AC 2012-3227: COMMON MULTIDISCIPLINARY PROTOTYPES OF REMOTE LABORATORIES IN THE EDUCATIONAL CURRICULA OF ELECTRICAL AND COMPUTER ENGINEERING

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Common Multidisciplinary Prototypes of Remote Laboratories in the Educational Curricula of Electrical & Computer Engineering

Abstract

On recent years, the educational paradigm of electrical and computer engineering has undergone a significant transformation with the advent and the exploitation of computer and communication technologies. Such transformation was necessitated in order to harmonize the learning process with the needs of the daily life. As a result, E-learning has been adopted and has added two major aspects to the learning process: 1) Interactivity; owing to the integration of simulation and multimedia technologies. 2) Ubiquity; owing to the integration of synchronous and asynchronous communication tools, and remote laboratories. Thereby, thanks to E-learning students incentives toward learning have increased.

There is no doubt that practical sessions have an intrinsic role in electrical and computer engineering education; they augment the learning outcomes by strengthening the understanding of scientific concepts and theories. However, cost and administration burdens have hindered the adoption of practical sessions in engineering education until the appearance of remote laboratories. Remote laboratories have tackled these concerns by bringing practical sessions online and providing workbenches unconstrained by neither geographical nor time considerations. For these reasons, remote laboratories have proliferated among many universities and institutes around the world to be adopted in most of the disciplines of electrical and computer engineering curricula. A study carried out by the authors deduced that most of the developed remote laboratories around the world are based on common prototypes that are subsets of a common architecture, which is going to be the main topic of this paper.

The paper reports on the common prototypes of today's remote laboratories for electrical and computer engineering education and addresses the most outstanding developments for the multidisciplinary applications that are based on such prototypes. These applications encompass embedded systems (e.g. Programmable Logic Devices (PLD) and microcontrollers), Digital Signal Processing (DSP), instrumentation and measurements, automation (e.g. Programmable Logic Controllers (PLCs)), machinery control, and others. The aim of this study is to foster the dissemination of remote laboratories in the learning process with regarding to the recommendation of the Accreditation Board for Engineering and Technology (ABET) and to foster, as well, the globalization of engineering education by pointing out the remarkable achievement in the remote experimentation field.

Background

The current ABET engineering criteria (2012 – 2013) has emphasized the role of laboratory practices in engineering education, stating that all engineering programs must demonstrate that:.

- Their graduates have ability to: 1) design and conduct experiments, as well as to analyze and interpret data. 2) use the techniques, skills, and modern engineering tools necessary for engineering practice.
- Their graduates must provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other.
- Modern tools, equipment, computing resources, and laboratories appropriate to the program must be available, accessible, and systematically maintained and upgraded to enable students to attain the student outcomes and to support program needs.

Remote laboratories have rendered the acquisition of practice skills more affordable by eradicating the geographic and temporal constraints. Several weeks before the IEEE Annual Global Engineering Education Conference (EDUCON) held in Madrid in April 2010, a survey was conducted on the conference webpage about the impact of the most promising technologies on engineering education. Virtual and remote laboratories received the most votes of any other technologies, obtaining 18% of the votes, as shown in Fig.1.

Answer	Votes	
Virtual & Remote Labs	52	18%
Open contents and learning objects (e.g. OCW)	41	15%
Mobile devices	29	10%
e-Learning	29	10%
New learning methodologies and paradigms	23	8%
Social networks	22	8%
Web 2.0	22	8%
e-Books	19	7%
Interoperability and Learning Services (Learning as a Service)	16	6%
Augmented Learning (Augmented Reality)	13	5%
Games & Virtual Worlds	10	4%
Other (see below)	6	2%

Figure 1. Results of the survey conducted before EDUCON 2010.

Remote laboratories are those laboratories that can be controlled and administrated online. They differ from the virtual simulated laboratories as they are directly interacting with physical instruments. The common generic architecture design of today's remote laboratory for Electrical and Computer Engineering could be structured as shown in Fig.2. Next, a

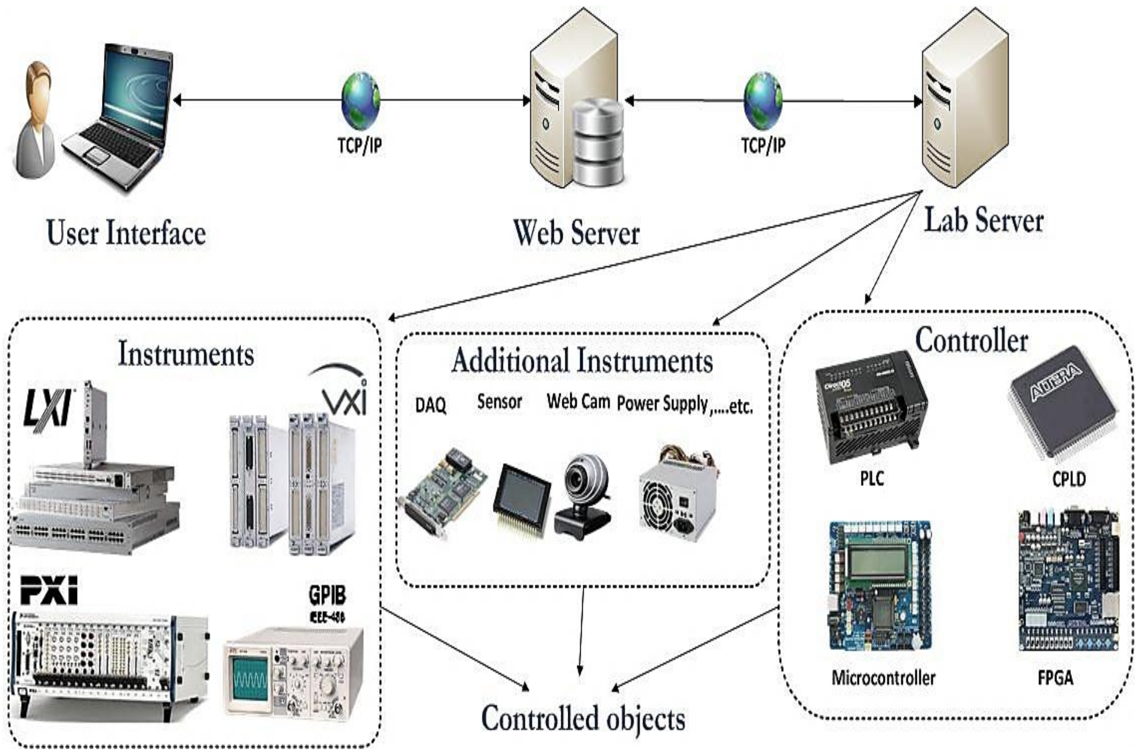

Figure 2. Common generic architecture for electrical Engineering remote laboratory.

comprehensive definition of the main components of this architecture is going to be presented, pointing out the available technologies they mostly rely on.

- *User Interface:*
  It is the virtual end-user workbench that handles all the lab administration process. It is a web site that runs on the user's web browser and usually requires a server-side programming language to retrieve user's data from database. The website could be supplanted by a software application written in a high-level programming language which is installed on the user-PC and connected to a database server (application server).
- *Web Server:*
  It is the server-PC that hosts the web site and the database files. The web server sends the user requests to the lab server in the form of XML messages through TCP/IP model over HTTP layer.
- *Lab Server:*
  It is the server-PC that hosts the instrumentation control software and it is connected directly to the instrumentation platform and the controller. The instrumentation control software sends commands to the controller regarding the received requests or the programed code from the user. The instrumentation control software could be built from scratch with a multi-purpose programming language such as C# and C/C++, or with graphical programming environment such as LabVIEW and MATLAB/Simulink. Or else, it could be proprietary software that comes with the controller. There are several modular types of instrumentation platforms such as PXI

(PCI eXtensions for Instrumentation), LXI (LAN eXtensions for Instrumentation), GPIB (General Purpose Interface Bus), and VXI (VME eXtensions for Instrumentation).

- *Controller:*
  It is a programmable device that directly controls the controlled objects and they are suited for all types of applications. The controllers that are typically used in remote laboratories are: Programmable Logic Controllers (PLC), Programmable logic devices (PLDs); Field-programmable Gate Array (FPGA) or Complex programmable logic device (CPLD), and Microcontrollers.
- *Object Under Control:*
  It is connected to the controller and to the instruments by connectors, converters, electronic boards, etc.

Next, the common multidisciplinary applications that are based on such prototypes are going to be presented pointing out the most outstanding developments.

Embedded Systems

Microcontrollers

The commonly used microcontrollers in remote laboratories applications are the 8, 16, and 32 bit ones. The microcontroller boards commonly have the following features: CPU, RAM, ROM or flash memory, clock generator, converters, and I/O connection ports. The microcontroller commercial board (or an added expansion board) may include peripherals such as LCD displays, a LED matrix, relays, solenoids, radio frequency devices, I^2C potentiometer, switches, sensors, Real-Time Clock (RTC), speaker, DC motor, Keyboard, AC phase controller, and others. The Integrated development environment (IDE) includes tools that let users edit, assemble, compile, run, and debug their code. Usually, students program their assignment works on assembly languages or a high-level programming language. The code file is sent by the student to the microcontroller and when the reception of an UDP packet is detected, a new hexadecimal file in the program memory of the microcontroller is loaded. Then a new program is executed by the microcontroller until it is replaced with other. The student monitors changing values of the inputs and monitoring the resultant outputs through a connected webcam. Packages of code are usually distributed by the manufacturers in the microcontroller's library. The authorized student could generate a binary file using his preferred development environment and upload it to the microcontroller through a website. The website could be hosted in the microcontroller's internal flash memory. A custom printed circuit board should be developed for every experiment. However, in [1], "Soft-wiring" system was designed with the purpose of giving the remote laboratory end-users the possibility to remotely change the interconnections between the microcontroller and its peripherals.

Among the notable microcontroller-based remote laboratories applications we could cite the following. In [2], a remote test workbench based on microcontroller was developed to support IEEE 1149.1 boundary-scan test lab assignments. In [3], a microcontroller-based heart monitoring system capable of detecting and distinguishing the normal heart signal from an abnormal one is developed. In [4], a microcontroller board, together with two transceiver modules, is added to a Freescale Microcontroller Student Learning Kit to allow wireless communication in the following applications: 1) wireless transmission and reception of keyboard strokes between two personal computers, 2) wireless control of a remote motor, 3) wireless transmission of sensor data for remote monitoring of manufacturing machines.

Programmable Logic Devices (PLDs)

The commonly used programmable logic devices in remote laboratories applications are CPLD and FPGA. Both are programmed with Hardware Description Languages (HDL); Verilog or VHDL. There exist libraries of complex functions and circuits, known as IP cores and typically released under proprietary licenses, to speed up the design process. Likewise, LabVIEW programming language, known as G, offers add-in modules for FPGA to simplify its programming. PLDs are hosted by an evaluation board containing the interface for programming and other peripherals like LEDs, push buttons, LCD display, A/D and D/A converters, EPROM, RAM, clock generator, and on-off switches connected to I/O lines of the device. The student can develop a program to interact with these peripherals and test the functionalities and the real behavior of the programmed functions. The student writes the code, simulates it, and obtains the binary file to be uploaded. Then, he monitors the PLD through a connected webcam. A PIC microcontroller may be used for its communication with the lab server. PLDs incorporate a fully featured USB communication module that supports both low-speed and full-speed communication for all supported data transfer types. Moreover, an I/O port expander with serial interface could carry out the communication between the microcontroller and the PLD via SPI bus in order to allow more devices on the bus. The lab server (http-based), however, could be installed on the same PIC microcontroller. For a wireless connection, RS-232 connection would be interfaced to an added wireless interface module [5].

Among the notable PLDs-based remote laboratories applications we could cite the following. In [6], A CPLD-based remote laboratory is successfully integrated within iLab Shared Architecture (ISA) to facilitate its distribution and sharing among universities in an efficient way. In [7], a FPGA/DSP-based remote laboratory is developed for experimentation with a 120-kVA multilevel power converter in order to control and supervise the performance of an AC motor in real time. A similar approach, described in [8], was realized to control a servomotor using a PID controller based on FPGA. Microprocessors could be embedded in a FPGA-based circuit in order to allow students to program the microprocessor and graphically depict the processor's internal state on the PC [9].

Fig 3. shows the embedded systems installed at our department which are integrated in the practices of undergraduate engineering curricula. The students access to the embedded devices remotely with their own account to program them and monitor the devices by an installed webcam for each device as shown in the figure.

Figure 3. Installed embedded devices for remote experimentation.

Instrumentation and Measurements

The combination of the commercial lab server software (Matlab or LabVIEW) with Data Acquisition Cards (DAQ) has allowed the development of a wide range of remote Digital Signal Processing (DSP) applications for instrumentation and measurements (Fig. 4).

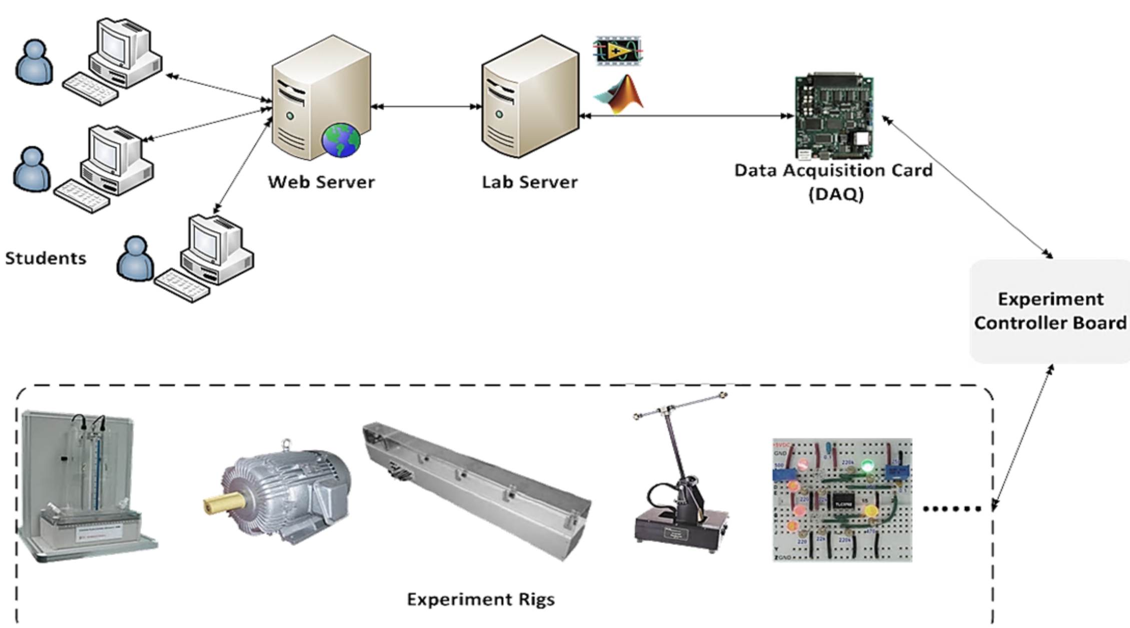

Figure 4. the Prototype for a remote laboratory for DSP applications.

These applications encompass monitoring and control of a huge number of experiments such as electric motors, inverted pendulum, etc. for all disciplines in Electrical and Computer Engineering education. A controller device is also involved in the design, in order to control the instruments, but this type of experiments is tailored for remote measurement applications rather than remote programing of a controller.

LabVIEW [10] is an industrial-leading graphical programming environment for developing, testing, controlling and monitoring systems using intuitive graphical icons, known as Virtual Instruments (VIs), which imitate the physical instruments. LabVIEW provides a built-in web server for publishing the web pages that allows its frontal panel of VIs to be embedded and directly controlled from a web browser (Fig.5). With DataSocket, LabVIEW allows data exchange between multiple users and applications efficiently over the internet without the complexity of low-level TCP programming. In the literature, a wide set of remote laboratories application have been developed using the LabVIEW along with its built-in web server as seen in [11-14]. The drawback is that web publishing tools require that users download and install the LabVIEW run-time engine.

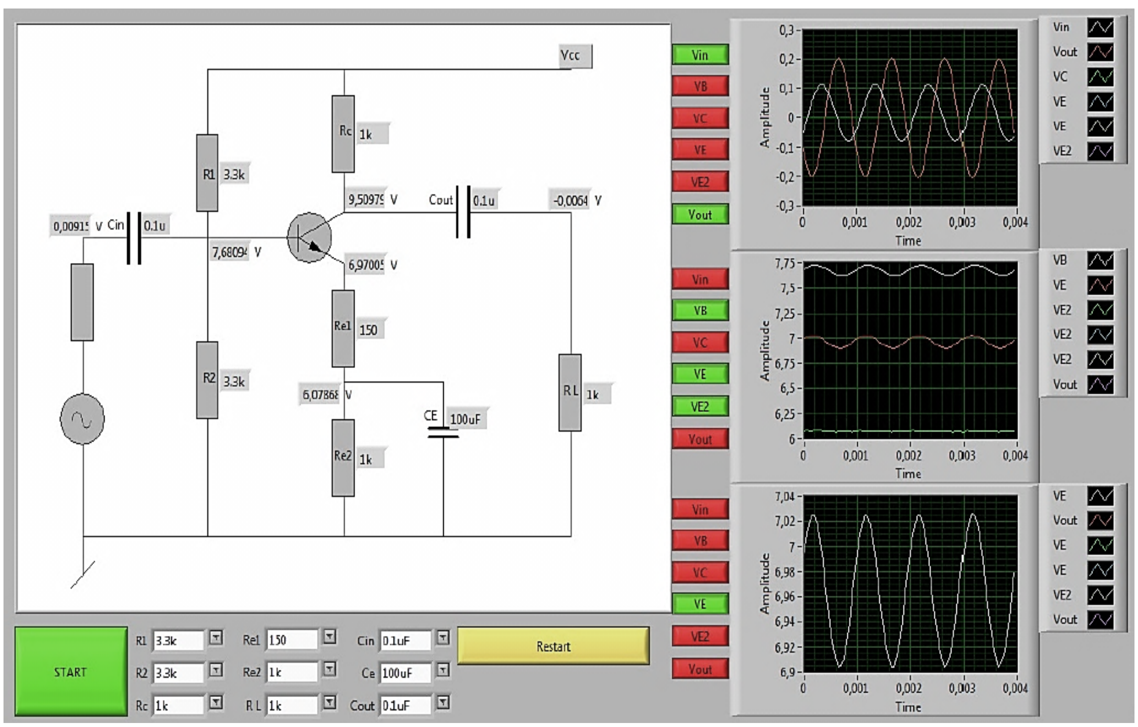

Figure 5. Frontal panel for a LabVIEW-based remote experiment [15].

MATLAB [16] is a high-level technical computing language and interactive environment for high performance intensive numerical computation, algorithm development, data visualization, and data analysis. MATLAB enables the creation of applications that use capabilities of the World Wide Web (WWW) by offering additional toolboxes that provide several possibilities for interoperability and data exchange with other GUI applications. The user sends input parameters of a particular test by the GUI (or by uploading an M-code). The Real-Time Windows Target Toolbox extracts the input parameters and updates the experiment Simulink blocks model. Afterwards, it compiles the model into ANSI C code and executes the code in the lab server PC while interfacing to real hardware using PC I/O boards. Thus, the users do not need to have locally installed MATLAB or to basically know anything about MATLAB programming. Remote laboratories based on MATLAB can be found in [17-19].

LabVIEW and MATLAB possess rich and powerful features to ease laboratories construction, among them are: 1) Data exchange with other GUI applications such as Component Object Model (COM), ActiveX, Common Gateway Interface (CGI), Java and .Net applications, and web services. 2) Support for standard Application Programming Interfaces (APIs) such as Interchangeable Virtual Instruments (IVI) [20] and Virtual Instrument Software Architecture (VISA) [21] to provide interface-independent communication with different platforms such as GPIB, PXI, VXI, USB, LXI, and others. 3) Connection with Open Database Connectivity (ODBC) or Object Linking and Embedding Database (OLEDB) compliance database; compilation as Dynamic Link Library (DLL) files to be called from the Lab server software as a driver to execute the experiments on the hardware. 4) Support for OLE for Process Control (OPC) Servers to enable Human-Machine Interface (HMI) and Supervisory Control and Data Acquisition (SCADA) [10, 16].

LabVIEW is the most outstanding representative of graphical programming language visualization and parameter tuning for remote operation, while MATLAB is the most powerful computing language for control algorithm development and simulation. Next, Common instrumentation and measurement remote laboratories applications for electrical and computer engineering curricula are going to be addressed.

Electronic Circuits measurements: by connecting, through a DAQ device, the lab server to a board on which an electronic circuit is mounted. It is possible to develop infinite number of remote laboratories applications for electronic circuit's measurements. For instance, in [12] a remote lab is developed for recording the amplitude characteristics of a T-notch filter, Recording diode I/O characteristics, recording input and output characteristics of PNP and NPN transistors, Recording characteristic of A and B class amplifiers, recording RC filters characteristics, and measuring circuits with operational amplifiers (adder, subtractor). In [15] a remote lab is developed for running experiments on a normal BJT common emitter amplifier circuit, while maintaining the possibility for the students to use a wide range of different setups.

Control and monitoring: In this type of applications the object under control (the experiment) is controlled through the received digital signals from the user by the DAQ and the monitoring of the experiment performance is achieved either by a connected web cam or by integrated sensors. For instance, in [13, 14] a remote experiment for controlling and monitoring water level is developed introduce to the students the principles of control engineering, such as the feedback loop, the concept of open-loop control, feedback control, Proportional-Integral-Derivative (PID) control, and PID tuning. In [22] a remote laboratory is developed to simulate closed and open loop continuous control as well as disturbance in a thermodynamical processes of heating air in a pipe allowing the possibility of fast and simple changes of the control unit, and the simultaneous implementation of temperature sensors with different characteristics. The possible educational tasks are testing of static and dynamic characteristics of sensors and actuators, modeling and identification of a process, and control algorithm synthesis and verification of the effectiveness of simulation and experiment. In [23] a remote laboratory of an inverted pendulum is developed for demonstrating basic features and limits of different linear and non-linear control concepts. In [24], a developed remote laboratory for AC machine for distance detection of an incipient rotor bar fault and three-broken-rotor-bar fault. A similar approach [25] is developed for induction motors fault detection. In [19] a remote laboratory is developed for DSP-controlled induction motor in order to control its speed using vector-controlled strategy. In [26] a remote laboratory is developed for separately excited dc motor and generator. It allows speed control of the DC motor using armature and field voltage, generator no load, and terminal voltage characteristics. Similar approaches are found for PID speed-controlled DC motor [27, 28] and for speed-controlled four-quadrant DC motor [17].

Programmable Logic Controllers (PLC)

PLC-based remote laboratories for controlling devices such as motors, motion drives, pneumatic actuators, etc. (Fig. 6), are commonly used in automation and system courses. The student programs the PLC device by uploading his code written in a PLC programming language (e.g. ladder-style logic or Instruction List) in order to define an adequate control strategy such as PID control. And then, monitors the feedback through a web-cam or through HMI software which allows control and real-time handling of the system [29, 30]. By this way, the remote laboratory acts as a SCADA system [31, 32] which is widely used in the real industrial world. Web-based PLC applications for remote experimentation are easily developed and integrated with OPC standard compliances such as LabVIEW [32] and .NET [33] applications. OPC is an industrial standard that defines a set of methods that allow exchanging data between hardware systems and computers with Microsoft's OSs.

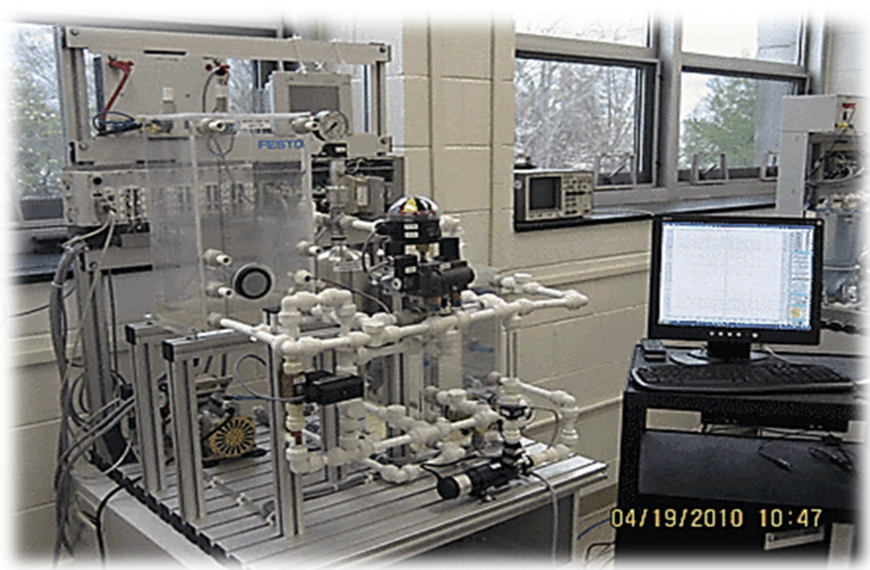

Figure 6. Remote controlled Hydraulic plant experiment controlled with PLC at our department.

Case Study

During the academic course 2009-2010, our department started deploying a remote laboratory for designing, wiring and measurements of analog electronic circuits, known as VISIR [34], on the practices of the subjects "Electronic Circuits and Components", a first grade subject of the technical industrial engineering career. The system has been proven to withstand a high functional capacity and complex electronic circuit's practices such as:

- Half-wave Rectifier with and without filter.
- Regulators with zener diode.
- Inverter and non-inverter operational amplifier.
- Common emitter and collector BJT.

A preliminary survey was carried out among the students that have used it and the results are shown in Table 1.

Table 1. Results of a survey on VISIR deployment

Questions	Results
VISIR was useful for studying and preparing the subject	85.6%
It helped me to understand the subject contents	78.4%
It is useful for trying more circuits without any fear of errors	95.6%
It is always available	95.6%
It improved my real practical skills	92.8%
It ensured my practical understanding after the traditional lab sessions	85.6%
It satisfied my perceptions about this kind of labs	88.4%
It must be used in other subjects	92.8%
I recommend it to other students	95.6%

Conclusion

The intrinsic role of practical sessions in engineering education caused that many universities developed their own remote laboratories solution in order to integrate them in the educational curricula. In this contribution, the common multidisciplinary architecture of today's remote laboratory for electrical and computer engineering education have been discussed pointing out the development process of each part generically. The contribution as well has shown the different scenarios of the common applications adopted at many universities highlighting the relevant developments and remarking the learning outcomes. This is in order to promote the integration of practical sessions in electrical and computer engineering education and to foster remote laboratories acquisition avoiding the constraints that accompany their traditional counterparts.

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