

Virtual and Remote Laboratory Development: A Review

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ABSTRACT

The Internet technology has provided additional teaching strategies, with online education being one of the most exciting enhancements. A particular challenge for online education in engineering is how to extend the traditional hands-on laboratories to the Internet. Currently, there are two approaches to conducting labs online, virtual and remote labs. Virtual lab is based on software to simulate the lab environment while remote lab, by definition, is an experiment which is conducted and controlled remotely through the Internet. These experiments use real components or instrumentation at a different location from where they are being controlled or conducted. There are many emerging technologies which have been used to develop the virtual and remote laboratory. However, there are few papers that review the virtual and remote laboratory development. In this paper, a review of the different online delivery methods for virtual and remote laboratory development is presented. The open research issues and conclusion with possible future directions on the virtual and remote engineering laboratory development is also presented.

INTRODUCTION

The rapid development of Internet technology and its increasing popularity has had an enormous impact on engineering. This technology provides new tools across the range of engineering disciplines; meanwhile, it also facilitates the development of additional teaching strategies, including vivid and interactive ways of illustration, simulation, demonstration, experimentation, operation, communication, and so on (Selmer et al. 2007). Broadband access and data compression allow for the delivery of audio and video streaming of lectures via the Internet. Nowadays, computer and Internet based learning has become an important part of education. The results of the Sloan Survey of Online Learning, "Staying the Course: Online Education in the United States, 2008", shows that over 3.9 million students were

taking at least one online course during the 2007 Fall semester, a 12 percent increase over the number reported the previous year (Allen and Seaman 2008).

A particular challenge for online education in engineering is how to extend the traditional hands-on laboratory settings over the Internet. From the earliest days of engineering education, hands-on laboratories have been an essential part of undergraduate engineering programs (Feisel and Rosa 2005); concepts taught through lectures are often complemented with laboratory experimentations. Hands-on education allows students to experience the backbone of engineering by conducting experiments, observing dynamic phenomena, testing hypotheses, learning from their mistakes, and reaching their own conclusions. With the rapid progress of the microprocessor and communication technologies, more and more instrumentations can be reconfigured and controlled remotely. These new functionalities have been making remote hands-on training via Internet possible. New possibilities in the way lab exercises are performed include the simulation lab environment, the automated data acquisition and the remote control of instruments, all of which are online. Currently, there are two approaches to conducting labs online, virtual and remote labs.

The virtual lab is based on software such as LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench), Matlab/Simulink, Java Applet, Flash or other software to simulate the lab environment. Virtual labs can be used for experiments that would normally require equipment that are too expensive, unsafe (e.g. nuclear reactor) or unavailable. Virtual labs also allow students to repeat an experiment multiple times, giving them the opportunity to see how changed parameters and settings affect the outcome. One of the very important features of the virtual lab is to let the students learn from failures without causing any real damages. Learning from failure is one of the nine objectives for the engineering education laboratory defined by ABET (Feisel and Peterson 2002). The “Virtual Reality Laboratory Accidents” project was developed at University of Illinois Chicago (Bell and Fogler 2001) by using virtual reality technologies such as Virtual Reality Modeling Language (VRML) and Java 3D. It is believed that these accidents will have more impact on users than written rules, even if it is not as much as real accidents.

Remote lab, by definition, is an experiment which is conducted and controlled remotely through the Internet. The experiments use real components or instrumentation at a different location from where they are being controlled or conducted. For example, the University of Houston offers access to their remote laboratory for the Smart Materials and Structures Laboratory (Song et al. 2007). The logistics of tailoring a real laboratory, particularly when dealing with a large number of students, is often a big problem to universities; the requirements for space, instrumentation, and human support are high. Remote laboratories are more suited to handle a large number of students, especially some small in size or limited in availability experiments, e.g. the nanotechnology experiments (Chang et al. 2002).

A large amount of research on virtual and remote laboratory technologies has been recently reported, ranging from LabVIEW and Matlab/Simulink to Java applet, Flash, Ajax and other techniques. Our objective is to provide a deeper understanding of the current technology for online laboratory development, and to identify some

open research issues on virtual and remote laboratory development. Ibrahim and Morsi (2005) compared the different delivery methods for online engineering education; however, there are few papers to review the virtual and remote laboratory development.

WEB-BASED EXPERIMENT FRAMEWORK

The system block diagram of the Virtual and Remote Laboratory (VR-Lab) is shown in Figure 1. The functionality of the server is to work as the web publisher, the lab scheduler, the data and database manager. The workstations are used to execute the users' requirements and control the lab devices such as the National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS) to conduct the experiments. The camera will let the user to see the system response in real time. The users can use the client computers to do the experiments virtually and remotely.

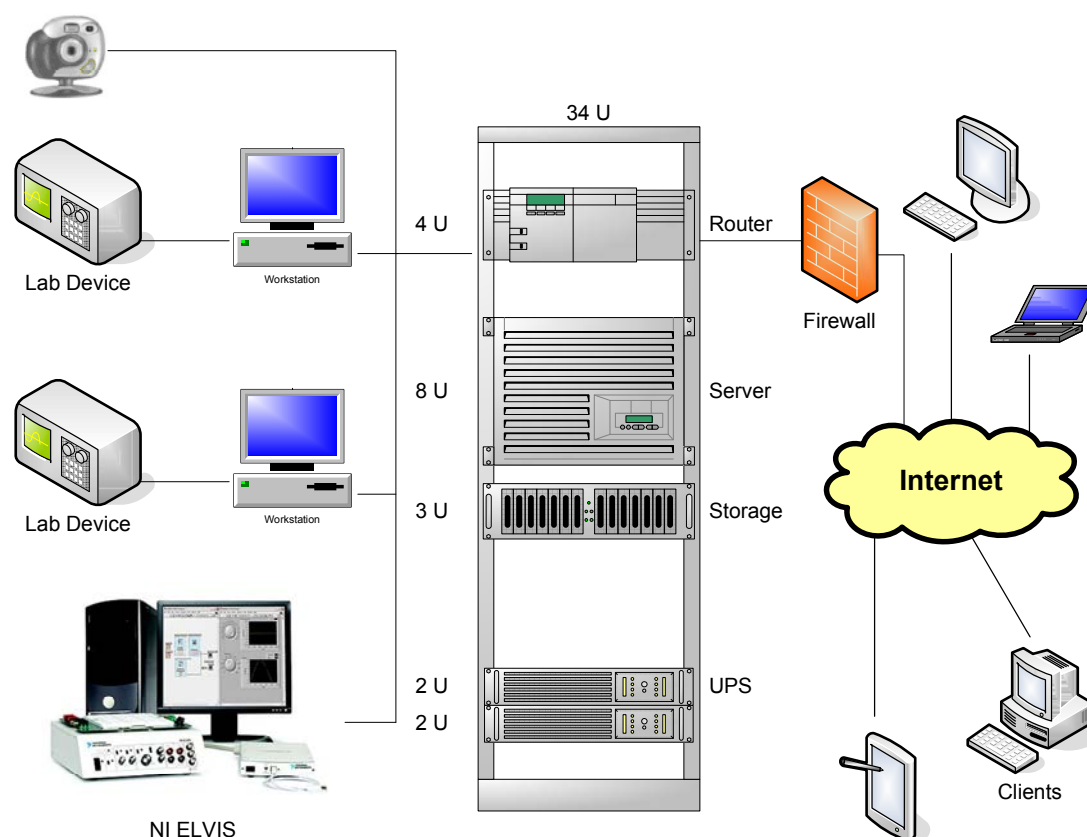


Figure 1. Web-based experiment framework.

VIRTUAL AND REMOTE LABORATORY DEVELOPMENT TOOLS

Java

Java was released in 1995 as a core component of Sun Microsystems' Java platform. It promised "Write Once, Run Anywhere" (WORA), providing no-cost run-time plug-in on popular platforms. Major web browsers soon incorporated the ability

to run secure Java applets within web pages, and Java quickly became popular (Morelli and Walde 2006). Java has been involved in many virtual and remote laboratories since then. A Java Applet virtual lab was created by Chen et al. (2008). This virtual laboratory was for teaching the Resistor Color Code. It has two modes, the learn mode and the quiz mode, the default being the learn mode. In this mode, the user can use the combo box to select different combinations of the color bands. The resistor value is then calculated by Java Applet. When the user picks the quiz mode, the Java Applet randomly generates a combination of color bands, after which the user inputs the resistor value into the textbox. A SUBMIT button is built for users submitting the answer for checking. Röhrig and Jochheim (2000) presented a framework using Java applets in the MySQL database for remote experiments at the University of Hagen, Germany. The developers developed a platform for setting up the remote experiments. A similar Internet based control engineering laboratory was later developed by Wu et al. (2006) that used Java applets to control a servo motor, inverted pendulum, coupled tank and fan-plate systems for the Zhejiang University, China. The control algorithms are implemented on PC-based or embedded microcontroller-based control servers. However, the developer developed the remote laboratory for some experiments but did not develop a standard framework so that others can use that framework and develop other experiments from different disciplines. Also, to run the remote experiments, the users had to install Java Runtime Environment (JRE). And the client does not communicate strictly by web based protocols and ports. Firewall transparency is, therefore, not possible.

Flash

A big advantage of Flash is that there is practically no browser compatibility issue. Since Flash files are only viewable with a plug-in, Flash will work the same when the user is on Firefox or Safari or IE, on Mac or PC. Flash has found a lot of applications in virtual laboratory design. A virtual microscopy was developed with Flash at the University of Delaware (Barrett et al. 2009). However, few people report using Flash for remote laboratory design. One of the Flash based remote laboratories was developed at the HAMK University of Applied Sciences, Finland (Goffart 2007). A Flash interface was developed for the Programmable Logic Controller (PLC) control and real time PLC data display.

VPN

The work by Eslami et al. (2008), an online operation of a remotely controlled PLC unit is presented. Software including Remote Desktop and Virtual Private Network (VPN) has to be installed in the client computer.

XML

XML stands for EXtensible Markup Language (Bray et al. 2008). It is a markup language much like HyperText Markup Language (HTML). However, XML is not a replacement for HTML; XML was designed to transport and store data, with the focus on the type of data. HTML was designed to display data, with focus on how the data looks.

A XML-based remote control lab and electronic laboratory were reported by Pastor et al. (2005) and Bagnasco et al. (2005), respectively. Both of the works used XML to write the experiment configuration file; a Java enabled web browser was required to operate the experiments. The XML-based approach allows educators to create new Internet-based labs using legacy code (Pastor et al. 2005).

Matlab/Simulink

Matlab and Simulink are common tools in engineering and technology degrees in most universities. The Matlab environment, the Simulink toolbox and the Real-Time Workshop toolbox enable educators and students to focus on system design, implementation, and evaluation rather than on time-consuming, low-level programming. In Schmid (2001), a virtual laboratory which uses Matlab/Simulink for simulations using virtual reality is presented. In Casini et al. (2001), an Automatic Control Telelab (ACT) using Matlab/Simulink and Java servlet (interface) was developed. In Sánchez et al. (2004), a Matlab/Java based remote control system experiment for an inverted pendulum is presented. In their approach, they were using Matlab software with WinCom from Quanser as an interface.

LabVIEW

National Instruments' (NI) LabVIEW is popularly deployed software for academic and industrial application. It is easy to control a real time process with NI's graphic interface, hardware and drivers. DataSocket, an Internet programming technology included in the LabVIEW package, simplifies real time data exchange among computers connected through network (Edwards 1999; Edwards 2000). DataSocket is designed specifically for sharing, subscribing, and publishing real time data to multiple clients where a Uniform Resource Locator (URL) is used by the users to connect to a data source location in the DataSocket server. It provides the capability of the remote laboratory system to be accessed by multiple clients to do different experiments simultaneously.

In Chang et al. (2002), Yang et al. (2005), Cotfas et al. (2006), just to name a few, LabVIEW and DataSocket based remote laboratories are developed. To bring the expensive and availability limited nanotechnology experiments into class, a nanopositioner control experiment for a senior undergraduate class is reported in Chang et al. (2002). Even with the graphic programming language, DataSocket, Internet Toolkit and other techniques provided by NI, the developers still need to take a lot of efforts to develop a remote laboratory. To simplify this procedure, a software prototype named Remote Lab Generator (RLGen) was proposed by Hasnim and Abdullah (2007). Based on the experiment design and the HTML documents for the experiment, RLGen will auto-generate the student's website where the student will then take the experiment through Internet. However, the RLGen did not solve the known compatibility issues of the ActiveX that is used for measurement and control purposes with the NI LabVIEW.

One of the well developed remote labs is the Massachusetts Institute of Technology (MIT) iLab (Harward et al. 2008). iLab relies on a three-tier Web architecture including client applications, service broker and lab servers (Harward et al. 2008). However, some of the iLab control interfaces are based on LabVIEW and

the user interface is based on ASP and ASP.NET web pages for web publishing. LabVIEW generally leads to version compatibility problems when updated and both ASP and ASP.NET pages are proprietary and only compatible with Microsoft Windows servers. The adaptability to other operating systems (Linux and Mac) and web browser is still not guaranteed.

Web 2.0

The term “Web 2.0” first became notable after the O'Reilly Media Web 2.0 conference in 2004 (O'Reilly 2005). Web 2.0 is not any updated technical specification as one might think. It also does not represent any great technological advancement, since most of the technologies have been around since the early days of the commercial Internet. Web 2.0 refers to a perceived second generation of web development and design that aims to facilitate communication, secure information sharing, interoperability, and collaboration on the World Wide Web (Wikipedia 2009b). Web 2.0 has been widely applied in the last few years as the Internet continues to develop and mature. Examples of Web 2.0 web sites are Wikipedia, Gmail, YouTube, and Facebook. One of the rich media techniques used to develop Web 2.0 web site is Ajax; one successful example is Gmail.

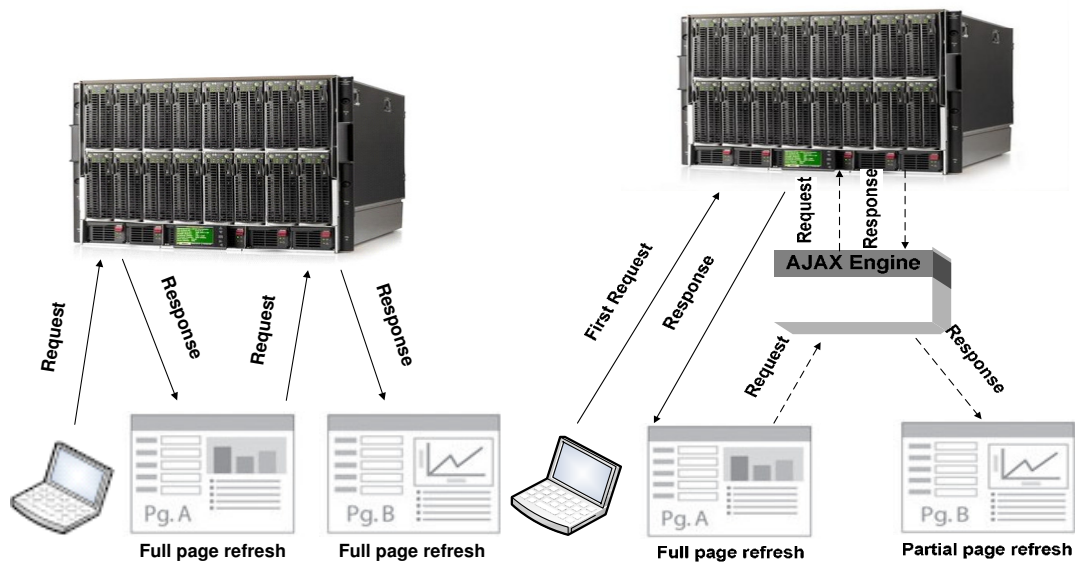


Figure 2. The traditional web traffic. Figure 3. The AJAX web traffic.

AJAX stands for Asynchronous JavaScript and XML (Wikipedia 2009a). Ajax is a development technique that mixes (X)HTML, JavaScript, Cascading Style Sheets (CSS), Document Object Model (DOM), XML and XSL Transformations (XSLT) to create interactive Web applications. XML and XSLT are for the interchange, manipulation and display of data, respectively. XML is not required for data interchange and therefore XSLT is not required for the manipulation of data (Wikipedia 2009a). If one does not use JavaScript and/or XML, the acronym AJAX has thus changed to the term Ajax. JavaScript Object Notation (JSON) is often used as an alternative format for data interchange if the XML is not used for data

interchange. The traditional web traffic flow is shown in Figure 2. When using AJAX, the page is loaded entirely only once, the first time it is requested. Not including the HTML and CSS code that make up the page, JavaScript files in some of the AJAX engines are also downloaded. All requests for data to the sever will then be sent as JavaScript calls to this engine. The AJAX engine then requests information from the web server asynchronously. Thus, only small page bits are requested and sent to the browser as they are needed by the user. The engine then displays the information without reloading the entire page as shown in Figure 3. This leads to a much more interactive and responsive interface because only the necessary information is passed between the client and server, not the whole page. This produces the feeling that information is displayed immediately, which brings web applications closer to their desktop relatives (Alikonweb 2007).

Using Web 2.0 concepts to design remote laboratory interfaces is relatively new to the web-based engineering lab designer. A work was reported by de Ipiña et al. (2006), where transforming a conventional WebLab into a Web 2.0-enabled application was described. Since Ajax was used in their remote lab design, fragments rather than the whole web pages are updated after user interaction. Therefore, the amount of data transferred between web server and client application is reduced dramatically and thus it is very suitable for the mobile domain.

OPEN ISSUES AND FUTURE DIRECTIONS

There are lot of virtual and remote laboratories developed with LabVIEW, Java Applet and Flash. LabView is a graphic programming language. The laboratory experiments based on the VI concept can be easily made ready for Internet delivery. A LabView Run-Time Engine must be installed on client side, but it has compatibility issues between the different versions. Java applet and Flash are becoming more popular. Most of the PC distributors have preinstalled software for the users, but Object Orientated programming skills are required for the virtual and remote laboratory development (Chen et al. 2009). From the perspective of users, the plug-in, platform and operating system compatible are big issues.

To develop a remotely accessible laboratory, the developers have to master computer hardware and software, data digitization and collection, data transmission and visualization, and network. An engineering education laboratory developer usually has expertise in their research field, but not necessarily in remote laboratory development. The development of a unified user friendly remote laboratory publishing tool for laboratory developer is in great demand.

In the remote laboratory setup, the end users use a thin client (web browser) to run experiments. Compared to desktop application based on thick clients (also called a rich client or a fat client), the first generation web browser (Web 1.0) is less interactive. Consequently, many technologies have been developed (and are still being developed) to add accessibility and power to web applications. Notable examples include Java applets and Flash, which require the users to install separate runtime engines into their web browsers. Web 2.0 websites allow users to do more than just retrieve information. They can build on the interactive facilities of Web 1.0 to provide Network as Platform computing, allowing users to run software-

applications entirely through a browser (Wikipedia 2009b). Web 2.0 sites often feature a rich, user friendly interface based on Ajax, OpenLaszlo, Flex or similar rich media (Wikipedia 2009). Bringing the web 2.0 technology to develop a lightweight, more interactive and responsive remote laboratory is a new challenge to remote laboratory developers.

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