eLab - Remote Electronics Lab in Real Time

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Abstract - **The ongoing integration of telecommunications with the learning and collaboration process has enabled many of the engineering projects to take advantage of the remote access to laboratories that it allows. However, most of the remote laboratories today are simulated or else real, but with a fixed configuration. The present paper establishes a connection scheme for real, remote laboratories based in data acquisition systems, their publication for remote access, and the ability to reconfigure, in real time, the components conforming the experiment by using relay matrices and DAQ accessories interconnected by a server. This scheme reduces the needed space for traditional Electronics laboratories, the staff needed to operate it, and the overall cost of equipment required, as well as allowing the lab practices to be customizable, remotely accessed through Internet, and that both the results and the changes made to the circuit be reflected in the measurements in real time.**

Index Terms - Remote Laboratories, Tele-Training, Virtual Laboratories, Distance Learning.

INTRODUCTION

The accelerated pace at which both the computing and telecommunications worlds are advancing, along with their ever increasing availability are creating a new relationship between the teaching process and the way students are learning, thus revolutionizing the way this process is carried out altogether. So, we are bombarded with a countless number of tutorials, online courses, information pages, and network resources almost entirely devoted to the transmission of knowledge. However, the real and practical experience cannot be excluded from this process since it would have a negative impact in the learning process. Likewise, collaborative work and at-a-distance projects are beginning to have more attention in the engineering world. With the integration of telecommunication technologies and computer science with virtual instrumentation, real, remote laboratories can be developed and accessed through Internet in real time, ensuring a richer collaborative experience for the student while avoiding some of the growing limitations of traditional laboratories, such as the lack of enough work area, expensive instrumentation, lack of personnel, time assigned to a laboratory, and their availability in non-working office hours.

To be able to connect the virtual and remote world with a real experiment, advantage can be taken from today's data acquisition (DAQ) cards and their ability to provide a development benchtop for measuring and instrumentation that can be easily connected, controlled, and processed with specialized software. Once a workstation has been connected to a computer, it can be easily controlled with virtual instruments created with the software which, at the same time, can be published into the network and be, not only accessed, but controlled via Internet, allowing for the lab application to be used from any network connection.

In the scheme implemented in the present work, various circuits and experiments were built on the DAQ station, such as power sources, voltage amplifiers, device characterization circuits, and filters; depending on the specific needs of each circuit, a connection to a function generator, variable voltage sources, and digital ports was provided. Given the fact that actual cards have enough analog input ports, multiple measurements in different points in the circuitry can be taken, same that can be displayed in real time in the virtual instruments' screen, giving the student the opportunity to choose from different measurement points, unlike traditional oscilloscopes which commonly provide only two input channels. Besides, thanks to solid state programmable components, an array of these and data acquisition elements was set up to allow the student not only to make measurements in the circuit, but to also be able to make changes in the circuit's components' configuration and connections, all in a real-time, remote, and non-simulated experience.

The overall experience, together with the fact that the process is being taken from a real circuit, the ease-of-use of the graphical interfaces, the remote access from virtually any place and any time, and, most importantly, that it is all done in real time, give the user a richer experience. To laboratory coordinators, this allows for the elaboration of better practices with a far lower cost than traditional laboratories, the creation of remote laboratories with a minimal space required, and the ability to implement customized instrumentation based in software and low-cost hardware.

PROBLEM DEFINITION

In the past few years, there has been an increase in the information and content added to all basic electrical and electronic engineering courses, forcing an efficient use of resources in order to achieve an effective learning. However, laboratories used for these basic subjects have deteriorated in their equipment compared to the new emerging technologies, due mainly to the cost that the maintenance of a lab of this nature implies. Nonetheless, for pedagogical reasons, the real experience of any laboratory should not be left aside. [1]

A viable alternative to support these courses and applications for collaborative projects are remote laboratories and, though in present time there has been a vast investigation about these kind of applications, many of them take the simulated way, in which the user only sees the emulated results of an action taken in the experiment. As an experience, although effective at a certain level, it detriments from the fact that the process is not a real one but a process, most of the time, taken and simulated with ideal conditions.[10] Another class of these laboratories are the ones that put physical processes (real) on line, which gives a better experience of use, but being limited by the fixed configuration of these experiments, which can only have simple input parameters reconfigured but without modifying the process of the experiment itself. [7]

For this kind of applications, a remote laboratory that allows the real time reconfiguration of the process or circuit under experiment and maintains many of the experience qualities of a traditional laboratory would present a solution to a latent necessity of effective, distance interoperability in collaborative projects and courses focused on remote education.

JUSTIFICATION

For the present work, the creation of an appropriate interconnection structure for remote laboratories was seeked, focused particularly to the Electronics area but with application to any other field with requirements for remote control and collaboration applications. [5]

By integrating data acquisition equipment controlled through a port in a computer, software specialized in measurement and control, and a network/matrix of digital solid-state components, relays, and digital switches with today's internet technologies, a remote Electronics laboratory can be deployed, similar to a traditional laboratory, making measurements and control of the circuit fully available through the network without having to be physically present in front of the experiment.

When the equipment is connected to the network, it is controlled and accessed by the user through a user-friendly graphical interface capable of loading into any machine with a web explorer, also providing all the necessary elements for the control and reconfiguration of the circuit as well as the measurement display, all in real time for the user.

Since the user is given the ability to remotely control and reconfigure the experiment and it is made available through Internet, care must be taken not to allow two or more simultaneous users, for every user would want to make changes to the circuit, most likely conflicting with another user. This calls for the implementation of a scheduling system, which would provide the means to block access to simultaneous users by allowing only one registered user per time slot.

DEVELOPMENT

The coming of new Information Technologies, an exponential increase in the amount of information and the accumulation that it requires in all courses, just like the swift changes in it and the technology itself have brought as a result the necessity of a constant and continuous professional development. [11]

A tool that turns out to be extremely useful in this kind of needs are the redesigned courses meant to be taken through a computer, especially, laboratory practices. However, although these kind of systems called "Computer Based Training" (CBT) have been developed in the past 10 years to replace traditional engineering courses [3, 7, 1, 3], they have some limitations that have stopped their total immersion in the scholar curriculum, such as programming difficulties, complicated structures, use and hardware limitations, and perhaps the most important reason, the cost of implementation.

Thanks to the versatility and increasing availability of the Internet especially in the educational field, a desire to give access to the information of all courses through the network has been arising, allowing it to be used from virtually anywhere with an Internet-connected machine. Laboratories are no exception, although due to the difficulty to prepare the necessary equipment for this kind of activities for their functioning in a network, their development has been delayed. However, there have been efforts to take advantage of the use of a user-friendly graphical interface in such a versatile medium as the Web, making it possible for the students to have control of the experiment in a remote fashion. These kinds of applications have been denominated Virtual Laboratories.

A Virtual Laboratory (VL), in the literature, has different descriptions. For the Internet2 Consortium [2], a VL is defined as an heterogeneously distributed environment that allows the collaboration between geographically separated groups as well as the work in a common project. For Guimares [4], a VL is a system that allows its users to plan and conduct experiments, as well as obtaining and analyzing data through teleimmersion mechanisms. In general, virtual laboratories can be classified into two categories: simulated and remote. [12]

In the case of simulated laboratories, these give access to both the equipment to be used as well as the environment in which they operate in a simulated way and through an Internet connection. The advantages that this laboratory scheme presents are that it allows testing and experiments in extreme or complex conditions without any damage to the equipment, besides being able to serve multiple users, avoiding equipment damage due inexperienced users. The connection scheme for this kind of laboratories is shown in Figure 1. As can be seen, this connection scheme has a simulation of the process being executed in a server machine (simulated laboratory), while the parameters to simulate or manipulate are being monitored and controlled by a client machine (student).

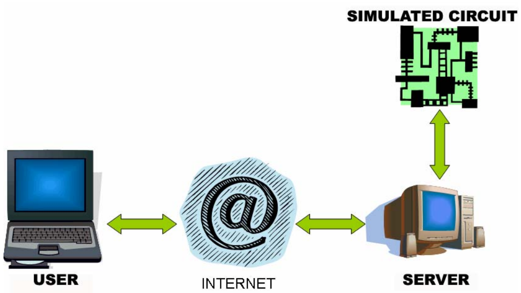

FIGURE 1
VIRTUAL LABORATORY AS A SIMULATED LABORATORY

In the case of remote laboratories, the access to the physical equipment is made through a computer connected to the Internet and DAQ systems, which have access to analog and digital ports with both input and output capabilities, counters, switches, etc.. In this kind of laboratory, the user experiments with equipment in a real environment, taking data and experiment status by means of real sensors and transducers, which makes the experience more effective. However, care must be taken not to lead the experiment into extreme conditions to avoid damage to possibly expensive equipment. The connection scheme for this kind of laboratories is shown in Figure 2. In this Figure, the difference between the simulated and the remote laboratories can be appreciated, since the server machine in the remote laboratory is no longer simulating the process or the circuit under experiment but accessing a real process through the teleimmersion interface (data acquisition/generation) and allowing the client machine to access the information and to control the real circuit parameters, thus giving the student the possibility to monitor and control the behavior of a real, distant process. It is precisely this type of laboratory which is of interest to the present work.

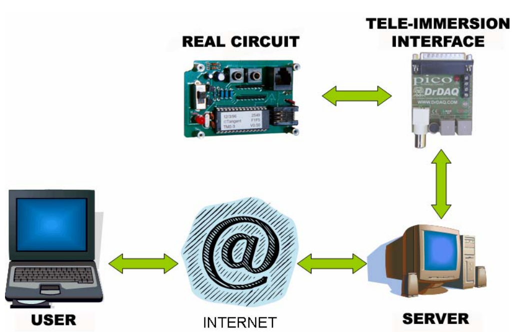

FIGURE 2
VIRTUAL LABORATORY AS A REMOTE LABORATORY

Although, in theory, a remote laboratory should give the user total access to the process, in reality this does not happen, especially due to the difficulty to remotely make changes to a process and the cost of the necessary equipment for this kind of interaction. Instead, pre-defined experiments are set up online, of which the user can obtain information, but it is not very common for the user to be allowed to make changes in the structure of the experiment itself, which means that the student does not have room for error or mistakes.

For instance, in the case of Electronics laboratories, a common remote laboratory only permits to define the experiment's characteristics (input signals and configuration of the electronic circuit) as initial conditions, but it is not possible to change, at any time and even less in real time, the state of connections or value of the elements in the circuit under experimentation, which limits the educational experience to a pre-established experiment process. [9]

However, the advance towards tele-engineering projects, educational laboratories, and collaborative development of projects has been advancing and integrating new data acquisition technologies, digital manipulation, and software-applied measurement instrumentation. [8] An example of this type of software-applied measurement instrumentation are the so-called Virtual Instruments. Through a specialized software tool, graphical user interfaces (GUIs) that allow the control of accessories as well of data acquisition and generation can be easily created. Besides, the functionality to allow a GUI to be published as a web page immediately is available in certain software packages, giving access to the students to a remote process in real time.

Some of the instruments required in a remote laboratory may be to have a function generator, variable and fixed power sources, frequency analyzer, multimeter, input and output ports, and digital and analog ports. [6] All this, together with control and acquisition through a card or port in the computer, allow the student to access different measurement and test points throughout the remote circuit.

The implementation of a remote laboratory with this kind of equipment reduces implementation and operational costs in a significant way, mainly because of the low cost of instrumentation and application of measurements through software and not specific hardware. For example, the average cost of a basic work table in an Electronics laboratory, consisting of a DC power source, multimeter, function generator, and digital oscilloscope is around US$6,300, while the application of a remote laboratory, with the same generation and data acquisition capabilities but implemented through a data acquisition card can be less than US$4,000, reflecting a cost reduction of approximately 45 percent. However, it has been established that the use of real instruments may present a better performance, so, as a high-performance option, the lab can be implemented using real instruments connected to the DAQ card of the computer rather than virtual ones. This option, however, elevates the cost of a remote lab considerably, becoming a secondary option. Table 1 shows a brief, detailed comparison between the cost of a common workstation in a traditional laboratory and the cost of implementing a similar workstation but in a remote way with DAQ equipment and virtual instrumentation in a low-cost implementation, and with a remote scheme with commercial instrumentation in a high-performance development.

This cost comparison, however, does not take into account that, in the traditional laboratory costs there are not only those generated by the equipment needed, but also those for the space required for it and the working personnel, as well as the infrastructure costs.

TABLE I
LABORATORY COSTS. SOURCE: ITESM DIEC

Traditional Lab Cost		Remote Laboratory Cost			
		Low-Cost		High-Performance	
Cost	Equipment	Cost	Equipment	Cost	Equipment
$1200	Power Source	$2200	Data Acquisition System	$5800	Common Station minus Multimeter
$500	Digital Multimeter				
$1800	Function Generator	$1200	Server Computer	$1200	Server Computer
$2800	Digital Oscilloscope	$100	Digital Components	$100	Digital Components
1 Workstation **Subtotal: $6300** 5 Workstations **TOTAL: $31500**		Low-Cost **TOTAL: $3500**		High-Performance **TOTAL: $7100**	

Concerning the cost of space required for the laboratory, a remote laboratory such as the one implemented in this project, implies a significant reduction since the required space for a computer and a DAQ platform as the ones used here is much smaller than the one required for a traditional laboratory workstation. Together, a group of workstations for a remote laboratory would occupy a far smaller space than the one a few traditional workstations would. Besides the reduction in space costs, the number of teams that the laboratory can service is increased by making its overall use more efficient.

As for the laboratory personnel, the cost in a presential laboratory is inherently greater, since at least one lab instructor is required, maintenance staff for both the equipment and the facilities is also required to maintain it in optimum conditions, and also it requires staff to handle the component and equipment administration. In a remote scheme such as the one implemented in this work, the cost of personnel is greatly reduced since it only requires at least one person for practice maintenance and a general network administrator for the laboratory.

Infrastructure is a cost that usually is overlooked, when in reality, it represents a very high percentage of the operational cost of any laboratory. In the traditional case, each individual equipment in every work table consumes electricity; also proper, constant illumination and air conditioning are required during work hours. In a remote laboratory scheme, electrical consumption decreases significantly due to the low power consumption of a computer (even less if the monitor is turned off), also due to the fact that, since the practice is carried out remotely, the place where the laboratory server resides does not require constant illumination nor air conditioning.

As for time efficiency, a remote laboratory would also allow access to it in non-working hours, which is not common in traditional laboratories, such as weekends and night-time. This allows for a better use of the resource and allows better service to a greater number of users in a greater number of hours, since the laboratory is available in these time slots. For example, a traditional laboratory workstation, taking into account that it would work with teams of 3 persons and in three-hour sessions, it could give service to **15 teams a week** if it is available 9 hours a day, 5 days a week, which is a traditional schedule for these laboratories. A traditional lab, however, consists of five of these individual stations. If a remote laboratory is implemented with only one server computer and DAQ equipment, it is usually connected 24 hours a day, 7 days a week, and the service would be available to **56 teams a week**, with the same team and time per practice conditions. Now, taking a more conservative view, if the remote laboratory is kept operational from 8AM to 10PM (14 hours a day) from Monday to Saturday (6 days a week), it could service **28 teams a week**. A summary of these times is presented here (Table 2).

TABLE 2
TIME COMPARISON

Traditional Lab	Remote Laboratory	
9 hours/day	**14 hours/day**	24 hours/day
5 days/week	**6 days/week**	7 days/week
15 teams/week	**28 teams/week**	56 teams/week

Besides all of this, the possibility of access for a remote laboratory is one of its main advantages for both educators and students, since a practice in a real circuit can be achieved but accessed through a network connection from virtually any geographical point, without having to be physically present in front of the circuit or process to be analyzed. Also, it may provide more flexibility, since the student decides when and at what time the practice will be performed.

IMPLEMENTATION

Currently, a Data Acquisition (DAQ) station consisting of an NI-ELVIS set, a DAQ card, variable power sources, function generators, and a relay system has been set up to allow the student to measure different points in different circuits as well as to modify the input parameters in such experiments and it has also been set up to work remotely through proprietary, remote, stand-alone Graphical User Interfaces (GUIs). Also, it has been made available to 18 teams. Figure 3 shows the interconnection scheme proposed.

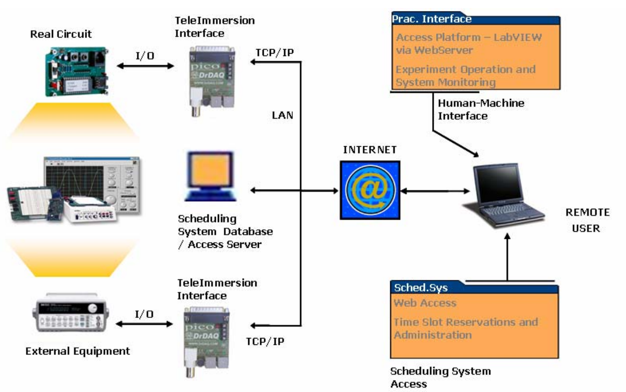

FIGURE 3
INTERCONNECTION SCHEME FOR A REMOTE LAB STATION.

Since access is carried out remotely, a Scheduling System was implemented, consisting of an access web page in which the user, having previously requested a user account and being validated by the lab administrator, logs in and selects up to two hours to access the automation station. Once the user has secured these time slots, they don't become available for any other user, thus avoiding double reservations. The system also validates that each user account can only reserve up to two time slots and can only change any existing reservations or select new ones with up to two hours prior to the selected time slot. Any time slot before that becomes immediately blocked for all users.

A very plausible advantage (and one of its best features) of a remote lab set up with this scheme is precisely the freedom of the user to select appropriate time slots, therefore, not being tied up to a fixed weekly schedule and being able to adapt the lab to the user's own schedule. Also, the two available time slots per user do not have to be necessarily selected in succession; this means that a user may select one time slot one day and the second one in another, adding to the flexibility feature. This last benefit is especially good for fast-learning users who don't need the two time slots to complete the tasks in a practice. Two examples of a scheduling table for different weeks of use is presented in Figure 4.

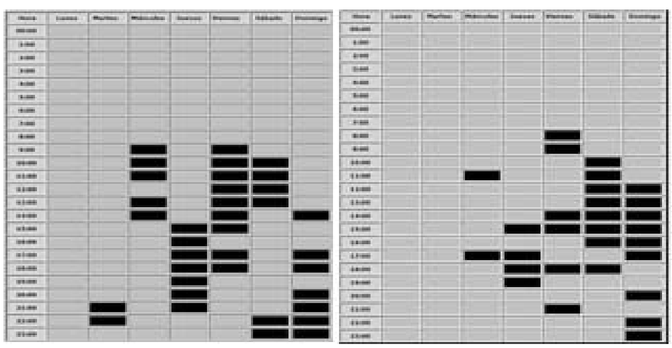

FIGURE 4
SCHEDULING TABLE EXAMPLE FOR TWO DIFFERENT WORK WEEKS.

Figure 4 clearly shows that, while the teams are the same, both weeks have different time slot reservations. This is due, mainly, to each user's activities for every week, letting the lab adapt itself to the user's schedule. It is also visible that the users, being students, tend to do their lab work leaning towards the weekend (approximately 35 percent) and, sometimes, during late hours, something that would not be possible to do in a traditional laboratory of any sort. A usage analysis of these reservation tables shows that a staggering 52% of the users prefer to work during non-office hours (After 5PM and during the weekend), showing once more the great advantage that a remote lab like this presents.

Once the schedule has been set up, the user can proceed to access the laboratory's practice interface at his reserved time slots. Such access is carried out via a proprietary stand-alone application created specifically for the each experiment to be accessed. Such application consists of a GUI where the user can modify input variables to the control hardware and provoke certain reactions in the circuit such as changing the input of a voltage amplifier and see the results of such an input change at the circuit's output. This GUI is embedded into a webpage, which greatly simplifies the usage of the practice interface for the user only requires a web browser and a software plug-in (which is automatically downloaded if the user's machine doesn't have it) in order to carry out their experiments. Inside the interface the user is presented with various controls and displays, depending upon the current practice and circuitry available. Examples of these controls and displays are variable DC power sources, function generators, switches to allow for specific parts of the circuit to be activated or disconnected, temperature readouts, and a 4-channel oscilloscope-like display with multiple measurement points. This client application also connects to the server computer to check for the user's credentials; if the reservation time-slot is right, then the user is permitted access and control of the process. Figure 5 shows the practice login interface, which connects itself to the scheduling system to verify that the user has the required credentials and time slot reservations to perform the practice.

FIGURE 5
PRACTICE LOGIN INTERFACE FOR THE REMOTE ELECTRONICS LAB.

Then, if the user provided the right credentials and had the proper reservations, the system then displays the practice interface, which gives the user the ability to control the circuit as well as to take different measurement points in the system. Other functions, depending on the current practice, may be activated. Figure 6 shows an example of a practice interface.

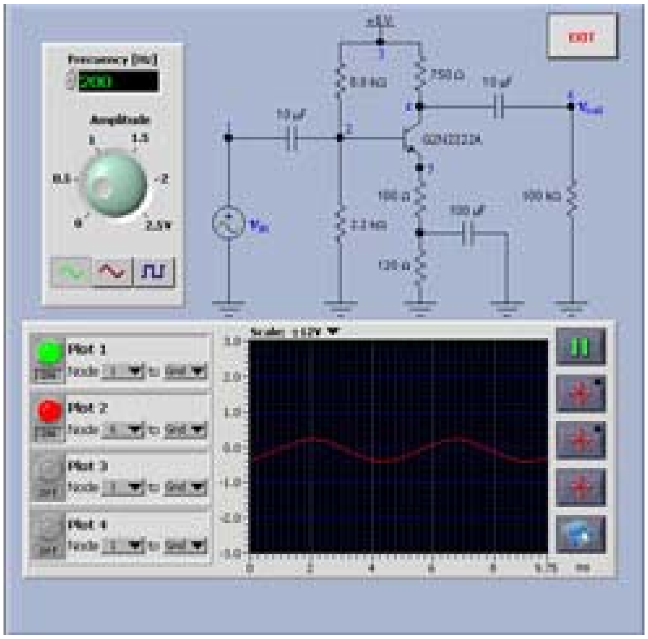

FIGURE 6
PRACTICE INTERFACE FOR THE REMOTE ELECTRONICS LAB.

With the practice interface, the user is given control of the circuit in its entirety and is able to reconfigure it in real time. However, the way each user carries out each practice is not predefined, but dependant of every user. During a practice, each student may get to the final result taking several different ways, many of them including errors and mistakes. It is a known fact that the user must be permitted to have mistakes during the practice for, after all, learning usually arises from making errors. These mistakes, however, do not necessarily require being lethal to the circuit. This control given to the user via the practice interface calls for an extra effort from the instructor's side: safety. When an electronics lab is set up to be remotely used, and during non-working hours too, the need for 'safe' circuits becomes critical. This safety criterion has to be implemented before the user can perform fatal operations in the circuit. Some of the safety criteria include limiting the input signals, preventing dangerous connections during remote re-wiring, and choosing circuits components correctly.

SUMMARY

Inside the objectives achieved by this structure, an integration between the data acquisition equipment and the server machine is achieved so that it can be able to maintain an effective communication between both of them without constant problems for the user.

Likewise, an interconnection model for variable components and selective wiring is established for the user, allowing him to make changes in the tested circuit's configuration, both in input parameters and design and wiring, all in real time.

A login and scheduling systems were implemented to allow the users to carry out their practices in their own time, without conflicting with other users.

A graphical interface was also generated, making it completely user friendly, while also providing enough flexibility for the laboratory administrator so as to make changes in the circuits or projects, minimizing the programming complexity in a structured, complete graphical environment.

It became clear that, once the system was made available to students, it provided with a better time flexibility than a traditional laboratory, but retaining the learning benefits of the latter. To make sure the students did learn the proper concepts through the remote practices, a lab practice report (such as the one they would present in a traditional lab) is handed in and graded by the instructor.

It is also important to note that, although very effective, a remote lab is not meant to replace traditional labs at all, but to enhance the learning process by supplying a remote, flexible laboratory for those basic subjects that lack a traditional one.

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