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Remotely Accessible Laboratory for Instrumentation and Sensors

Daniel Anton, Ramon Bragós, Pere J. Riu
Technical University of Catalonia (UPC). ETSETB. Electronic Engineering Department.
c/Jordi Girona 1-3. 08034, Barcelona, Spain. Email: rbb@eel.upc.es

Abstract – *This communication describes a project developed at the Technical University of Catalonia (UPC) in Barcelona, Spain. The goal was to solve the trade-off between the need for performing real laboratory practices in engineering education and the emergent implantation of distance learning in our curricula. Most of our courses in Electronic Engineering have 50% of the load devoted to laboratory work and our aim is to avoid a reduction of the lab charge and its substitution by virtual labs based only on simulation. The subjects of the experience are the instrumentation and the sensor laboratories.*

The solution developed was a remote workbench, based on a web server, a set of controlled instruments and several circuits, sensors and actuators connected to the instruments through a switching matrix. Control and user interface software was developed using LabView 6.1, and Perl routines were used to provide access control and system protection.

From the didactic point of view, the main problem of remote or virtual labs, is the fact that a given experiment often gives a unique solution or set of results. This fact leads the user to a feeling of lack of reality. In our system, each realization of a given experiment becomes different thanks to the influence of the workbench room conditions or by introducing random parameters through the instruments. There is no need for manual operation to change the experiment conditions.

Examples of the remote lab sessions are:

- *Characterization of the time response of thermal systems to different electrical stimulus.*
- *Closed loop control of these systems and identification of the resulting time and frequency response.*
- *Remote calibration of a custom thermometer by switching references and using several methods.*
- *Management of remote smart sensors using the IEEE 1451.2 standard.*
- *Identification of frequency response of adjustable electrical filters.*
- *Uploading and execution of instrument control routines under LabView.*

Keywords – *Remote instrumentation, Web-based education, Smart sensors*

I. INTRODUCTION

Laboratory courses with real experiments are necessary not only to develop skills but to attain in-depth comprehension of theoretical aspects in EE courses. The use of Information Technologies can provide means to extend these experiences to distance-learning students but also to enhance the conventional educational experiences and optimize the use of resources [1]. Leaving aside virtual laboratories based only on simulation, there is a considerable amount of remote laboratories that provide real-time access to real instruments. There are educational research lines devoted to the study of is topic [2]. Most of the r emote labs for engineering education are found in control [3],[4],[5] and electronics or circuit theory [6],[7],[8] areas.

The electronic Engineering Department of the Technical University of Catalonia offers a semi-distance degree (Master level) in Electronic Engineering. Our aim is to achieve for students that combine professional activities with scholarship a similar level of theoretical and experimental training to full-time students while reducing their physical presence at the university. Another objective is to reach a success rate for this kind of students comparable to the rate obtained by full-time students [9].

To complete and modernize the laboratory contents, and also to reduce the number of conventional sessions, we designed and implemented a remote workbench which allowed the realization of real practices, based on actual instruments connected to a server and accessible to the students through the web. This remote lab should partially cover the Instrumentation and the Sensors and Signal conditioning subjects.

In most remote or virtual labs, a given experiment often gives a unique solution or set of results. This fact has two drawbacks: the difficulty for the instructor to know the originality and the authorship of the data analysis reported by the students and, more importantly, the students feeling that he or she are dealing with a passive automata that simulates the experiment (whether this is true or not). The aim of our remote workbench is to overcome both limitations.

From the technical implementation point of view, most of the solutions proposed in the literature require the download or installation of software in the client computer (Java applets[4], [6]; ActiveX [7], Visual Basic specific application [8], and in some cases subject to manufacturer license (LabView) [5].

II. PROPOSED APPROACH

The field of application is, as was mentioned, the instrumentation and the sensors subjects. The topics to cover will be thus related to measurement techniques, signal acquisition, instrument control and also sensor characterization and calibration.

The requirements we have established for the laboratory design are the next:

- Remote sessions complementary to the conventional sessions and planned to optimize the use of time in the laboratory.
- Interactive structure: need for the student of performing data processing to access the different steps of the remote sessions
- Minimum or null downloading of software to the client computer.
- Security of the server.

A. Materials

The experiments are supported by a dedicated VXI system already available in the laboratory. A compact-PCI /PXI system or even discrete instruments connected through IEEE-488 could also be used to implement the laboratory.

In our case, the VXI system was composed by the following modules:

- HP E1401B mainframe
- HP E1406A control module
- HP E1411B 5 ½ digit DMM
- HP E1429A 20MSa/s two channel digitizer
- HP E1420B universal counter
- HP E1328A four channel D/A
- HP E1340A 12 bit, 40 Msa/s arbitrary waveform generator
- HP E1463A 32 channel switching matrix

The computer that hosts the control software and the Web server is a Pentium III based PC, at 450 MHz, running Windows 2000.

The software tools employed are the following:

- Microsoft IIS 5.0 web server
- Active Perl 5.6.1
- LabView 6.1, National Instruments.

To implement the experiments, the following components are also included:

- 5V, 12V Power supply
- Weather station, Ultimeter 2000 (Pet Bros. Inc.)
- Custom weather station
- Counter, 7931 Trumeter, to implement a hardware based, system-level watchdog
- PCB board containing the custom circuits that implement the experiments
- Webcam that provides a real-time image of the system

B. Experiment selection criteria

- Zero maintenance, no moving parts, and low power and noise free experiments. This criterion led to the main use of electrical and thermal measurements.
- Low resource usage to allow concurrent use of the workbench
- Security in the experiment access and in the undesired control of the server.
- Modern approach in the experiments design, which means: use of low-power, low-voltage circuits, avoidance of manual adjustments for zero and sensitivity tuning, and use of recent standards to provide information interchange with the smart sensors (weather stations) based on the IEEE 1451.2 standard.

The use of weather dependent variables ensures the uniqueness of results. Each experiment based on the thermal system is dependent on the room temperature and also on the time since the last use. Electrical measurement experiments include variables that are controlled by random parameters provided by the control software, this control being transparent to the student.

III. RESULTS

As a result of this project we considered the implemented experiments and the way they are used by the students. According to the design criteria and with the materials and systems described, the resulting remote workbench is the following:

A. System architecture

The structure of the implemented system is shown in Figure 2 and a general view of the system can be seen in Figure 3. The client (student) accesses the welcome web page offered by the Internet Information Server and navigates to a selected experiment page. The first web page, in Figure 1, (http://virtualab.upc.es) contents general information: system description, help and access to the desktop webcam view.

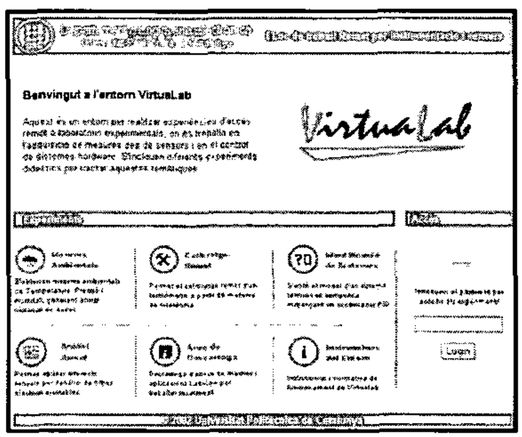

Figure 1.- welcome web page (http:virtualab.upc.es)

To execute the selected experiment, the student enters to a restricted access session with a time limit of 30 minutes. The experiment parameters, that should be provided by the student (result of previous calculations), are introduced in a form. The form page includes Java code that evaluates the formal correctness of introduced parameters. After validation, the parameters are evaluated by a CGI script in the server, which generates a parameter file that is provided to the LabView VI associated with the experiment. This VI provides a remote panel to the client page with the real time results, through the LabView Webserver and, if necessary, provides a downloadable file. The VXI instruments are controlled via VISA sessions and SCPI commands through an IEEE488 bus.

Some experiments, which include a higher level of mathematical complexity (system identification), execute Matlab routines under LabView control.

The commercial and the custom weather stations are connected to the server via RS232 ports and controlled via VISA sessions.

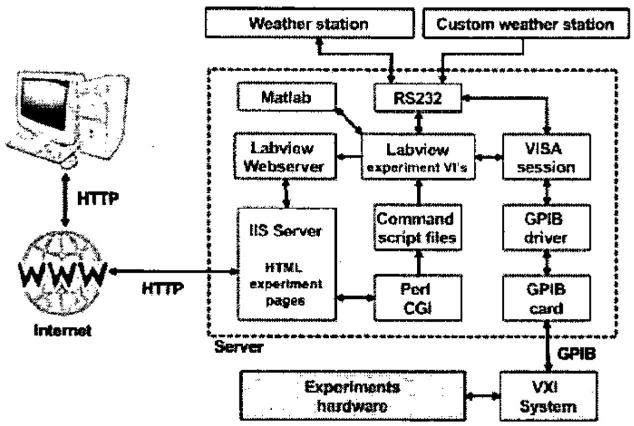

Figure 2.- Resource organization

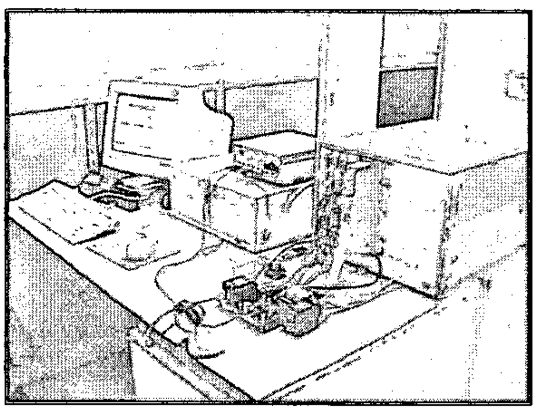

Figure 3.- General view of the system

B. Implemented experiments

1. Management of smart sensors using the IEEE1451.2 standard [10], [11]:

The goal of this experience is to provide means to understand the transmission and calibration of complex sets of data from remote sensors using a standard. Students access remotely to on-line actual measurements or to one-day records of two different weather stations (Temperature, pressure and relative humidity). The custom weather station is a PIC based circuit plus sensors and a conditioning circuit in which development the students have previously worked. The students access the raw data (A/D output) of this circuit. By comparing these data sets with the data from the reference weather station at different times, the students should obtain the calibration coefficients for each parameter and the cross-correlation of temperature with pressure and RH. Custom developed LabView tools to manage the Transducer Data Sheet (TEDS) are provided (TEDS read, write, edit and a tool to analyze the effect of the calculated coefficients in the processed data). The students fill the fields of the MetaTEDS, ChannelTEDS and CalibrationTEDS and provide a set of calibrated data and graphs comparing the commercial and custom weather station results using a different set of data than the used to calculate the calibration coefficients. Figure 4 shows the calibration TEDS panel.

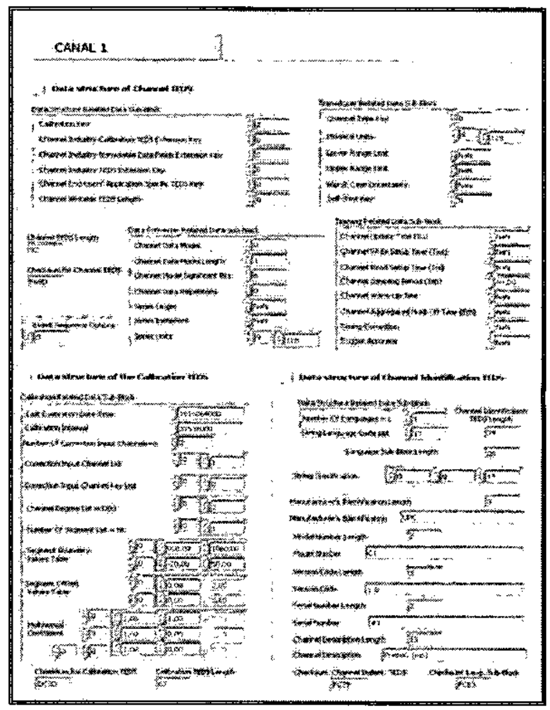

Figure 4.- Panel of the LabView tool to fill the calibration TEDS

2. Characterization and control of a thermal system

The thermal system is composed by a Peltier cell attached to a ventilated heat exchanger. A standarized thermistor is attached to its cold face. The current driver that feeds the Peltier cell is controlled by a D/A of the VXI module and the thermistor is connected to the digital multimeter. The experiences that could be performed with this system are the following:

- Acquisition of the real-time step response of the Peltier-thermistor system
- Excitation of the Peltier cell with a pseudo-random sequence and parametric estimation of its frequency response through ARX method using Matlab system identification tools.
- Tuning of a discrete PID controller
- Acquisition of the closed-loop real-time step response of the system

Figure 5 shows the PCB that contains the Peltier cell and its associated circuitry, as well as the circuits for the other experiments. Figure 6 displays examples of the step response of open and closed loop system.

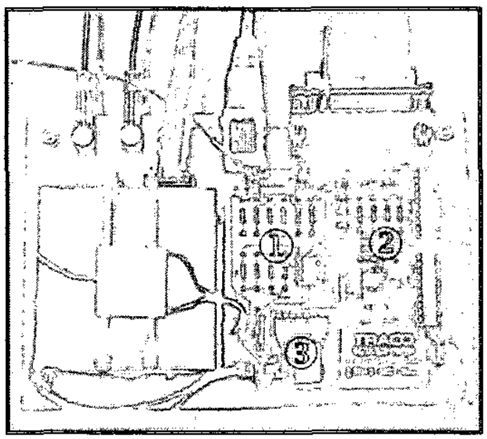

Figure 5.- PCB containing the experiments. The black block at the left is the heat exchanger with the Peltier cell (white) on its top and the thermistor on the cold face. c marks the circuit associated to the RTD experiment, d the switched-capacitor filter response identification and e the Peltier cell controlled current driver. The fan for the heat exchanger is placed through a hole at the bottom side.

3. Remote calibration of a RTD sensor

In this session, a PT100 RTD connected to a conditioning circuit is calibrated remotely in real-time. A switch structure from the VXI commutation matrix toggles between the RTD and two 0.1% metal film resistors that present the resistance value for the RTD at 0°C and 50°C respectively. The students have previously analyzed the conditioning circuit that is composed by a Wheatstone bridge and an instrumentation amplifier (IA). The bridge supply is driven by a D/A from the VXI system, providing sensitivity adjustment. A second D/A injects a current at an internal node of the IA, providing zero adjustment. By the previous analysis, the students should provide initial values for the D/A outputs. Then, observing the results for the 2 calibration resistors, they should provide the calculated values for the zero and gain adjustment. The corrected temperature is then compared in real-time with the room temperature provided by the internal weather station temperature sensor. This experience allows a time reduction in the realization of a lab session in which the students perform similar operations under microprocessor control.

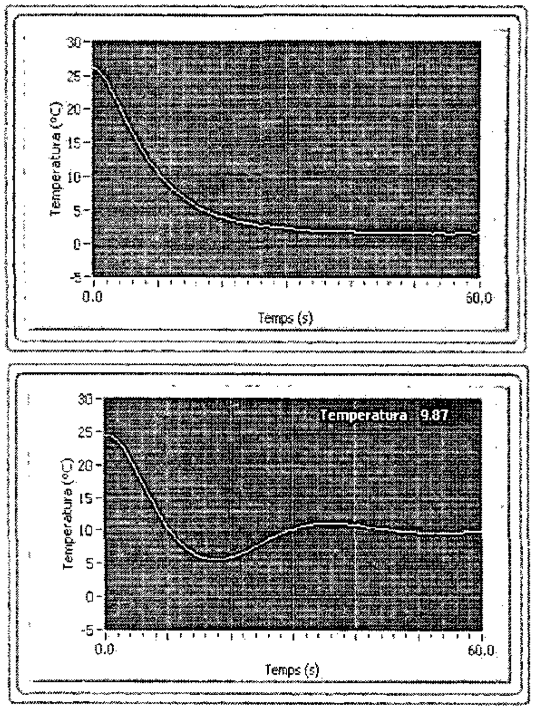

Figure 6.- Step response of open (upper) and closed (lower) loop of the Peltier cell.

4. Identification of the frequency response of tunable filters

A system under test, composed by a universal switched-capacitor filter (LMF100, National Semiconductor) has its input connected to the VXI arbitrary signal generator. Both input and output are connected to the two channels of the 20 MSa/s digitizer. The high-pass, low-pass, band-pass or notch structures can be selected through the VXI switching matrix and the characteristic frequency of each realization can be selected by the control software in the 2 kHz to 100 kHz range using the clock signal. The frequency response up to 7 MHz can be determined using spectral estimators of the input and output signals. Waveform, signal and acquisition parameters and windowing can be selected among several options. This experiment is prepared for the use of uploadable VI's, but this option is not currently enabled for security reasons.

C. Implementation of the remote lab sessions

Semi-distance students have a lower amount of traditional lab sessions due to the need of devoting several sessions to course management and assessment. The remote lab is then used to save time in the normal lab sessions, where the students can dedicate to the qualitative observation of circuits and sensors behavior, discharging those sessions of the need of obtaining correct sets of quantitative results to be processed. These results can be obtained remotely, over a controlled experiment similar to which they have built in the lab, being every realization of these experiments unique. By this way, the data analysis is split of the lab experiment success.

The remote lab sessions are not, however, limited to data harvesting operations. The students access each remote session a minimum of two times: First they set-up the experiment parameters and collect an initial set of data. After processing these data, they should re-enter and set-up additional parameters (calibration or control coefficients) as a result of their calculations. Then, they observe and collect the effect of their action and iterate the process if the result was not correct, according with the expected behavior of the circuit they have set-up in the corresponding conventional lab session.

IV. CONCLUSIONS

There is a considerable amount of remote labs and plenty of simulated, virtual labs. The aim of our work was not the definition of an original, unique solution but the implementation of a remote laboratory that solved our educational needs. The resulting design offers a set of features and characteristics that differentiate this remote lab from others and, from our point of view, presents several advantages:

- Specifically focused to Instrumentation and Signal Conditioning for Sensors.
- Remote sessions planned as a complement to normal lab sessions, allowing the separation between the experiment success and the data collection and processing.
- Uniqueness of the data obtained in the remote lab sessions thanks to the dependence on thermal room conditions or random parameters.
- Interactive structure of the remote sessions, with an initial data collection, experiment set-up from the students' calculation results with these data, and final data collection with modified parameters.
- User interface focused to maximize the security of the remote lab server, with minimum or null download of software to the client computers.

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