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

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***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. For several years now, the workbenches have been used concurrently with on-site ones in regular, supervised lab sessions. The students are encouraged to use them on a 24/7 basis for example, in preparation for supervised sessions. 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 to disseminate 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.**

***Index Terms*—Electronics, Grid, Remote labs, Workbench.**

I. INTRODUCTION

For centuries, scientists have performed physical experiments in order to verify and test theories, and to create proper mathematical models, to describe reality well enough. Such experiments are the only way to "communicate" with nature and to learn its principles. Only recently has it become 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 due to the task of handling the dramatically increased number of students, whilst 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 Engineering and Technology) in the USA has demonstrated that learning objectives for laboratory work must exist and subsequently, be evaluated [2, 3]. Thus, the amount of hands-on laboratory work in a course must be correlated to its learning objectives. Unfortunately, a substantial rise in base funding resources is unlikely to manifest itself in a real life environment.

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

Nowadays, students want 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 address this situation. The iLabs project at Massachusetts Institute of Technology in the USA, for example, has developed a suite of software tools that facilitates online complex laboratory experiments, and provides an 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 began 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 that 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 the 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 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 code [13].

This template can be used for designing grid laboratories for other areas of interest. ASB has identified a laboratory for mechanical vibration experiments as a strategic and appropriate candidate, because those lab workbenches are very expensive and mathematical models generally provide a too simplified picture of the reality, even for introductory courses. Measured vibration signals frequently exhibit complicated properties compared to the vibration signal models frequently utilized in education. Selecting appropriate estimators and estimator settings, enabling extraction of different accurate estimates of vibration quantities from measured vibration signals, generally provides a substantial challenge for the inexperienced person. Moreover, the dynamic properties of a mathematical model of a structure and the actual dynamic properties of said structure, generally differ. Of significance; an online mechanical vibration laboratory provides the opportunity for engineering students to access the practical and theoretical knowledge advancement in experimental vibration analysis that is highly attractive for the industry.

II. 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/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 using his/her fingers and uses instruments to measure what s/he cannot perceive directly with human senses as, for example, the electrical current. Experiments that are possible to perform in this environment are mainly limited by the set of components provided by the instructor.

In instructional laboratories at most universities, there are a number of lab workbenches where the same number of students, or usually a pair of students, perform 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 number of experiments in each session and in the correct order as required by the syllabus. Alternatively, 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 values of the components controlling the time constants properly. 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

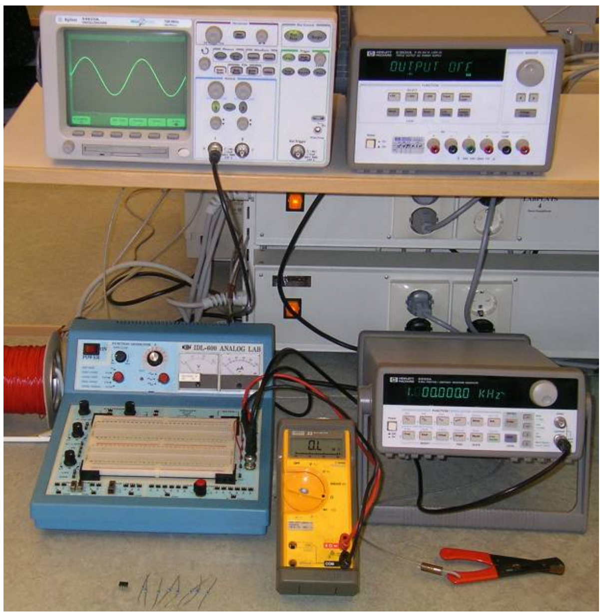

Figure 1. Workbench in a local electronics laboratory at BTH

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 when compared with the traditional one in Fig.1. It is, of course, not possible for students to manipulate the components and to remotely wire a desired circuit on the breadboard using their fingers. A telemanipulator e.g. a relay switching matrix must be used. The instruments are plug-in boards installed in a PXI chassis connected to a 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 oscilloscope, 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 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 for distance learning courses, where the students are scattered all over the country. Remote desktop software and MS Messenger has been used to communicate between the students themselves and between the students and the instructor. More advanced means of communication will be adopted [14].
- Students can prepare supervised lab sessions and perform the experiments at home, knowing that the equipment in the traditional laboratory looks and behaves in a similar fashion. They can also repeat experiments afterwards! Inexperienced or less confident students requiring more time, appreciate these possibilities. A student wanting, for example, to master the oscilloscope, can practice in the privacy of his/her own home.

Figure 2. Equipment Server

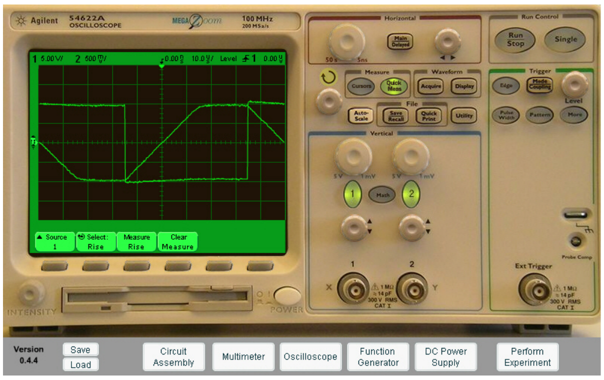

Figure 3. Screen dump showing the oscilloscope

So far, the research has been focused on recreating as accurately as possible, the laboratory experience for a remotely based learner.

III. 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 this 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, Princess 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 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 the 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.

IV. 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 already been published [16, 17]. In this grid-based laboratory, a measurement workflow 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. 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 activated. 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 in the BTH laboratory 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 instruments and the circuit under test must be located closely 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.

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 displayed 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.

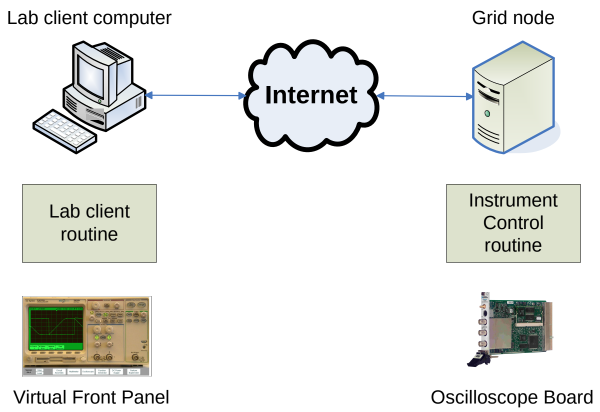

Figure 4. Oscilloscope service

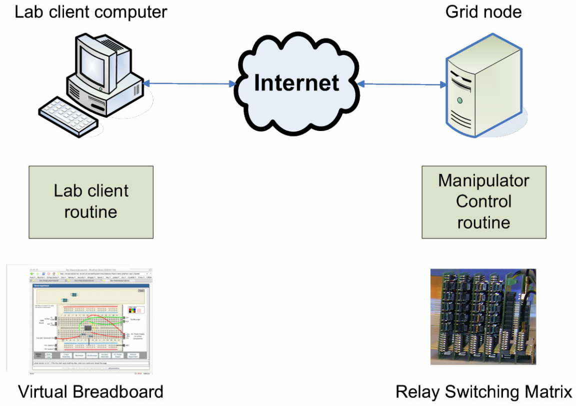

Figure 5. Wring service

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.

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.

TABLE I.
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.

V. CONCLUSIONS AND FUTURE WORK

BTH is disseminating software for an online workbench, comprising the same equipment as a workbench in a traditional electronics laboratory. The equipment used in the BTH workbenches form robust references for universities who are interested in implementing similar remote or online laboratories. A number of students can perform experiments on such a workbench simultaneously by time sharing. This will be a way for universities to provide free access to experimental equipment for their students in order to produce true experimenters without increased running cost per student. Two universities have already implemented such workbenches using the VISIR software, and are now using them in their own courses. 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. An approach to reach this more ideal situation would be constituted by increasing the number of online workbenches and organizing them in a grid. Further research is required to accomplish real time performance comparable with that of the local workbench, when a web service approach is to be adopted. The goal is to offer a lab experience that is as genuine as possible, despite the lack of direct contact with the actual lab hardware. Other research groups have developed advanced communication methods, appropriate for a grid laboratory. Such methods will be adopted.

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