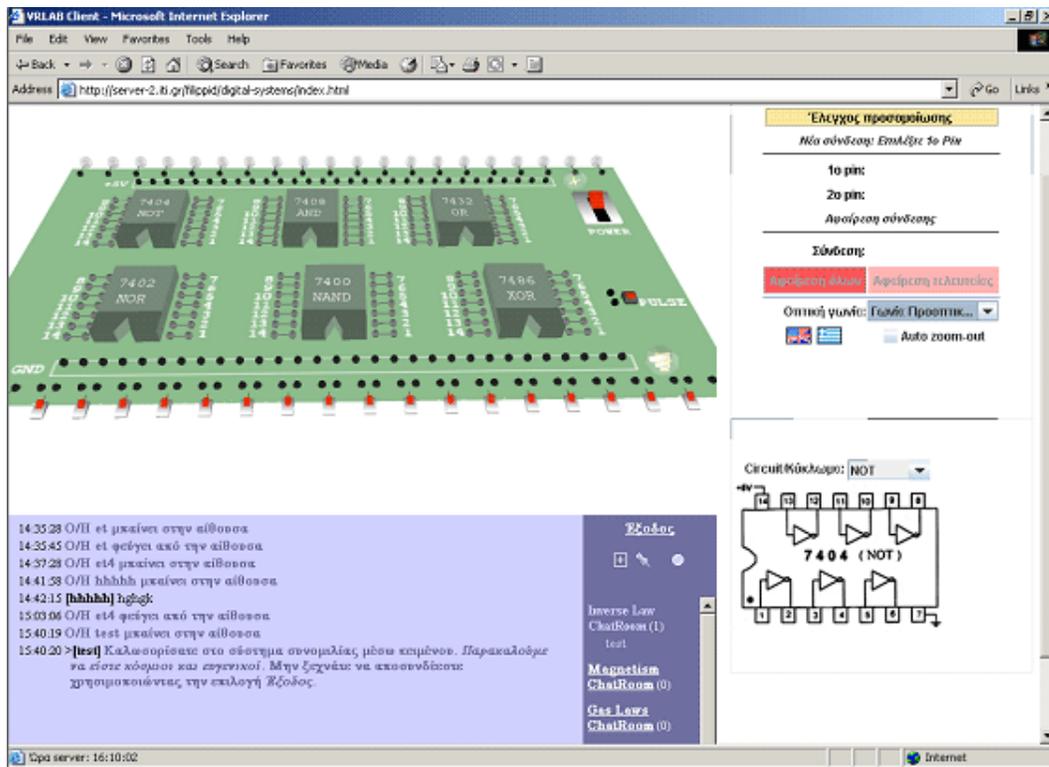


Figure 3: VRLab Digital Design Simulation

In the future, the system can be relatively easily modified in order to support more experiments.

4. EXPERIMENTAL RESULTS

All systems described above are currently in the final stages of development. A server station supporting the four aforementioned experiments has already been installed in the ITI-CERTH facilities and final testing is planned

for September-October 2005 using the students of the academic institutions involved in the project. Additional information about the system as well as working demos can be found at the project's Web page: <http://vrlab.itl.gr>.

5. CONCLUSIONS AND FUTURE WORK

The wide use of computers in the secondary education and the introduction of new technologies in teaching, in combination with modern pedagogical perceptions, which focus on the inquiring learning, the solution of problems and the procedure of making decisions have a significant effect on the teaching and learning procedure and tend to change the traditional way of the educational practice [14]. Within this context, the educational software is connected directly with the renovation of the teaching methods and the design-development of educational software constitutes a priority of great importance, which is combined closely with the general educational plan and programs of studies [15].

A lot of efforts for the development of Greek educational software of high quality have been made in the last years. These efforts aimed to cover the gap of the Greek educational software and had the support and the guidance of the Ministry of Education and the Pedagogical Institute [16]. However these efforts include mainly providing multimedia educational material, development of 3-D Virtual Reality learning environments and the development of experiment simulations.

VRLab was designed and implemented to promote the coordinated use of Virtual Reality technologies along with video streaming and remote control combined through a web interface in order to provide a new approach to multi-user remote experimentation for educational purposes. We firmly believe that we fulfilled the goals set for this project and developed an innovative system that goes beyond any previous remote experimentation system by combining VR technologies with more conventional e-learning methodologies and tools, thus creating a new approach to e-learning.

Now reaching its final stages in development, the pilot system is ready to be evaluated by students and teachers from the participating educational institutions as well as from other interested parties.

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REFERENCES

- [1] T. A. Fjeldly and Michael S. Shur, Editors, *LAB-on-the WEB. Running Real Electronics Experiments via the Internet*, John Wiley and Sons, 2003, <http://nina.ecse.rpi.edu/shur/remote/>
- [2] E-lab, Portugal, <http://www.e-escola.pt/>
- [3] I-Lab, Chalmers University of Technology, Sweden, <http://www.ic.chalmers.se/ilab/>
- [4] Internet Remote Experimentation, National University of Singapore <http://vlab.ee.nus.edu.sg/intr.html>
- [5] ITS Laboratorium, Blekinge Institute of Technology, Sweden, <http://www.its.bth.se/distancelab/english/>
- [6] UniK University Graduate Center, Kjeller, Norway. <http://www.lab-on-web.com/>
- [7] RETWINE (REmoTe World-wide Instrumentation NETwork), <http://micro.fu.uam.es/retwine/html/gb/home.php3>
- [8] Ruhr-University Bochum, Germany, <http://vclab.esr.ruhr-uni-bochum.de/>
- [9] VirLab, University of Hagen, Germany, http://prt.fernuni-hagen.de/virtlab/info_e.html
- [10] WebLab, MIT, USA, <http://weblab.mit.edu/>
- [11] Remote-Lab, Germany, <http://remote-lab.ld-didactic.de/>
- [12] Science On Line, Israel, <http://www.science-on-line.com/>
- [13] Cyberlab, Norway, <http://www.cyberlab.org/>
- [14] Vassilis I. Komis, *New Technologies and Education: Approach through the study of students representations, notes for the lesson Teaching of Information*, Department of Computer Science, University of Crete, October 1996
- [15] G. Papadopoulos, A. Gogoulou, E. Gouli and E. Xousou, *General Specifications of Educational Software*, Minutes: 2nd Conference The Information in the Secondary Education, Economic School of Athens, 4-5 December 1998.
- [16] X. Zagouras, Greek Educational Software Projects, *Minutes: 2nd Conference The Information in the Secondary Education*, Economic School of Athens, 4-5 December 1998.

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