A Flexible Instructional Electronics Laboratory with Local and Remote Lab Workbenches in a Grid

Ingvar Gustavsson
Blekinge Institute of Technology
Department of Signal Processing
SE-372 25 Ronneby, Sweden
ingvar.gustavsson@bth.se

Kristian Nilsson
Blekinge Institute of Technology
Department of Signal Processing
SE-372 25 Ronneby, Sweden
kristian.nilsson@bth.se

Lars Håkansson
Blekinge Institute of Technology
Department of Signal Processing
SE-372 25 Ronneby, Sweden
lars.hakansson@bth.se

Johan Zackrisson
Blekinge Institute of Technology
Department of Signal Processing
SE-372 25 Ronneby, Sweden
johan.zackrisson@bth.se

Javier Garcia-Zubia
University of Deusto
Faculty of Engineering
Apdo. 1, 48080 Bilbao, Spain
zubia@eside.deusto.es

Ingvar Claesson
Blekinge Institute of Technology
Department of Signal Processing
SE-372 25 Ronneby, Sweden
ingvar.claesson@bth.se

Thomas Lagö
Acticut AB
Gjuterivägen 7
SE-311 32 Falkenberg, Sweden
thomas.lago@acticut.com

Abstract

The Signal Processing Department (ASB) at Blekinge Institute of Technology (BTH) has created two online lab workbenches, one for electrical experiments and one for mechanical vibration experiments, mimicking and supplementing workbenches in traditional laboratories. Since some years, the workbenches are used concurrently with on-site ones in regular supervised lab sessions. The students are also free to use them on their own around the clock e.g. for preparation. The electronic workbench can be used simultaneously by many students. The aim of a project known as VISIR (Virtual Systems in Reality) founded by ASB at the end of 2006, is disseminating the online lab workbenches using open source technologies. The goal is to create a template for a grid laboratory where the nodes are workbenches for electrical experiments, located at different universities. This paper focuses on standards, pedagogical aspects, and measurement procedure requirements.

1   Introduction

During centuries scientists have performed physical experiments in order to verify and test theories and create proper mathematical models, describing reality well enough. Such experiments are the only way to "communicate" with nature and to learn its principles, often quite revealing. Only recently, it has been evident that mankind must live in symbiosis with nature and focus on sustainability and understanding. Thus, the demand for experimenters will increase. However, during recent decades the amount of hands-on laboratory work, for example, in engineering education has been reduced. The prime cause is clearly the task of handling the greatly increased student numbers, while staff and funding resources have scarcely changed [1].

Reducing the number of lab sessions is easy because laboratory work is seldom evaluated and the cost reduction obtained is often considerable. However, for example, ABET (Accreditation Board for Engi-

neering and Technology) in USA has pointed out that learning objectives for laboratory work must exist and be evaluated [2, 3]. Thus, the amount of hands-on laboratory work in a course must be correlated to the learning objectives of the course. Unfortunately, a substantial rise of base funding resources is not probable.

It is, of course, also fundamental for students to understand theories and mathematical models. Often appropriate and low cost tools are hand calculations and simulations. The use of computer simulations has increased very much in engineering education in the last decades. However, to properly assess differences between mathematical models and real world, experiments are indispensable [4, 5]. On the other hand traditional laboratories have limited accessibility and high running costs.

Nowadays, students want an extended accessibility to learning resources and increased freedom to organize their learning activities which is also one of the main objectives of the Bologna Process. From a technological perspective, such flexible education corresponds to an adequate exploitation of information, communication devices and infrastructures, especially the Internet. Today, many academic institutions offer a variety of web-based experimentation environments so called remote laboratories that support remotely operated physical experiments [6-9]. This is one way to compensate for the reduction of lab sessions with face-to-face supervision.

The remote or online laboratories around the world are used in a variety of disciplines. However, the wide range of user interfaces is a problem for students and teachers. Efforts are being made to handle the situation. The iLabs project at Massachusetts Institute of Technology in USA, for example, has developed a suite of software tools that facilitates online complex laboratory experiments, and provides the infrastructure for user management [10]. A somewhat different approach would be to create a grid laboratory where the nodes are online lab workbenches distributed among a number of universities or other organizations. In such a laboratory intended for the same type of experiments it would be possible to organize supervised lab sessions with as many students or student teams working concurrently as are optimal for one instructor. Such supervised lab sessions could, for example, take place in a traditional laboratory where some students could use the local lab workbenches and others could perform the experiments remotely on distant grid nodes. Then it should be possible for each university to offer more time in the laboratory for its students.

In 1999, ASB started a remote laboratory project. Today ASB has two online lab workbenches, one for electrical experiments and one for mechanical vibration experiments, based on the BTH Open Laboratory concept [11]. The concept is about providing

new possibilities for students to do laboratory work and become experimenters by adding online lab workbenches to traditional instructional laboratories to make them more accessible for students, whether they are on campus or mainly off campus. These workbenches are equipped with a unique interface enabling students to recognize on their own computer screen the instruments and other equipment most of them have previously used in the local laboratory.

At the end of 2006, ASB started the VISIR project together with National Instruments in USA and Axiom EduTech in Sweden, to disseminate the online laboratories at BTH using open source technologies. Axiom EduTech is a supplier of education, technical software, and engineering services for noise and vibration analysis. The project is financially supported by BTH and by VINNOVA (Swedish Governmental Agency for Innovation Systems).

What type of instructional laboratory would be feasible for creating a template for a grid laboratory? There are reasons for starting with a grid laboratory for electrical experiments:

- There are instructional electronics laboratories at most universities around the world containing the same equipment, (oscilloscopes, waveform generators, multi-meters, power supplies, and solderless breadboards) although models and manufacturers may vary. Such laboratories are already in a way a de facto standard.

- There are standards defining the functionality for instruments common in an electronics laboratory. The IVI Foundation is a group of end user companies, system integrators, and instrument vendors, working together defining standard instrument programming interfaces [12].

- Today BTH has an online electronics laboratory running in regular education where the software produced is released as open source [13].

Then this template can be used for designing grid laboratories for other areas. ASB has identified a laboratory for mechanical vibration experiments as an appropriate candidate because those lab workbenches are very expensive and the mathematical models are not accurate enough even for introductory courses.

2 The Open Electronics Lab at BTH

An experiment is a set of actions and observations, performed in the context of solving a particular problem. Experiments are cornerstones in the empirical approach to acquire a deeper knowledge of the physical world but also an important approach to verify that a model is accurate enough. The experimenter sets up and operates the experiment with his or her hands and/or with actuators. As an example, a lab

workbench in an instructional laboratory for low-frequency analog electronics at BTH is shown in Fig. 1. The student wires a test circuit on the breadboard with the fingers and uses instruments to measure what s/he cannot perceive directly with the human senses as, for example, the electrical current. The experiments possible to perform in this environment are mainly limited by the set of components provided by the instructor.
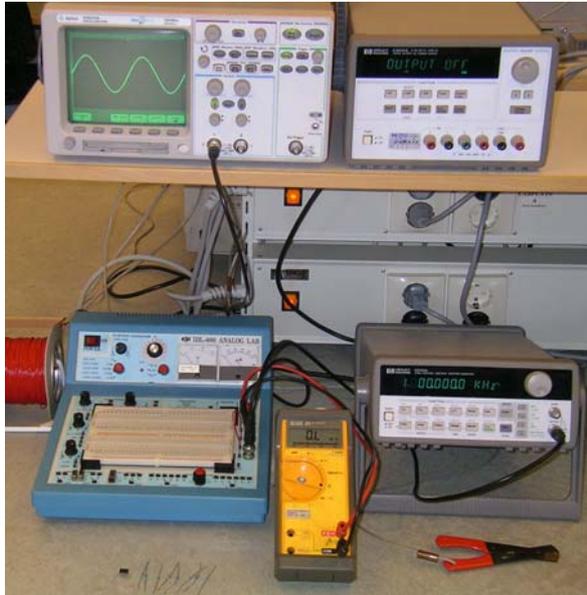

Figure 1: Workbench in a local electronics laboratory at BTH

In instructional laboratories at most universities, there are a number of lab workbenches where the same number of students or usually pair of students performs experiments supervised by an instructor. The students are permitted to be in the laboratories only during lab sessions when an instructor is present. The number of lab workbenches in a laboratory is usually selected, considering how many students an instructor can supervise if a workbench is not too expensive. Typically, electronics instructional laboratories are equipped with eight identical workbenches. Fewer lab workbenches mean more teaching hours per course but less investment. It is a pedagogical advantage if the lab workbenches are identical because the students can then perform the same experiments in each session and in the correct order required by the syllabus. On the other hand, it implies larger investments i.e. more duplicates of each instrument [9].

In electronics, it is possible to perform the same experiment in different time scales by selecting the electrical size of the components. This "feature" is used in the online electronics laboratory at BTH containing only one workbench to allow simultaneous access by time sharing. A single workbench can replace a whole laboratory with many workbenches. The maximum duration of a single experiment i.e.

circuit creation and measurement procedure is currently set to 0.1 second to get a reasonable response time even with a large number of experimenters. The experiments are set up locally in each client computer. Only by pressing a *Perform Experiment* button the experimenter sends a message containing a description of the desired circuit and the instrument settings to the workbench (server). If the workbench is not occupied, the experiment procedure is performed in a predefined order, and the result or an error message is returned to the requesting client computer. Otherwise, the request is queued.

The online lab workbench at BTH is different versus the traditional one in Fig.1. It is, of course, not possible for students to manipulate the components and wire a desired circuit on the breadboard with their fingers remotely. A type of circuit-wiring robot e.g. a relay switching matrix must be used. The instruments are plug-in boards installed in the PXI chassis connected to the host computer as shown in Fig. 2. This chassis and its contents are manufactured by National Instruments. The corresponding virtual front panels are photographs of the front panels of the instruments in Fig. 1. As an example, a screen dump displaying the multi-meter is shown in Fig. 3. The card stack on the top of the PXI chassis in Fig. 2 is the switching matrix. A subset of the components a teacher or the laboratory staff has installed in the matrix is displayed on the client computer screen adjacent to a virtual breadboard where the student wires the desired circuit to control the matrix. It is possible to assemble a circuit with up to 16 nodes by engaging a number of relays in the matrix. Apart from a controller board the card stack contains two types of board: one with component sockets and one for connecting instruments. The nodes passing all boards can be connected to sources, instruments, and/or components installed in the sockets via relay switches. The online electronics laboratory at BTH is used in three ways:

- In supervised lab sessions in the local laboratory where the students can select if they want to perform the experiments locally or remotely. However, in the first lab session it is mandatory to do the wiring on the real breadboard.

- In supervised lab sessions in distance learning courses where the students are scattered all over the country. Various communication methods are used to communicate between the students themselves and between the students and the instructor.

- Students can prepare supervised lab sessions and perform the experiments at home knowing that the equipment in the traditional laboratory look the same and behave in the same way. They can also repeat experiments afterwards. Especially inexperienced or less confident students requiring more time appreciate these

possibilities. A student wanting, for example, to master the oscilloscope can practice at home without anybody watching.

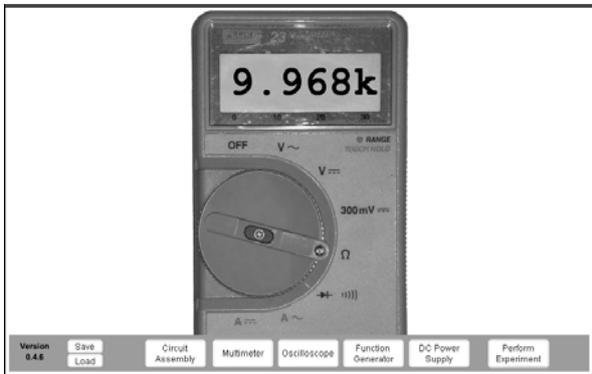

Figure 2: Equipment Server

Figure 3: Screen dump showing the multimeter

So far the research has been focused on recreating as accurately as possible the laboratory experience for the remotely based learner. Remote desktop software and MS Messenger has been used for communication. More advanced communication means will be adopted [14].

3 The VISIR project

The aim of the VISIR project is to form a group of cooperating universities and other organizations, a VISIR Consortium, creating/modifying software modules for online laboratories using open source technologies and setting up online lab workbenches [15]. A number of such scattered lab workbenches may be nodes in a grid laboratory. The VISIR Initiative is not confined to electronics laboratories but the VISIR project has started with lab workbenches for electrical experiments, since that is an easy and straightforward application to demonstrate the powerful concept. So far, the following universities are participating or are interested in participating in the project FH Campus Wien in Austria, University of Deusto in Spain, University of Genoa in Italy, Prin-

cess Sumaya University for Technology in Jordan, Carinthia University of Applied Sciences in Austria, Gunadarma University in Indonesia, UNINOVA (Institute for the Development of New Technologies) in Portugal, and ISEP (Instituto Superior de Engenahria do Porto) in Portugal. The first two universities have already implemented online workbenches using the currently released software. BTH will act as a hub for the development and maintain a server from which the current version of the software can be downloaded.

The overall goal of the VISIR project is aimed at increasing the access to experimental equipment in many areas for students, without raising the running cost per student significantly for the universities. The means are shared online laboratories created by universities in cooperation and supported by instrument vendors. Sharing of laboratories may lead to sharing of course material. The ultimate goal of our research at BTH is ubiquitous physical experimental resources, accessible 24/7 for everyone, gender neutral, as a means of inspiring and encouraging children, young people and others to study engineering and become good professionals or to be used as a means of life-long learning.

4 A grid laboratory for electrical experiments

Grid computing has emerged as a way to harness and take advantage of computing resources across geographies and organizations. Grid architecture for an electronics laboratory similar to the BTH one has been published [16, 17]. In this grid-based laboratory a measurement workflows execution service takes care of executing the measures according to the rules and sequence described in a measurement workflow repository. It invokes instrument services and manages multi-user concurrent sessions on the same physical test bench. The composition of measurement workflows is in charge to teachers, who provide the description of the measurement process in terms of, for example, instruments activation process. Sharing one lab workbench is the same approach as in the current online laboratory at BTH. On the other hand knowing how to handle the measurement process is an important part of lab assignments. To display a transient on the oscilloscope, for example, the oscilloscope must first be armed and then the transient is started. Each student or student team in front of a client computer should have a workbench at their own disposal for exclusive access as in the local laboratory. Then the *Perform Experiment* button is no longer required.

It should be possible to organize a grid laboratory distributed among universities around the world. The workbenches should be the proper grid nodes. Smaller nodes are not feasible because the instru-

ments and the circuit under test must be located close together. The instruments and the circuit creation manipulator would be device services accessible by the lab clients via virtual front panels or a virtual breadboard, Fig. 4, 5. Web services prescribe XML-based messages conveyed by Internet protocols such as SOAP. However, real time performance requires protocols without significant latencies and overhead. For example, the oscilloscope display should be updated at least every second.
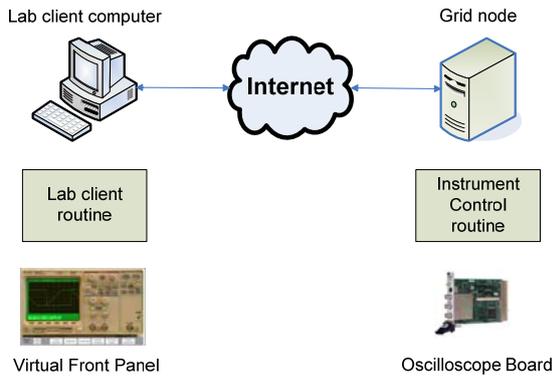

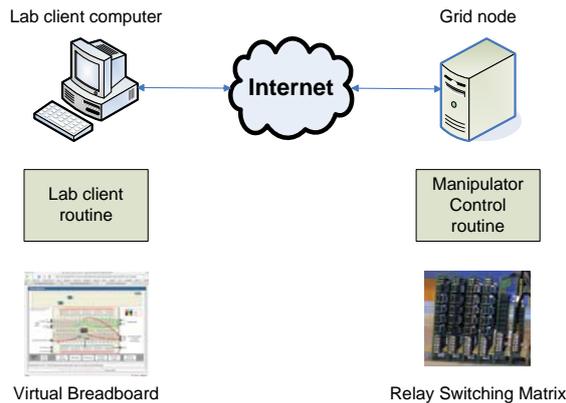**Figure 4: Oscilloscope service**

Figure 4: Wiring service

It is possible to combine a virtual front panel representing a particular instrument from one manufacturer with the corresponding hardware from another as long as the performance of the hardware matches that of the depicted instrument. The VISIR client software package is modular and it is recommended that every university creates virtual front panels representing the instruments they have in their local laboratories to preserve the student's context.

Instrument I/O is a well-studied domain with established industrial standards. Most commercial products follow the Virtual Instrument System Architecture (VISA) or the Interchangeable Virtual Instrument (IVI) standards [18]. The IVI foundation creates instrument class specifications. There are currently eight classes, defined as DC power supply, Digital multi-meter (DMM), Function generator, Oscilloscope, Power meter, RF signal generator,

Spectrum analyzer, and Switch. Within each class a base capability group and multiple extension capability groups are defined. Base capabilities are the functions of an instrument class that are common to most of the instruments available in the class. For an oscilloscope, for example, this means edge triggering only. Other triggering methods are defined as extension capabilities. For example, the functions supported by the VISIR oscilloscope are listed in Table 1. The goal of the IVI Foundation is to support 95% of the instruments in a particular class.

Table 1: The VISIR oscilloscope capabilities

Group Name	Description
`IviScopeBase`	Base Capabilities of the IviScope specification. This group includes the capability to acquire waveforms using edge triggering.
`IviScopeWaveformMeas`	Extension: IviScope with the ability to calculate waveform measurements, such as rise time or frequency.
`IviScopeTriggerModifier`	Extension: IviScope with the ability to modify the behavior of the triggering subsystem in the absence of a expected trigger.
`IviScopeAutoSetup`	Extension: IviScope with the automatic configuration ability.

It is not necessary to use IVI drivers but to enable interchangeability between grid nodes VISIR recommends functions and attributes defined by the IVI Foundation to be used to describe the capabilities of the lab hardware. In this way it should be possible to create a standardized approach which is easy to adopt.

5   Conclusions and future work

BTH is disseminating software for an online workbench comprising the same equipment as a workbench in a traditional instructional electronics laboratory. Two universities have already implemented such workbenches using the VISIR software. A number of students can perform experiments on each of these online workbenches simultaneously by time sharing. However, each remote student or student team should have a workbench at their own disposal to be able to control each step of the measurement process. A way to reach this ideal situation would be increasing the number of online workbenches and organize them in a grid. Further research seems to be required to get real time performance comparable

with that of the local workbench when a web service approach is to be adopted. The goal is to offer free access to experimental equipment for students and a lab experience that is as genuine as possible despite the lack of direct contact with the actual lab hardware. The universities will also be able to produce experimenters without increased running cost per student.

References

[1] D. Magin and S. Kanapathipillai, "Engineering Students' Understanding of the Role of Experimentation", *European Journal of Engineering Education*, 2000, Vol. 25, no. 4, pp. 351-358

[2] L. D. Feisel and A. J. Rosa, "The Role of the Laboratory in Undergraduate Engineering Education", *Journal of Engineering Education*, January 2005, pp 121-130.

[3] Cooper, M., "Remote laboratories in teaching and learning – issues impinging on widespread adoption in science and engineering education", *International Journal of Online Engineering*, Vol. 1 No. 1, 2005.

[4] Nedic, Z., Machotka, J., and Nafalski, A., "Remote Laboratories Versus Virtual and Real Laboratories", *Proceedings of the 33rd ASEE/IEEE Frontiers in Education Conference*, Bolder, USA, November 5 – 8, 2003.

[5] J. Ma, and J. V. Nickerson, "Hands-on, simulated, and remote laboratories: A comparative literature review", *ACM Computing Surveys*, 2006.

[6] D. Gillet, A. V. N. Ngoc, and Y. Rekik, "Collaborative Web-Based Experimentation in Flexible Engineering Education", *IEEE Transactions on Education*, Vol. 48, No. 4, November 2005 .

[7] Z. Nedic and J. Machotka, "Remote Laboratory Net-Lab for Effective Teaching of 1st Year Engineering Students", *Proceedings of the REV 2007 Conference*, Porto, Portugal, June 25 – 27, 2007.

[8] A. M. Scapolla, A. Bagnasco, D. Ponta, and G. Parodi, "A Modular and Extensible Remote Electronic Laboratory", *International Journal of Online Engineering*, Vol. 1 No. 1, 2005.

[9] J. Garcia-Zubia et al., "WebLab-GPIB at the University of Deusto", *Proceedings of the REV 2007 Conference*, Porto, Portugal, June 25 – 27, 2007.

[10] iLabs: Internet access to real labs - anywhere, anytime, http://icampus.mit.edu/iLabs/, 2007-07-20.

[11] L. Gomes and J. Garcia-Zubia (eds), Chapter 11 in *Advances on remote laboratories and e-learning experiences*, University of Deusto, Bilbao, Spain, 2007, pp. 247 – 267, ISBN 978-84-9830-077-2.

[12] http://www.ivifoundation.org/, 2007-12-15.

[13] I. Gustavsson et al., "An Instructional Electronics Laboratory Opened for Remote Operation and Control", *Proceedings of the ICEE 2006 Conference,* San Juan, Puerto Rico, July 23 - 28, 2006.

[14] MJ. Callaghan, J. Harkin, TM. McGinnity and LP. Maguire, "Paradigms in Remote Experimentation", *International Journal of Online Engineering*, Vol. 3 No. 4, 2007.

[15] I. Gustavsson et al., "The VISIR project – an Open Source Software Initiative for Distributed Online Laboratories", *Proceedings of the REV 2007 Conference*, Porto, Portugal, June 25 – 27, 2007.

[16] A. Bagnasco, A. Poggi, A. M. Scapolla, "A Grid-based Architecture for the Composition and the Execution of Remote Interactive Measurements, "*2nd IEEE International Conference on e-Science and Grid Computing*, Amsterdam, the Netherlands, Dec. 2006.

[17] A. Bagnasco, A. Poggi, A. M. Scapolla, "Computational GRIDSs and Online Laboratories", *1st International ELeGI Conference on Advanced Technology for Enhanced Learning*, 2005.

[18] Y. Yan, Y. Liang, X. Du, H. Saliah-Hassane, and A. Ghorbani, "Putting Labs Online with Web Services", *IT Pro*, March/April 2006, Published by the IEEE Computer Society.