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Remote Experimentation for Communication: from Remote Desktops to Gateways

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Abstract

With continuous development of information technology and mature communication channels through the Internet, remote labs may potentially overcome many constrains faced in hands-on laboratories (e.g., minimizing expenses, providing flexible lab schedule, and sharing limited resources among multiple students). This paper presents a comparative study among three different remote lab implementation options, which include all the unique solutions used in simple-to-sophisticated system development. The testbed is eComLab, a radio-communication remote laboratory system developed by the authors; it has been used in several courses at the department of Electrical and Computer Engineering, the University of Texas at San Antonio (UTSA). The implementation options are discussed as various evolutorial stages of the eComLab, which evolved from a simple single-user remote desktop application to a multi-user system architecture that operates as a gateway connecting four remote sides: (1) PC-controlled experiment, (2) users such as students, (3) instructors and (4) system administrators. In its latest version, users may utilize a regular web-browser to access remote experiments. The system provides various handy functions and enables group work capabilities. The paper also provides intervention data in the classroom through the analysis of surveys collected among students.

1. Introduction

Nowadays, laboratories that work with hands-on experiments are among the core components of engineering studies. Hands-on experiments help efficiently digest theoretical concepts and train students to rely on the facts according to physical evidence. On the other hand, high equipment cost and the lack of the necessary maintenance and assistance have led to reduced importance of hand-on laboratories on the curriculum. Software simulators, based on mathematical models, can be an alternative method to replace the traditional hands-on laboratories; however, the valuable pictorial element is removed from the practical learning processes.

The continuous progress of information technology combined with the increasing stability of the Internet provides a potential environment for Web-based remote applications. A web-based remote laboratory application can overcome various difficulties and limitations in offering hands-on training (i.e. minimized expenses, flexible times, and resources sharing among students).
students). Unfortunately, only physical experiments, which have PC-controlled features can be implemented in remote settings, which limit the conceptual applicability of the specific educational areas such as radio-communications. One of the main design challenges is to establish an architecture that can provide adequate access to the remote hardware in the remote laboratory development. Hardware that generates real time signals is the core factor in the remote laboratory architecture, while software is the alternative hardware management component, which provides connection between the user orders and the hardware. In addition, a software layer provides a Graphical User Interface (GUI) where the experiment results can be visualized.

The simplest remote laboratory may be a single user, one-by-one experiment that reports feedback data of visualized measurement results from the hardware. Moreover, more sophisticated systems may handle several experiments with different apparatus and manage multiple user accesses.

Currently, several academic institutions provide different Internet-based laboratories (e.g. AIM-Lab [1], ReLOAD at University of Leeds [2], and remote lab at UTS [3]) with different physical experiments from various topics of engineering. In AIM-Lab, the user (client) connects to the experiment to control the hardware with proprietary software. This proprietary software plays an intermittent role between the experiment and the user. As for the scopes of the system infrastructure, ReLOAD has been designed as a gateway server, which connects multiple experiments with the central management server through the Internet by LabVIEW web server with a static IP address. However, the system architecture in UTS lab integrates central management server and experiments with isolated interfaces by utilizing virtual machines. Virtual machines are located in the central management server, which is considered as experiment PCs connected to experiment hardware. The discussed remote labs have GUI features to assist the users. For example, the UTS lab provides video streaming and chat function in the experiments, while the ReLOAD supports the video feature only.

The eComLab system’s architecture has been developed in three generations (simple-to-sophisticated) — conventional remote desktop, server-centric, and server as the gateway architectures. In this paper, we present the technological solutions used in each eComLab generation. Each eComLab generation development has been driven from the previous generation’s defects. During the development, we had to come up with several solutions to overcome these defects. All these solutions are presented in further sections.

The latest generation of eComLab is based on the gateway architecture, which connects multiple instructors, experimental equipment, and users from different locations via Internet.
The GUI of the current eComLab platform includes several handy features, which help users interact (chat rooms) and monitor the hardware with real-time video stream through the motorized Web-camera. The eComLab uses the NI ELVIS [4] /DATEx [5] telecommunications bundle as the hardware-based experimental equipment. eComLab is a very flexible platform, and it is capable to connect new educational experiments (hardware laboratories) directly to a gateway (central) server, or from remote locations. This platform allows multiple users to access and operate with the same experiment simultaneously by following two parallel (the queue and the group policy) methods. Finally, the eComLab is accessible through a regular Web-browser with Java and Flash plug-ins, which eliminates the necessity to install any additional hardware driver in the user computer. The detailed information about the different eComLab generations is discussed in the following sections.

2. **First Generation of eComLab—Conventional Remote Desktop**

2.1 **Architecture**

The first generation of eComLab [6] is based on a straightforward system architecture that uses conventional remote desktop application (Teamviewer [7]) to connect the users to the experiments. The host computer known as the experiment server is attached to the hardware equipment (NI ELVIS/DATEx). It contains all the necessary software components (NI ELVISE and DATEx SFP) to control the hardware and monitor the results on the host machine. Figure 1 shows the system architecture of the first generation eComLab. The first generation of the eComLab is based on one-by-one communication system architecture. Multiple requests are treated with the first-in-first-out queuing policy, parallel connections are not supported.

2.2 **Graphical User Interface (GUI)**

Figure 2 is a snapshot of the first generation eComLab’s GUI. In this architecture, eComLab uses the TeamViewer as the remote desktop software.

![Diagram of the first generation eComLab's GUI](image-url)
The operation system of the experiment server is Windows XP professional edition. Security polices built in Windows XP have been used to secure the host computer by granting the users access only to the specific list of software.

![Image of eComLab GUI](image)

Fig. 2. The first generation of eComLab GUI

Once the users connect to the host/experiment machine, they have complete control over the experiment-related software. They can manipulate hardware-based experiments remotely. Connection is established using TeamViewer with their corresponding ID and password. In addition, Teamviewer has several handy built-in functions (e.g. chat and file transfer), which can be used during the remote experiment.

2.2 System Review

The remote desktop architecture has been designed as a one-by-one communication scheme, so the first-in-first-out queueing policy is applied to the concurrent connections when multiple users request to access the experiment. Under this architecture, users cannot collaborate with other users to execute tasks in groups. Queued users have no information for how long he/she needs to wait for the experiment. Besides, users are required to install the additional remote desktop software in order to connect to the hardware attached experiment server.

3. Second Generation of eComLab—Centric Server

3.1 Architecture

The second generation of the eComLab was designed to address the defects of the first generation reported by the students. It is a multi-user system based on a centralized system architecture.
In this centralized architecture ([8] and [9]) shown in Figure 3, the central server contains several virtual machines, which are independent host computers and several server management software. It is running Ubuntu Linux to provide the Web interface from an Apache HTTP server, a MYSQL database for storage, and a Red 5 for streaming real-time video. Each virtual machine connected to the experiment machine is attached to experiment hardware equipment with all necessary software installed to operate the hardware.

![Server-Centric architecture](image)

**Fig. 3. Server-Centric architecture**

Additionally, a user management program installed on the central server side is connected to the UTSA Blackboard user database, which simplifies the system access for the students. UTSA students do not need to have extra login information to log in to the eComLab. They simply use their log in information from the Blackboard. After signing in the system, the centric server redirects users to the corresponding virtual machine by creating the link between the user and the selected experiment from the experiment list.

The number of virtual machines that the central server can host depends on several factors: network bandwidth, experimental equipments, central server hardware constarints (e.g., memory size, processor speed, etc.) The eComLab has three virtual machines with ELVIS/Emona DATEx experiment trainer for communication experiments attached. The system was serving a wireless communication class with 25 students.

### 3.2 Graphical User Interface (GUI)

The second generation of the eComLab is an advanced system with a user friendly GUI [9]. The system can be accessed by using any regular Web browser, which makes third part softwares on user machines unnecessary. The remote experiment room in second generation eComLab is shown in Figure 4.

The eComLab GUI provides several handy functions. One of the main system functionalities is a multiuser support. The users are able to log in the same experiment concurrently.
However, only one user can control the experiment, while the others can observe it. The system manages the rotation of the users. The users can monitor their experiment control time or the position in the queue through the status bar. The students have the option to decrease the quality of the image that is being transmitted by the remote desktop through the control bar; this is particularly useful to overcome the bandwidth constraints. Finally, users can observe the experiment hardware through the real-time video transmission, and communicate with each other through the chat room.

![GUI of second generation eComLab](image)

**Fig. 4.** The GUI of second generation eComLab

### 3.3 System Review

In this generation, eComLab has gradually improved. A new central system architecture was built. Users could access the system by a simple Web browser; no extra software was required in the user side. Multiple users could execute multiples experiments at the same time. In addition, users could communicate with each other through a chat room, and all the video of the experiments were transmitted in a real time fashion.

Although, the response collected from the users were very positive. Some users asked for some other features, among them, such as experiment control switch function among the users without the queuing constraints, camera control (i.e. zoom in, zoom out and change the video streaming angle), and a dedicated general discussion board for all users.

### 4. Current Generation of eComLab—Gateway Server

#### 4.1 Architecture

The latest version of eComLab is the combination of the central server and server as gateway architectures. The central server can either host experiment machine or connect experiment machines located in remote locations through the network. The gateway server architecture,
shown in Figure 5, connects four remote sides through the Internet: PC-controlled experiment, students, instructors, and system administrators.

Like in the previous generation, users of the last version of eComLab utilizes a regular Web browser to access the system. All the Web pages are coded in PHP using MySQL database. The remote desktop applet utilizes a modified version of the open source tight VNC [10]. The video streaming application is based on a modified Red 5 [11] player version written in flash.

![Gateway Server architecture](image)

Fig. 5. Gateway Server architecture

### 4.2 Graphical User Interface (GUI)

Different users access different GUI. The system redirects users to the corresponding GUI using the sophisticated user management application after verifying their credentials. Students can only access the experiment list, corresponding materials, surveys, and general discussion board, while instructors are able to manage experiments such as adding or editing the experiments, setting the experiments time and group size, and uploading or editing experiment materials, surveys, and questionnaires.

#### 4.2.1 Student Interface

Once a student logs in the eComLab, he/she can choose the preferred experiment from the experiment list. The main window of the student interface is shown in Figure 6. In the main window of student interface, the students have access to the three main system interfaces: menu, experiment list, and discussion board. With the help of the menu bar, students are able to navigate within the eComLab system. It allows the user to go back or forward from the main Web page to the contacts, the survey, the material area, the discussion wall, and the
experiment area. The user can log off from the system anytime by using the logout button located in the menu bar.

In the survey section, students can complete a short survey, which helps developers to collect user feedback about the system in order to improve it. Experimental materials and tutorial in text or video format are available in the material area. In addition, students are able to see the list of experiments in the experiments area. The eComLab defines the experiment status through special image figures, which are shown in the status column. It informs user that the experiment is free, and it is available for full use if no other user is in the virtual experiment room. The system can also notify the user about what experiment is being used and whether the user can join the group as an observer. When the maximum number of users for an experiment is reached, the eComLab automatically blocks access to the experiment.

The discussion wall in the student interface allows students to post comments or questions for a public view, which can be answered or further commented by all users, including instructors and other students. Besides, the eComLab provides individual walls for all the experiments. The wall link on the right hand side of each experiment (Fig.6) corresponds to

![Main menu of Student Interface](image_url)
the discussion wall. The system automatically changes the discussion wall located under the experiment list once a user points to the wall link.

After choosing an experiment, a user accesses the experiment area that includes the remote desktop application, the real time video, the chat room, the status and the control bars as shown in Figure 7. The remote desktop application is an applet that allows students to control the experiment remotely. This applet periodically communicates with the main central server to check which student has the right to control the experiment, how many users are in the experiment room, and automatically updates the user queue. Note that the system allows only one student to have control over an experiment at a time. However, other students in the virtual experiment room can observe the experiment, the hardware from real-time video streaming, and discuss with others using the built-in chat room.

![Fig. 7. The third generation of GUI](image)

The status bar, located under the remote desktop application, shows the remaining experiment time for the main user, and the user position in the queue with the remaining time to gain experiment control for the other users.

The control bar is composed of four icons at the bottom, next to the status bar. They provide several additional useful functions: remote desktop transmission rate control, quality refresh, full screen mode, and passing experiment control to another user. The last two functions were implemented in order to fix the problems that were reported from generation two by the users. Full screen mode was designed in order to present the users a bigger working area. The experiment control passing function allows a user to pass the control of an experiment to another users, in a way that a group of users can collaborate to execute an experiment together.
4.2.2 Instructor Interface

The instructor’s GUI has been designed to manage the eComLab remotely. The instructor can manage the experiments, academic materials, users, and surveys through a Web browser application. Figure 8 shows the instructor interface's main Web page. Most importantly, instructors can set up new experiments or edit the old ones, set up the number of students in the experiment group, define the list of student names authorized to access an experiment, and the set the experiment duration. Instructors also have access to set up a physical experiment server such as hardware and camera settings. Instructors can also upload or edit tutorials and videos in the academic material area.

In the user area, the instructor is able to manage users such as create or delete users, edit user passwords, and decide whether a user is going to be in the role of a student or an instructor. The instructor can also post messages to students in the wall area, and can reply private messages left by students through the contacts function.

![Administration interface](image)

Fig. 8. Administration interface

4.3 System Review

The current version of the eComLab has improved the defects that arose in previous two versions, and it offers several additional functions (i.e. experiment control passing, full screen, camera control buttons, and administration interface). The significant improvement of the current system is the usage of a central server as a gateway, which connects PC-controlled experiment, students, instructors, and system administrators from remote locations through the Internet.

5. eComLab Questionnaire Results

As described in the introduction, eComLab has passed by three generations: the conventional remote desktop, the central server, and the gateway server. All the three generations have been offered in the Communication classes for both undergraduate and graduate levels at the department of Electrical and Computer Engineering since 2008. In [8], our previous works in
a radio-communication domain with pedagogic concerns have shown that students can have a better understanding of the course after hands-on experiments. We have presented feedback questionnaires for each different version of e-Comlab in a way to evaluate and improve the system. The survey questions have a five-level Likert scale from “Strongly Disagree” to “Strongly Agree”, which corresponds to the answer options. The minimum score is one and the maximum score is five. The questions are classified into three categories: usability, usefulness, and acceptance.

Chart 1 summarizes survey results (mean value) conducted among the 97 undergraduate and 34 graduate students. The three eComLab generations are noted as first (F), second (S), and Third (T). Chart 2 shows the corresponding standard deviation for three eComLab generations.

The mean values of the ‘usability’ category for the first generation is MV=3.78 (F) and for second generation is MV=3.81 (S). As the results demonstrate in this category, the students’ feedbacks have positively increased over the development stages of the eComLab. All the GUI improvements, which were done based on students’ feedbacks, made the eComLab a more user-friend system (MV=4.26 (T)).

Similar to ‘usability’ category, the results of the ‘usefulness’ are also increased from one generation to another. The mean value of survey results in ‘usefulness’ category are MV=3.82 (F), MV=3.82 (S) and MV=3.96 (T). Similar results are obtained for the ‘acceptance’ category MV=3.86 (F), MV=3.91 (S) and MV=4.02 (T). The results in this categories show that all the improvements over the development stages made the eComLab very useful and in general acceptable system.

The standard deviations of the “usability” (SD=0.96 (F), SD=0.95 (S) and SD=0.85 (T)), “usefulness” (SD=1.01 (F), SD=0.97 (S) and SD=0.95 (T)), and “acceptance” (SD=1.17 (F),
SD=1.09 (S) and SD=1.07 (T)) are decreased from one generation to another. The results show that the number of students who answer positively to the survey questions has increased over the eComLab development generations.

Generally, the students’ feedbacks have improved from one generation to another. It also demonstrates that the system improvements based on the user feedbacks were successful, which increased the users’ interest in the eComLab. Besides the sophisticated system architecture, the eComLab was turned into a user-friendly and useful system, which can successfully replace the traditional hands-on laboratories.

![Standard Deviation Chart](image)

**6. Conclusion**

This paper has presented the different generations of eComLab, in terms of architecture, GUI platform, and pedagogical survey concerns. In the current version, eComLab has been implemented as a gateway server to connect instructors, students, and experiment servers from remote locations. It has successfully dedicated the GUI platform with computer-like remote experiments without requiring any additional software or hardware-based driver installations on the user side. All the three generations has been successfully tested since 2008 in the communication classes at the University of Texas at San Antonio.

Finally, pedagogical surveys collected from students show an improvement from generation to generation of the eComlab. Furthermore, this work shows that remote laboratories, like eComlab, are viable alternative to the traditional hands-on laboratories at least in radio communication domain, which may optimally utilize limited resources and provide flexibility to the students in the sense of time and location.
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