Open your laboratories for remote access to offer experimenting for students on-campus or off-campus 24/7

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ABSTRACT: Physical experiments are indispensable because they offer the only possibility of seeing differences between mathematical models of nature and nature itself. It is possible to increase the capacity of instructional laboratories without raising the cost per student significantly by opening them for remote access and lab work 24/7. In this paper an on-line workbench mimicking a hands-on workbench in a laboratory for electrical experiments is presented. Here mimicking means that students on their computer screen are able to recognise the instruments and other equipment that most of them previously have used in a hands-on laboratory. In the on-line workbench, mouse-cursor-on procedures supplements hands-on ones. At the end of 2006, the Department of Electrical Engineering (AET) at Blekinge Institute of Technology (BTH) in Sweden started a project known as Virtual Instrument Systems in Reality (VISIR) to disseminate the lab concept now denoted the VISIR Open Lab Platform. The software representing 20 person-years of work is published as open source. So far, three other universities have implemented replicas of the on-line workbench at BTH.

INTRODUCTION

Only recently has it become evident that mankind must live in symbiosis with nature and focus on its sustainability. Thus, mankind has to adapt to, and meet the demands of, nature, i.e. improve present technologies, develop new technologies, etc. Here, information extracted from measurements of nature's response to applied technologies is crucial. This, in turn, requires that people are able to make relevant and accurate measurements on nature, as well as making appropriate analyses that provide estimates of relevant quantities of the measured data. Thus, the demand for engineers with documented laboratory experience should increase [1]. This demand is very much in line with the Bologna Process, where universities are required to declare the developed skills of graduate engineers, and the aims and learning outcomes for each course. Still, a substantial rise in base funding resources is unlikely to happen. Furthermore, students nowadays want extended accessibility to learning resources and an increased freedom in organising their own 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 usage of information, communication devices and infrastructures, especially the Internet [2].

AET started a remote laboratory project as a feasibility study in 1999. The vision was to create an on-line replica of a traditional hands-on laboratory workbench for electrical experiments in order to provide free access to the laboratory for the students. Figure 1 shows a hands-on workbench in a laboratory for electrical experiments at BTH. The small components (an operational amplifier and 8 resistors) in the lower left corner of Figure 1 at the arrow are the set of components provided by the instructor to be used in a laboratory session. An on-line workbench can supplement such workbenches, enabling students to perform physical electrical experiments 24/7 within limits set by the teacher, using a Web browser only. The on-line workbench will be presented in the next section.

Today, many academic institutions offer a variety of Web-based experimentation environments, so-called remote laboratories that support remotely operated physical experiments [3-5]. These are new tools enabling universities to provide students with free experimentation resources without a substantial increase in cost per student. At the end of 2006, AET started a project known as Virtual Instrument Systems in Reality (VISIR) together with National Instruments in USA and Axiom EduTech in Sweden, to disseminate the on-line workbench concept created at BTH using open source technologies in collaboration with other universities and organisations. The VISIR project will be presented in a later section.

THE VISIR ON-LINE WORKBENCH MIMICS A TRADITIONAL ONE

Most instruments in a laboratory for electrical experiments have a remote control option but the solderless breadboard has not. Remote wiring of circuits requires a wiring manipulator that it is possible to control remotely. A switching

matrix equipped with controllable switches, i.e. electro-mechanical relays, can serve as such a device. Figure 2 shows an on-line workbench at BTH and replicas of this workbench are on-line at three other universities outside Sweden. The desktop instruments are replaced by PXI instruments. PXI (PCI eXtensions for Instrumentation) is an international standard for instrumentation. PXI instruments are PC-controlled plug-in boards with a tiny front panel fitted with connectors only.

Usually, the control knobs and buttons of these instruments are displayed on the monitor of the controller of the PXI system. An example of such a virtual front panel is shown in Figure 3. The chassis and the instruments in Figure 2 were manufactured by National Instruments. 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.
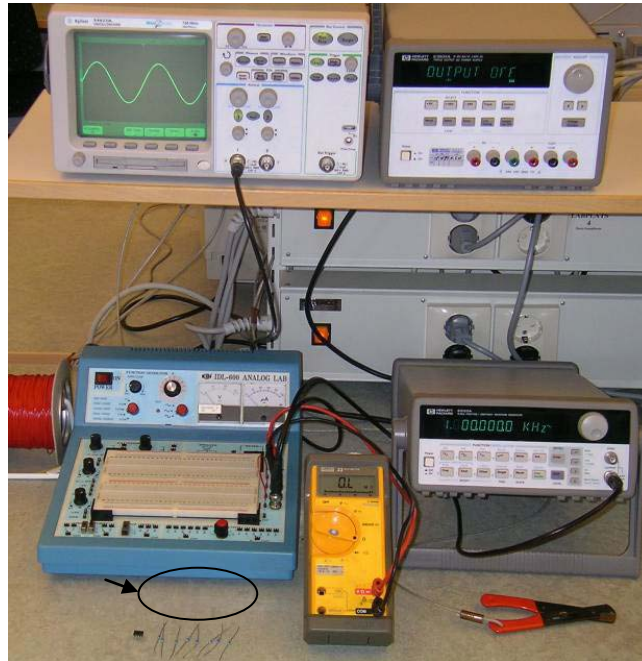

Figure 1: A workbench for electrical experiments in a laboratory at BTH.

Most universities around the world have hands-on workbenches similar to the one in Figure 1. It is a kind of *de facto* standard. However, instrument brands and models vary. An on-line workbench should provide a number of, for example, oscilloscope models to allow students or the teacher to select the model they want. In fact, the laboratory platform offers a virtual instrument shelf (Figure 4).

In the upper part of Figure 4 all instruments available are displayed and the lower part shows the instruments currently selected. Currently, the soft panels belonging to the PXI instruments and to the instruments of the workbenches at the BTH laboratories are available on the shelf. The client software package is modular and it is recommended that every university creates virtual front panels representing the instruments they have in their hands-on laboratories, to preserve the student's context.

Figure 2: The online workbench at BTH.

The switching matrix for remote wiring of electrical circuits is shown at the upper left side of Figure 2. It is the card stack on the top of the PXI chassis. The relays are arranged in a three-dimensional pattern together with instrument connectors and component sockets. Sets of components for a number of laboratory sessions are installed in component sockets at the edge of some of the boards of the switching matrix [6]. The PC to the right in the figure controls the workbench.
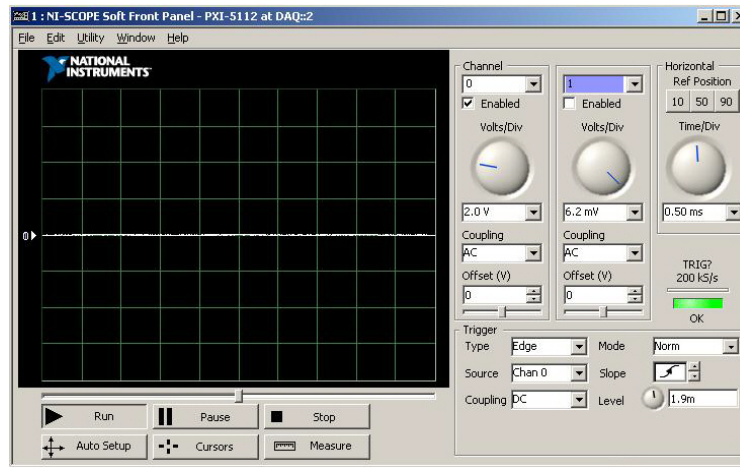

Figure 3: Virtual front panel of an oscilloscope.

STUDENTS WIRE DESIRED CIRCUITS USING A VIRTUAL BREADBOARD

A virtual breadboard shown in Figure 5 is used as a *virtual front panel* of the switching matrix. The breadboard is a photograph of an ordinary physical solderless one. Thus, the students control the matrix hardware by wiring on the virtual breadboard using the mouse. A short video demonstration can be accessed at the following site on the Internet: http://openlabs.bth.se/static/video/Opamp.html

A software module called Virtual Instructor checks that every circuit is safe before it is activated, i.e. that neither a component nor an instrument can be damaged. The laboratory staff creates the rules for the Virtual Instructor when configuring the matrix. Thus, it is up to the laboratory staff to make sure that no hazardous circuit can be created physically.
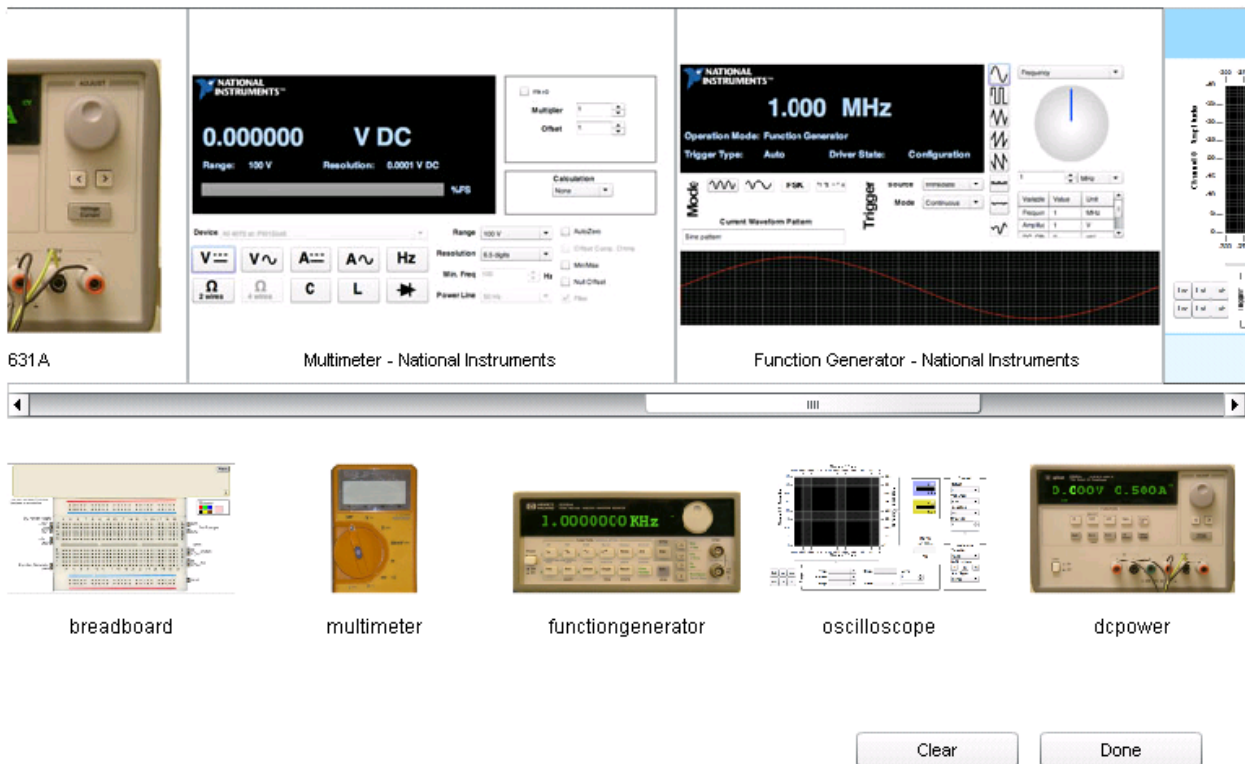
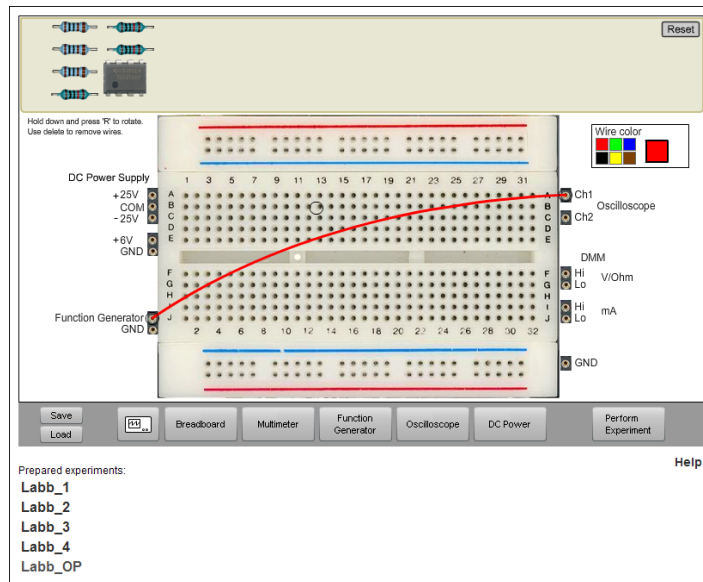

Figure 4: Virtual instrument shelf.

Figure 5: Virtual breadboard view.

MANY REMOTE STUDENTS CAN PERFORM PHYSICAL EXPERIMENTS SIMULTANEOUSLY USING MODEM SPEED INTERNET CONNECTIONS

By selecting appropriate values of the components controlling the time constants, it is possible to study a certain phenomenon at different timescales. This *feature* of electronics is used in the on-line workbench to allow simultaneous access for many students by time-sharing. In this way, the workbench can emulate a whole hands-on laboratory. Still, the students can use all the time they need to wire their circuit and set up the instruments because they do it in their local computer.

The desired circuit and the instrument set-up are sent to the server only when they press the *Perform Experiment* button. Then, the client software 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, and the result or an error message is returned to the requesting client computer. Otherwise, the request is queued and is executed in proper order. The current time-slice period is 0.1 second. The teachers who design the experiments to be performed in a laboratory session are instructed to select the values of the components so that an experiment lasts less than this period.

Time-sharing means that you can only get a single acquisition from the oscilloscope when you press the *Perform Experiments* button. The *Run/Stop* button on the Agilent oscilloscope is red. However, if the administrator allows run mode, the *Run/Stop* button will be green when pressed. Then, run mode of the oscilloscope will be emulated and repetitive acquisitions ensue without the need to press the *Perform Experiments* button repetitively. To stop run mode the *Run/Stop* button should be pressed again. The reason why the administrator may not allow run mode is that the response time will be longer for other users who are on-line. Two types of error, which are special for the online version of the laboratory, are reported:

- The Virtual Instructor finds the desired circuit hazardous.
- The desired circuit may be safe but the Virtual Instructor has not been instructed to allow it.

The messages sent to and from a client machine is short. A message containing two oscilloscope traces is two kB. All other messages are shorter. The client software module is approximately 2.5 MB but it is downloaded only once. Thus, a modem connection is sufficient.

THE ON-LINE WORKBENCH IS USED IN REGULAR EDUCATION

The on-line workbench is used in three ways at BTH:

- In supervised laboratory classes in the local laboratory where students can select if they want to perform the experiments locally or remotely. However, in the first laboratory class, it is compulsory to do the wiring on the real breadboard. Fortunately, most of the students prefer the hands-on one.
- In supervised laboratory classes 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. In interviews, most of the distant students say they appreciate very much the possibility of participating from home in the supervised laboratory classes. They do not miss the hands-on version because they have experience from their work

of electronic instruments and components. Home experimentation could be a method for distant students without laboratory experience to acquire introductory hands-on experience and become familiar with electronic components and wiring, etc [7][8]. However, affordable devices such as an inexpensive multi-meter and/or a soundcard-based oscilloscope are only adequate for elementary experiments.

- Students can prepare supervised laboratory classes and perform the experiments at home, knowing that the equipment in the hands-on 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 practise in the privacy of his/her own home without anyone watching.

THE VISIR PROJECT

The VISIR project, which started at the end of 2006, is about disseminating the on-line workbench concept now called the VISIR Open Laboratory Platform [9]. Thus, VISIR does not provide prepared on-line experiments but offers a software distribution released under a GNU GPL licence and documentation, which can be used to implement on-line workbenches [10]. The aim of the VISIR project is establishing a VISIR Community of collaborating universities/organisations, further developing the laboratory platform and sharing laboratory resources and course material. The International Association of Online Engineering (IAOE) has organised a Special Interest Group for VISIR (SIG VISIR), for people interested in On-line Engineering, especially in opening university laboratories for remote access 24/7. The goal of the VISIR Community is to develop tools and methods, enabling universities to offer access to laboratory workbenches without raising the running costs per student. A side effect could be that many more people become interested in engineering education, if access is offered to the public when the equipment is not used in regular education.

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. 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 analyser, 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 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. 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 workbenches, VISIR recommends functions and attributes defined by the IVI Foundation be used to describe the capabilities of the laboratory hardware. In this way, it should be possible to create a standardised approach which is easy to adopt (Figure 6). The universities can use a variety of instrument platforms. Currently, VISIR supports PXI.
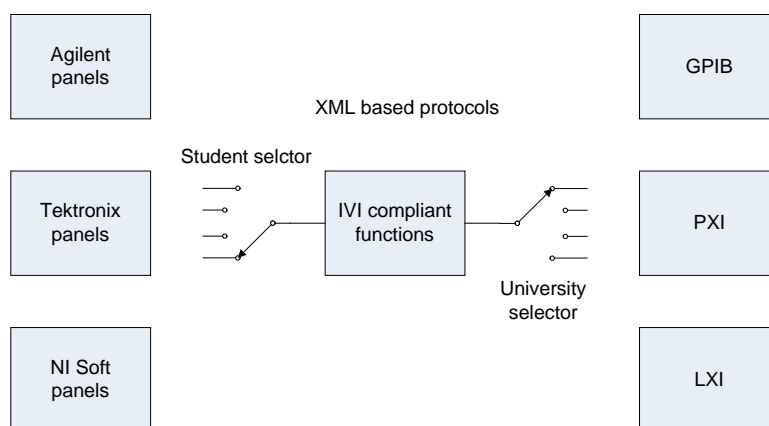

Figure 6: Virtual front panel and hardware platform selections.

CONCLUSIONS

A sustainable society needs engineers who are familiar with experimenting and laboratory work. Open instructional laboratories providing remote access and preserved context for students, not only offer physical experimentation 24/7 but also possibilities to practise laboratory work, albeit hands-on procedures are replaced by mouse-pointer-on ones. The platform can be used not only at university level but also in vocational education and life-long learning. It should be possible to access a VISIR on-line workbench from rural areas at modem speed connections only. The ultimate goal of the research on remote laboratories at BTH is ubiquitous physical experimental resources accessible 24/7 for students and for everyone as a means of inspiring and encouraging children, young people and others to study engineering or to be used as a means of life-long learning.

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