

## A NOVEL APPROACH TO REMOTE LABORATORIES

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**Abstract** - Remote laboratories are becoming widely accepted in universities for providing distance education and for augmenting traditional laboratories. There is a lot of interest in remote laboratories from pedagogical point of view. In this paper, a novel technique for establishing remote laboratories is presented. The technique used and tools developed are extendable for the provision of different laboratory applications. Central to the idea is an experimentation server designed using a core web technology called the "Web-Kernel" which provides a common access point for remote experiments. The server supports a number of analog/digital interface cards as well as allowing access to a number of modern laboratory instrumentation including oscilloscopes and signal generators. The web-kernel provides access to web sessions over the Internet from remote student workstations and allows fast, reliable and efficient development of applications. It is expected that the realistic facilities provided within the system will allow it to be used in engineering education.

*Index terms* - Remote laboratory, web experiments, distance learning, pedagogy.

### INTRODUCTION

Engineering education necessitates the use of laboratories for measurement, data collection, analysis and design activities as well as for hands on experience of equipment, physical devices and for empirical evaluation. Local laboratories are the traditional way of doing experimentation, understanding the theory and relating it to real world. Neither a virtual environment nor remote access can replace its function. The best experience is working and feeling in a real laboratory. That is what Aktan et al. [1] put forward and is approved by many scientists. They evaluated their remotely controlled/accessed Control Laboratory as "Second Best to Being There" (SBBT).

Disadvantages like fixed time and place, limitation on the number of equipment sets and hence the number of students who can use them, the need for some rare or expensive equipment are viewed as reasons for thinking of alternatives. The distance education concept has been put to use in many universities around the globe. This itself was enabled by developments in cheap computing power and widespread availability of data communication technology. Even though local laboratories are still the most widely used

technique for experimentation, the ideas of remote access to laboratories and virtual instrumentation were developed. Although there is still a lot of debate about the place of such tools in engineering education, it is obvious that a number of potential uses and benefits exist.

Fast processors, advanced computer graphics and visual programming technology have made computer simulation and visualization a reality on desktop machines. Virtual laboratories rely heavily on this technology and can be accessed locally or using networks. Virtual instrumentation is also a relatively recent development that allows the mimicking of real equipment and can be used in data collection, analysis and interfacing to real equipment. However, it is very expensive and time consuming to mathematically model many systems which is the first step in developing a simulation environment. Especially, making the simulation close to real is extremely complex since one needs to take care of many inner and outer parameters. Moreover, simulations are artificial and they cannot instill the sense of reality in the learner [2].

The above disadvantages of the virtual or simulation environments have led to the concept of remotely controlled and accessed laboratories called the online or remote laboratories [6]. Remote laboratories are software environments that run experiments by interacting with real devices, which allow remote users to communicate with measurement devices and experimentation setup to make experiments on a real system. Hence, remote laboratories are a synthesis of the "distributed and interactive nature of virtual laboratories" and the "reality of local laboratories". Mathematical modeling in the virtual/simulated system is interchanged with real experimentation, hence, reducing the cost of implementation. Remote experimentation may also develop skills like remote control and remote maintenance that may be quite useful in control or data communication courses [3].

The application areas of remote laboratories are:

- **"Shared" remote laboratory:** When laboratory equipment is very expensive and only one such unit is available at a distant university, remote laboratories may be established in order to access that equipment [2-9].
- **"Localized" remote laboratory:** In a university one can establish a laboratory that can be accessed over the Internet to perform experiments in a relaxed and time-free environment. It may also be applied to allow

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students to repeat/catch up a laboratory session that has been carried out earlier.

- **“Distant” remote laboratory:** remote laboratories can also fill the absence of practical sessions in distance education [6-7].
- **“Technical review” laboratory:** This type of laboratory allows industry professionals to test and evaluate new instruments and devices. They form an alternative for workshops, which are the traditional ways of evaluating hardware and software. The only commercial application that we came across during our survey is a good example of this type [10].

### DESIGN OF REMOTE LABORATORY SYSTEM

The main idea behind establishing a web enabled remote laboratory (R-Lab) is to enable students or learners to conduct laboratory experiments at a distance from the actual experimental setup. Access could be from anywhere where web access is possible. An additional objective is to free experimentation from fixed time limits and allow repetition. Table 1 lists the main advantages and disadvantages of such a system.

#### System

The system comprises of five essential components that are listed below. Figure 1 depicts the system view of R-Lab.

1. *Client stations:* these are PCs with access to the Internet. They can be home PCs or Lab PCs allowing access from either remote dial-up or campus laboratories. Their main software need is the ubiquitous web browser.
2. *Internet:* access through the Internet or the campus backbone is necessary to the experimentation unit through the R-lab server.
3. *R-Lab server(s):* one or more R-lab servers may be used to provide access to the experimentation units. At the core of a R-lab server is the Web Kernel software [12] which is developed for easy web application service (WAS) development. This is a key concept in developing flexible and expandable remote laboratory applications.
4. *Experimentation unit:* using purpose designed experimentation units one or more experiments may be supported at a time through each server.
5. *Instrumentation unit:* Instruments needed to conduct the experiment as well as provide real-time measurements form the instrumentation unit.

The prototype system uses a simple-minded approach to demonstrate the capabilities of the designed system. Both the experimentation and the instrumentation units are designed with minimal functionality in order to achieve speedy results. However, potential applications and expandability of the system are demonstrated.

### Hardware and Instrumentation

The hardware requirements of R-lab in terms of the experimentation and instrumentation units are dependent on the type of experiment to be conducted. Power supply unit, signal generator and oscilloscope are typical electronics laboratory instruments. They may be augmented or changed based on the type of the experiment needed to be set-up. The main requirement is that the measuring device be accessible via some well-known interface (e.g. serial/parallel port, GPIB or Ethernet) for control selection and setup, as well as remote data collection. Oscilloscope used in Figure 1 allows such remote access and control.

The existing experimentation unit (circuit) design is for the electronics course laboratory experiments. However, the R-lab approach allows any type of experimentation to be developed. A key component of the experimentation unit is the “switching matrix”. This is an electronic circuit built

TABLE I  
COMPARISON OF LABORATORY TYPES.

| Feature   | Real Lab Experiment   | Remote Lab Experiment  | Virtual Lab Experiment               |
|---|---|--|--------------------------------------|
| <b>Hands-on experience</b>                          | There is nothing like a real-experiment   | Very close to reality  | Completely virtual                   |
| <b>Feeling of reality</b>                           | High  | Reasonably high (if a camera used)   | Low                                  |
| <b>Feeling of and actual control</b>                | High  | Reasonably high  | Reasonably high                      |
| <b>Freedom of configuration and experimentation</b> | Open-ended experimentation is possible. Limited by lab facilities                 | Limited by pre-configured options.   | Limited by programmed possibilities. |
| <b>Tutor support</b>                                | Usually present during lab or office hours  | Students can e-mail questions. Pedagogical assistants or wizards may be built in.  | Student can e-mail requests          |
| <b>Technical support</b>                            | Technician availability   |  |                                      |
| <b>Access times</b>                                 | Limited to semester timetable   | Limited by set-up configuration  |                                      |
| <b>Access limits</b>                                | Students complete experiments in a lab period. They may have rolling lab periods. | No limits; queued access when other users are conducting experiments   |                                      |
| <b>Supervision</b>                                  | Lab assistants may be present for questions                                       | E-mail enquiries and discussions using chat software   |                                      |
| <b>Progress check</b>                               | Submitted reports can be checked throughout the semester for lab-mark assignment  | Academic staff may have software access to monitor student progress, and reports on student access or performance etc. may be sent |                                      |
| <b>Pedagogical enhancement</b>                      | Traditional   | Suitable for local/distance learning. Pedagogical enhancement through web links, animation and virtual reality software.           |                                      |

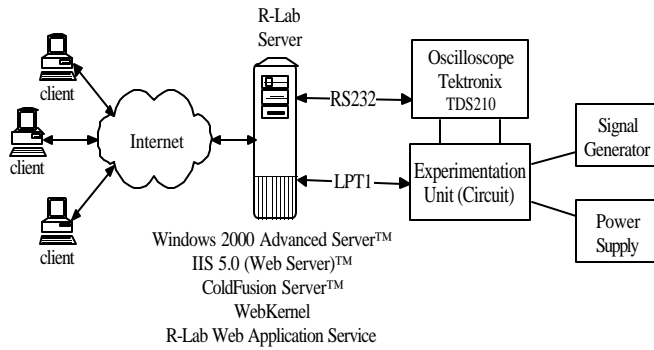


FIGURE. 1  
SYSTEM VIEW OF R-LAB.

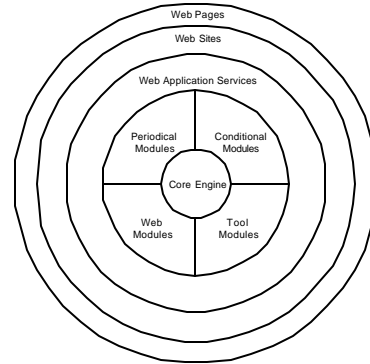


FIGURE. 2  
ONION-SKIN VIEW OF WEB KERNEL SOFTWARE.

using bi-directional switches and allows the inter-connection of different components to realize a given experimental configuration. A sample experimental configuration depicting an operational amplifier circuit is used in the prototype set-up. This is depicted in Figure 4 (bottom left hand corner of the diagram) In the prototype experimentation unit the circuit under test is closely linked to the switching matrix and both are produced on a single printed circuit board. In the next phase of development a much more flexible switching matrix is planned to be used for handling different types of circuit and component inter-connections.

**Software**

The R-Lab idea is based on the client-server model of operation. The client system is the traditional PC with a web browser. No other special modules are needed. At the core of the server system is the Web Kernel software [12] which provides all the facilities for Web based Application Services (WAS) development tools and environment. Figure 2 depicts the onion-skin view of the Web Kernel software system. The Web kernel provides all the core functionalities needed from a WAS. This includes the necessary databases and their attachment to the WAS, management of attached modules and inter-module messaging. It also has facilities for event queuing and management. Interfacing to the Web Kernel is also a very easy process; all interfaced unit modules appear as a WAS module for the Web Kernel. Figure 3 depicts the interfacing of Web Kernel software with the associated modules or units. External devices are interfaced using a middleware and driver approach. Hence, the device or model specific commands may be dealt with separately.

In the current example the instrumentation comprises of an oscilloscope (Textronix™ TDS210), power supply and signal generator (see Fig. 1). Only the oscilloscope has intelligent communication facilities with a computer. The software interface module is called the Monitoring Interface Software and is depicted in Fig. 3. The experimentation unit

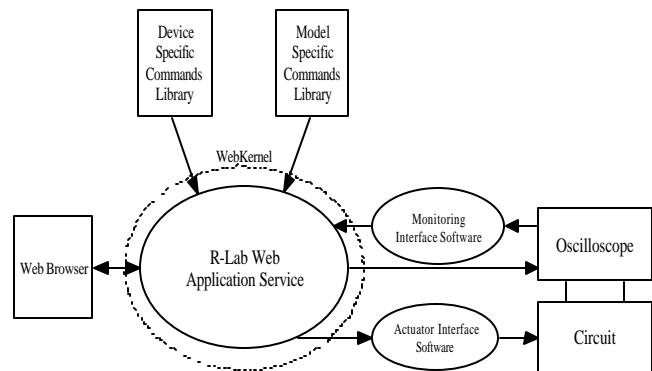


FIGURE. 3  
WEB KERNEL SOFTWARE INTERFACE WITH ASSOCIATED MODULES

(circuit) comprises of a small switching fabric and the circuit for the experiment. All the additional test configurations can be established through different selections from the options using a web interface. The web interface provides a Graphical User Interface (GUI) access to the experiment. The parameters that need to be varied in order to demonstrate a concept, or obtain more output for measurement are provided as selectable items through the GUI (see Figure 4). Any selection made through the configuration panel is transmitted using internal commands from the Web Kernel to the Actuator Interface Software module. This is then relayed as a new input to the switching matrix, which re-configures itself to provide the selected set-up configuration for the experiment. This is shown in Fig. 3.

**IMPLEMENTATION OF R-LAB**

The R-Lab system is implemented as shown in Fig. 1. In the pilot implementation only one experiment from the electronics course is carried out. The user interface and the circuit diagram are shown in Fig. 4. The circuit diagram shown is for the electronics experiment considered. In the

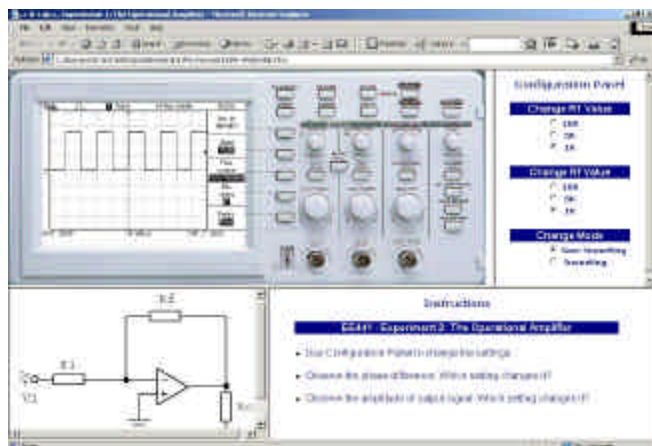


FIGURE 4  
USER INTERFACE OF R-LAB.

production model, a video camera is to be used to relay the actual experimentation view from the laboratory [11]. This will form a “reality” check for users. This is left for further work and will be an improvement on the pilot implementation.

It can be seen that the student is allowed to carry out the operational amplifier (op-amp) experiment using the given configuration but is able to change the circuit elements through the Graphical User Interface (GUI) provided. This is achieved through the configuration panel of the GUI; e.g. the feedback resistor  $R_f$  can be set to 10K, 5K, or 1K ohms value. Instrumentation (in this case the oscilloscope) controls are remotely accessible through the GUI. Further, the measured values are received back at the Web Kernel and relayed to the display area on the user terminal (PC monitor). The current set of instrumentation and experimentation controls are adequate but further extension of these capabilities for new instruments is expected through the expansion of the existing “middleware and driver” approach used within the Web Kernel. This is thought to provide one of the most flexible features of the system.

### STUDENT EXPERIENCES

The prototype system has been made available to a number of students from the electronics course. Their initial responses have been very encouraging. The facility has been found to be very useful. Some have even accessed the system from home. Positive views were expressed on the usability, versatility, reality and sophistication of the system. Similarly, there was a desire to have it used for all experiments in the series. One major concern expressed was the slow transmission of graphical images for the results display. This has been noted and a new design is planned for the hardware and software access to the measuring device using a faster interface such as the General Purpose Interface Bus - GPIB (IEEE 488).

### PRACTICALITIES AND PEDAGOGICAL IMPLICATIONS

It is expected that only a small number of different experiments can be conducted using a single switching fabric and experimentation unit. Hence further development is needed in order to develop a full “experimentation server unit (ESU)” for a complete set of experiments that will be needed in a given course. This will then enable the use of such a unit on a programmed delivery basis for experiments for a whole semester. Multiple course laboratory sessions can then be served through the use of multiple ESUs. The use of the Web Kernel means that it may easily be programmed to allow access to laboratory experiments in a timed fashion. The timetable of usage for each experimental session can be stored in a timetable-database.

A web based remote laboratory facility will not replace the real hands-on experience of engineering students. It can however be used to supplement laboratory hours, to allow more time for students to familiarize themselves with past or future experiments, as well as to learn the background to these experiments through the addition of supplementary learning material to the web page of each experiment. Further, it could be invaluable for distance learning courses to be offered in any engineering department. An important addition to the RLab idea will be the use of a student database for access control, study time recording and analysis, placement of tests and quizzes based on on-line progress as well as progress reporting. Sequenced access to different experiments in the series can then be given to each student based on their progress. Additional facilities could be the summary reporting of student access and progress statistics to the course instructor or lab assistant.

### CONCLUSION

The remote laboratory (R-Lab) idea is developed using a novel approach in which it has been defined as a Web Application Service (WAS) over a special software module called the Web-Kernel. In this manner all the facilities from a WAS development environment are made available to the R-Lab application. In developing the design, one of the key concepts has been identified as the generic use of experimentation interfacing modules. This has been achieved through the use of the middle-ware and driver software modules adaptable for each specific experimentation module design.

The idea has been implemented as a prototype over a fully working Web-Kernel software unit. The initial implementation is for the electronics lab experiment series. It is thought that the expandability issue can be demonstrated very easily for other groups of experiments and courses. Integration of experimental units for flexible and realistic use of the experimentation modules is a remaining work item; this is hoped to be reported in future publications.

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