Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard

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Abstract—This paper reports on a state-of-the-art remote laboratory project called Virtual Instrument Systems in Reality (VISIR). VISIR allows wiring and measuring of electronic circuits remotely on a virtual workbench that replicates physical circuit breadboards. The wiring mechanism is developed by means of a relay switching matrix connected to a PCI eXtensions for Instrumentation (PXI) instrumentation platform. The entire equipment is controlled by LabVIEW server software, in addition to a measurement server software that protects the equipment from hazard connections by verifying input circuit designs, sent by students, before being executed. This paper addresses other approaches such as remote labs based on Data Acquisition Cards (DAQs), NetLab, and RemotElectLab, comparing them with VISIR in order to emphasize its singularity. Topics discussed are as follows: the technical description, software, operation cycle, features, and provided services. In addition, the feedback received by students at several universities and the encountered drawbacks along with the proposed solutions are highlighted. The paper finally addresses the ongoing and future challenges within the VISIR community including its integration with Learning Management Systems (LMSs) and iLab Shared Architecture (ISA), its new hardware version release that is based on LAN eXtensions for Instrumentation (LXI), and its new open platform version that supports federated access.

Index Terms—Computer uses in education, computer-aided engineering, electronics, emerging technologies.

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1 INTRODUCTION

THE Signal Processing Department (ASB) at Blekinge Institute of Technology (BTH) in Sweden together with National Instruments in the USA (as a supplier of instruments) and Axiom EduTECH in Sweden (as a supplier of education, technical software, and engineering services for noise and vibration analysis) launched the Virtual Instrument Systems in Reality (VISIR) Project (http://openlabs.bth.se/electronics) at the end of 2006. The project was financially supported by BTH and the Swedish Governmental Agency for Innovation Systems (VINNOVA).VISIR is a remote laboratory [1] for wiring and measuring electronics circuits on a breadboard remotely. The user designs and constructs her circuit via PC-mouse on a seamlessly simulated workbench that resembles the real lab elements and components. Once the designed

circuit is submitted, it is first sent to be verified, then it is sent to be wired and measured by real instruments, and finally, it is received by the user on her PC-screen in real time [2]. VISIR allows realizing real measurement on physical equipment, which is not possible to achieve using simulation software. For instance, the resistance of a 10k Ω resistor may vary due to many factors such as temperature and hours of utilization. Thus, its real value measured by VISIR is not the same as its simulated value measured by an electronic circuit simulation software such as NI Multisim (www.ni. com/multisim/); the value measured by VISIR is 9.958k Ω, while the value obtained by NI Multisimis 10k Ω, as demonstrated in Fig. 1.

So far, six universities have already implemented VISIR after Blekinge Institute of Technology: Carinthia University of Applied Sciences and FH Campus Wien for Applied Sciences, both in Austria; Polytechnic Institute of Porto (ISEP) in Portugal; University of Deusto and the Spanish University for Distance Education (UNED), both in Spain; and Madras Institute of Technology (IIT-M) in India. The following universities have shown their interest in participating in this project but they have not yet implemented it: University of Genoa in Italy, Princess Sumaya University for Technology in Jordan, Gunadarma University in Indonesia, Institute for the Development of New Technologies (UNINOVA) in Portugal, and College of the North Atlantica in Qatar. A Special Interest Group of VISIR (SIG VISIR) was created by the International Association of

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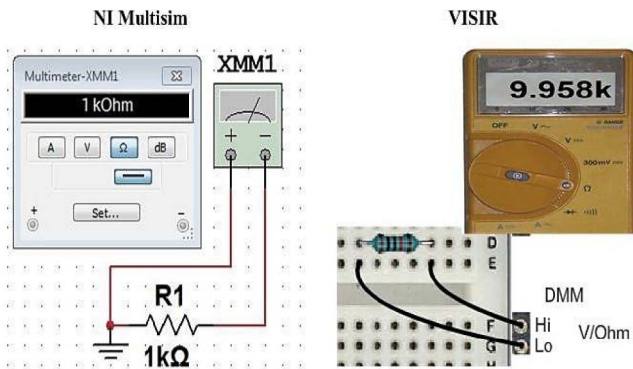
Fig. 1. Measuring a 10k Ω resistor using VISIR and NI Multisim.

Fig. 2. Topology of remote labs based on DAQ for electronic circuits measurement.

Online Engineering (IAOE) (www.online-engineering.org) to foster the collaboration within the community and to support the project dissemination.

A brief description of VISIR project was earlier presented by *IEEE Transaction on Learning Technologies* in [3]. Owing to the remarkable results achieved in its implementation and deployment in undergraduate engineering education at many universities [4], [5], [6], [7], as well as the widespread interest and the demands from researchers for further information and description of the project, this paper was released to accommodate these demands and to be an extension that updates the previously published one [3]. This paper compares the system with other emerging approaches and thoroughly details all the stages of the project development shedding light on its hardware and software aspects, operation cycle, provided services, installation, deployment experiences, drawbacks, as well as ongoing and future works. This is in order to promote the adoption of a new learning technology in undergraduate engineering education. This would pave the way for researchers to incorporate and contribute in the project development.

This paper is organized as follows: Section 2 addresses the related works, comparing them with VISIR. Section 3 describes the hardware components. Section 4 discusses the software development and the operation cycle. Section 5 outlines the main configuration keys. Section 6 reports on the deployment feedback received from several universities in general and from UNED in particular, along with the encountered shortcomings. Section 7 reports on the ongoing and future works that aim to enhance the system, increase its availability, and optimize its utilization. Finally, a conclusion is drawn in Section 8.

2 RELATED WORKS

2.1 Remote Labs Based on Data Acquisition Card (DAQ)

Remote laboratories for measurement of electronic circuits could be simply built by selecting appropriate lab server software such as Matlab, LabVIEW, or other software written from scratch by a high-level programming language, with connection to a DAQ that retrieves and sends digital and analog signals between the lab server and the measured circuit, Fig. 2. In addition, there are several modular types of instrumentation platforms, such as PCI eXtensions for 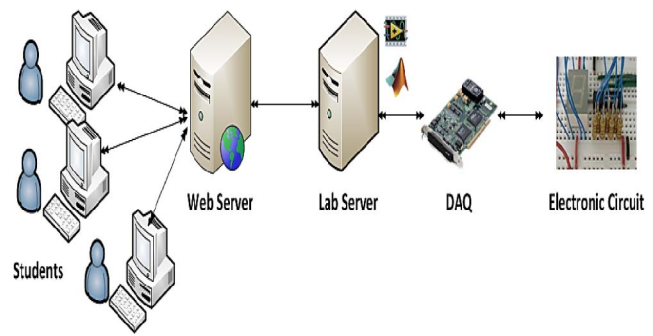Instrumentation (PXI), LAN eXtensions for Instrumentation (LXI), and general-purpose interface bus (GPIB or IEEE-488.2), which could be connected to the lab server in order to change the value of the circuit's parameters remotely. This combination has allowed the development of a wide range of remote digital signal processing (DSP) applications, among them electronic circuits' measurements. For instance, in [8], a remote lab is developed for recording the amplitude characteristics of a T-notch filter, I/O characteristics of a diode, I/O characteristics of PNP, and NPN transistors, characteristic of A and B class amplifiers, and characteristics of RC filters, and measuring circuits with operational amplifiers (adder, subtractor). In [9], 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. In [10], a remote lab is developed for measuring the characteristics of noninverting operational amplifier, integrators and differentiators, and half and full wave rectifier. In [11], a remote lab is developed for measuring I/O characteristics of a linear variable differential transformer (LVDT).

Most of the aforementioned approaches are based on measurement and monitoring of static circuits, as they only permit changing the instruments parameters of circuits. However, they still present a good alternative for their traditional counterparts.

2.2 RemotElectLab

RemotElectLab [12] is a remote laboratory for measuring electric and electronic circuits. It is based on the versatile design and prototyping educational integrated platform NI ELVIS (http://www.ni.com/nielvis/) that is released by National Instruments (NI) (www.ni.com/). NI ELVIS is integrated with 12 of the most commonly used laboratory instruments (oscilloscope, DMM, function generator, power supply, dynamic signal analyzer, a bode analyzer, two- and three-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyze). All these instruments are fully controlled with LabVIEW, and thus, are suited for remote control. In addition, a relay switching matrix, of double-pole double-throw (DPDT) electromechanical relays, has been developed in order to allow instruments to measure voltage or currents at different nodes of the circuit remotely. The switching modules are built with a double multiplexer design and they can be configured as shown: 1-to-8 (possible to measure up to eight differential voltages or currents in an equal

number of branches) and two 1-to-4 (possible to measure up to four differential voltages or currents in an equal number of branches). The maximum number of switching modules is 12. The modules selection is done by a 4-bit address bus and an 8-bit data bus, provided by the NI ELVIS platform. A small microcontroller is used for receiving data and configuring the state of each relay in the module.

RemotElectLab allows instruments to measure voltage or currents at different nodes of the circuit, and also allows changing instruments parameters of a circuit, as well as the components parameters of the circuit. However, it does not provide the flexibility for entirely constructing a new circuit online.

2.3 NetLab

NetLab (http://netlab.unisa.edu.au) [3] is a remote collaborative laboratory that allows electronic circuit's wiring and measurement. The instrumentation platform is based on GPIB, which includes an oscilloscope, a function generator, a power supply, and a digital multimeter (DMM). The VME eXtensions for Instrumentation (VXI) standard communication protocol is used for the internal communication within the command module. In addition, a 16×16 programmable relay switching matrix from Agilent (www.agilent.com) is used to switch the connection between the components and the instruments. The switching matrix is connected to the server via RS-232 protocol and to the components via the Inter-Integrated Circuit (I^2C) protocol. Laboratory LabVIEW is the software used for instrumentation control and the communication is based on Virtual Instrumentation Software Architecture (VISA) (http://www.ni.com/visa/) standard. The software application is written in JAVA and requires the installation of Java Runtime Environment (JRE) on the user-PC. A webcam is included, which has its own webserver and is fully controllable by the user. A chat window is provided within the software application; it displays the names of all logged-on users, including administrators. A booking system is also provided within the software application. The available components are as follows: resistors, capacitors, inductors, transformers, and programmable variable resistors. Other components can be easily added or removed. NetLab is limited to a maximum of 16 two-lead components, and its virtual workbench does not replicate a real physical breadboard.

The unique feature of VISIR is the flexibility provided by allowing wiring and measurement on a breadboard and by supporting a wide range of electronic circuit components. A brief comparison on the intrinsic features of the above-mentioned approaches and VISIR is given in Table 1. However, in some cases, it may be more feasible to select other solutions, depending on the type of application. For instance, if a university already has an ELVIS platform, it may be more appropriate to build RemotElectLab.

3 HARDWARE DESCRIPTION

3.1 PXI Platform

The instrumentation platform of VISIR is based on PXI from National Instruments. The NI PXI platform consists of instrument module cards, a controller card, and a chassis

TABLE 1
A Comparison between Different Types of Remote Labs for Electronic Circuits Measurement

	Measurement	Changing instruments parameters	Changing components parameters	Measurement at different circuits nodes	Building new circuits	Virtual workbench replicates breadboard
Remote labs based on DAQ	✓	✓	✗	✗	✗	✗
RemotElectLab	✓	✓	✓	✓	✗	✗
NetLab	✓	✓	✓	✓	✓	✗
VISIR	✓	✓	✓	✓	✓	✓

into which all the cards are plugged. For every component, there are various models depending on its technical characteristics and there is a flexibility to choose among them. Table 2 illustrates the components of the PXI Platform actually installed at UNED.

3.2 Relay Switching Matrix

The relay switching matrix is a stack of "PCI/104" (www.pc104.org) sized boards, manufactured at BTH, that controls the terminals connection of the components and the NI PXI-modules. It acts as a circuit-wiring robot and it is designed for low-frequency analog electric and electronic circuit experiments. It consists of two types of boards: 1) instrument boards, which handle the connection of their corresponding NI PXI-module, and 2) component boards, which handle the connection of the components installed in it. The NI PXI-chassis is connected to the relay switching matrix by a USB cable and the terminals of the NI PXI-modules are connected to it by either coaxial cables or cords.

Each board has a certain number of relays controlling the connections of the terminals of the NI PXI-modules and the components. There are common nodes that propagate within all the boards of the relay switching matrix, creating a node bus that acts as a breadboard, as shown in Fig. 3. A peripheral interface controller (PIC18F4550) is hosted on the source board and it communicates with the controller (PIC16F767) of each board in order to send commands to the relays of that board. These commands let the relays open or close with regard to the received design of the desired circuit. The common nodes are divided into two group. The first contains the nodes from A to I, and 0 (GND). The second contains the nodes from X1 to X6, and "COM." The ground terminals of the function generator and the oscilloscope are hardwired to the node 0 (GND). The function generator output is hardwired to the node A.

TABLE 2
PXI Platform Installed at UNED [13]

|	NI PXI-Chassis	NI PXI-Modules	NI PXI-Controller
Description:	It is the backbone of the PXI platform into which all the instrument cards (NI PXI-modules) and the NI PXI-controller are plugged.	The instrument cards that substitute the real instruments. They are plugged into the NI PXI-Chassis. All these cards can be added and removed depending on the demands.	It is an embedded PC plugged into the NI PXI-Chassis. It includes an integrated CPU, a hard drive, RAM, Ethernet, video card, keyboard/mouse connectors, serial, USB, Microsoft windows software etc. All these features are integrated. Hence, it eliminates the need for an external PC. But, it could be replaced by a PC.
Model installed at UNED:	NI PXI-Chassis (NI PXI-1031).	NI PXI-DC Power Supply (NI PXI-4110). NI PXI-Digital Multi-Meter (NI PXI-4072). NI PXI-Function Generator (NI PXI-5412). NI PXI-Oscilloscope (NI PXI-5114).	NI-PXI Controller (NI PXI-8105).
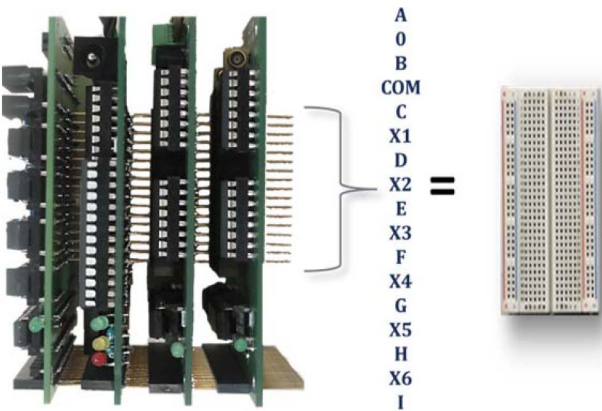
Fig. 3. The common propagating nodes within the relay switching matrix.

(SPST) relays. Thus, a relay switching matrix can contain up to 16×10 DPST relays as maximum (or it can contain 16×6 DPST relays and 16×4 SPST relays). In addition, two 20-pin
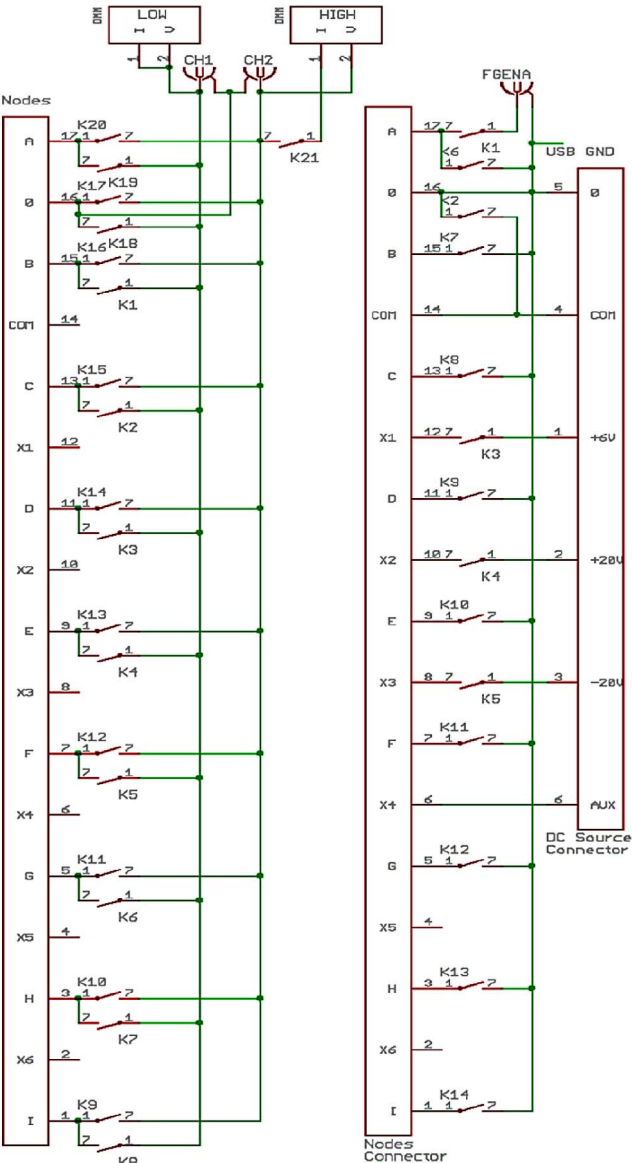
The oscilloscope channels, as well as the DMM channels, are dynamically connected to any node, depending on the user's circuit design. The power source connectors (0, COM, $+6V, +20V,$ and $-20V,$ and AUX) are connected internally to the node 0 (GND) and to the nodes of the second group (COM, X1, X2, X3, X4), respectively, then they are connected to the first group either by a shortcut wire or by two relay switches, as the second group are not supported in the current software version. The complexity of the matrix depends on the number of nodes it has (e.g., from N nodes we can obtain $N \times [(N-1)/2]$ branches). The current relay switching matrix has 10 nodes (A-I, 0), which are appropriate for undergraduate engineering practices [14]. The internal interconnection of the instrument boards is depicted in Fig. 4.

The relay switching matrix can hold up to 16 component boards. Each component board comprises 10 sockets for components with two leads, and each socket is connected to a double-pole single-throw (DPST) relay. Four of these sockets can be connected to eight single-pole single-throw

Fig. 4. The internal interconnection of the instrument boards.

TABLE 3
Corresponding Board Number of Each (I^2C) Label

Board Type	Board Number	I^2C Label
Component board 1	1	COMP 1
Component board 2	2	COMP 2
Etc.	…	…
Oscilloscope board	16	OSC 16
DMM board	17	DMM 17
Source board	24	SRC 24

integrated circuit (IC) sockets for complex circuit connections are provided in each component board. Two leads components occupy one relay, while more leads components (e.g., an amplifier) occupy more relays. Putting the relay switching matrix into a closed case is not recommended because it should be easy to swap components and rewire branches. However, it is very important to protect the relay switching matrix from nonqualified persons. According to the data sheet, the maximum carry current of the relays is 2 ampere (A) and the minimum life expectancy is 3×10^8 operations (approximately two operations per second continuously for 5 years).

The component list file describes all the installed components and instruments in the relay switching matrix to make them known to the software. There is only one component list per relay switching matrix and each added component or instrument is listed in the file with regard to its value, the number of the relays on which it is mounted, the nodes to which it is connected, and the number of the board on which it is located. The user can only build circuits corresponding to the allowed connections in the component list file. The relays of the component boards are numbered as follows: 1, 2, 3, 5, 7, 8, 9, 10, 11, and 13, respectively, i.e., this is in the case that all the relays are DPST. In the case that the DPST relays (5, 7, 11, and 13) are replaced with SPST relays, the numbering will be from 1 to 14. Each board has an Inter-Integrated Circuit label that corresponds to a number, as shown in Table 3. For instance, "R_2_7AB 10K" represents a resistor of 10k ohms installed on the relay number 7 of the board number 2 and connected to the nodes (A, B), as shown in Fig. 5. The entire connection of VISIR is shown in Fig. 6.

4 SOFTWARE AND OPERATION CYCLE

The VISIR software is an open-source that is released under a GNU General Public License (GPL) [15]. In this section, a step-by-step presentation of the operation cycle is shown along with the description of the development of each software component.

4.1 User Interface

The user interface is the frontal web page of VISIR that handles all the administration, access, and authentication process. It is written in the scripting language PHP (Hypertext Preprocessor) in connection with a relational database management system MySQL, and it is hosted in an Apache HTTP webserver. It uses the secure protocol Hypertext Transfer Protocol Secure (HTTPS) and it provides many features similar to those provided by a learning
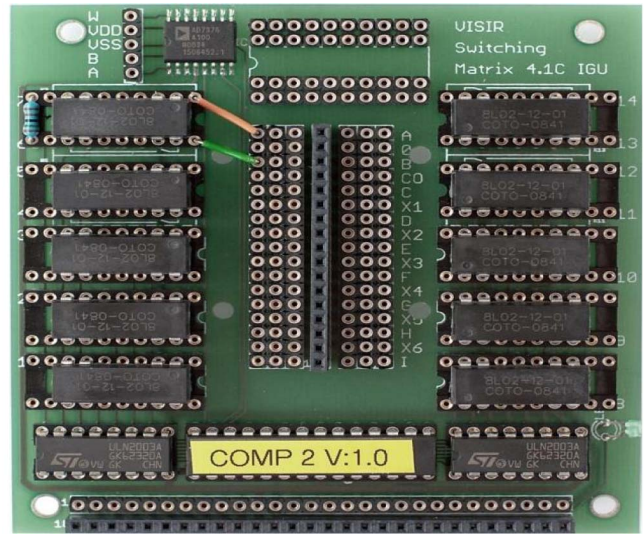

Fig. 5. A component board with 10 DPST.

management system (LMS) in order to facilitate the implementation of VISIR in the learning process. The capabilities and limitation of these features are associated with the account types. Next, the properties and the privileges of each account type are presented.

4.1.1 Administrator Account

The administrator account is the account of the lab provider. VISIR can have one or more administrator account. The administrator account has the following privileges:

- It can create contents in the user interface through the WIKI markup syntax.
- It can upload files, videos, manuals, etc.; this can be done by uploading them to the webserver (Apache) and linking them to the PHP code of the Page.
- It can create update, and delete courses associated with a start and an end date, a maximum number of users, and assigned teachers and/or instructor accounts.
- It can modify or remove any user account.
- In any course, the administrator account can switch to "teacher view" to have all the teacher privileges in that course.
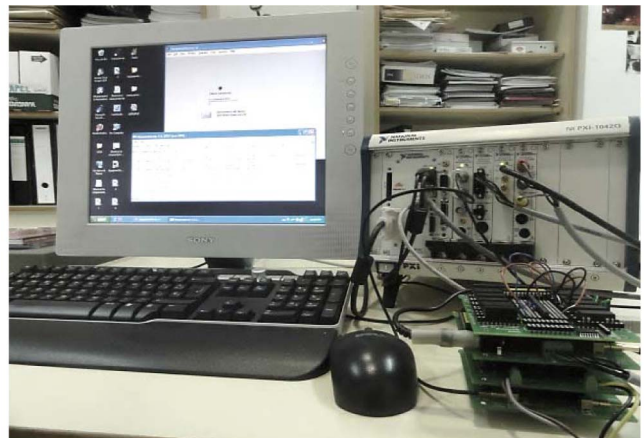

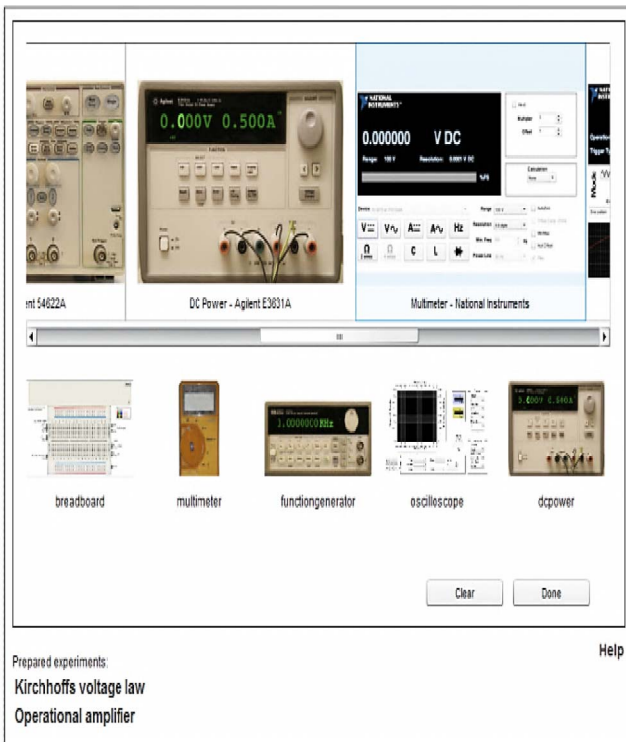Fig. 6. A connected VISIR system [16].

Fig. 7. Student selects the instrument interface with which he is familiar.

4.1.2 Teacher Account

The teacher account is created by the administrator and associated with a certain course. It has the following privileges:

- Add and remove experiments; this is done by allowing certain components to appear to the student in each experiment.
- Add, remove, and modify student accounts.
- Make a teacher scheduled reservation; the teacher reserves a number of seats within an interval of time so that,she can put her students in groups and assign an instructor to each group. These seats are visible to the student with the teacher's name. Accordingly, the student chooses her group and reserves her seat.
- The teacher can switch to "student view" to view the contents as seen by her students.

4.1.3 Student and Instructor Accounts

The student and instructor accounts are created by the teacher and are associated with a certain course. They only allow access to the experiments that are created by the teacher within such course. The student and the instructor, likewise, can make a scheduled reservation separately or reserve a seat belonging to the scheduled reservation of the teacher.

4.1.4 Guest Account

The guest account is a public limited trial account created by the administrator, and it does not require registration. It can be utilized by anyone wanting to try an available experiment prepared by the teacher assigned to that account.

4.2 Experiment Client

The experiment client is a simulated workbench embedded in the HTML code of the user interface. It is written in
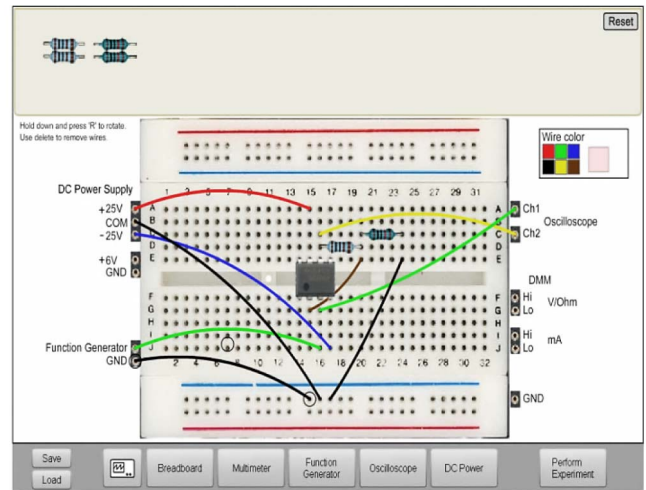

Fig. 8. Simulated workbench.

Adobe Flash and located inside the same folder of the user interface files, which are hosted by the lab server. The user chooses the instrument interface with which she is familiar regardless of the model or the manufacturer of the corresponding real instrument, as shown in Fig. 7. In this way, it is possible to use a virtual front panel depicting an instrument model to control another instrument model as long as the performance of the real instrument is equal or better than the performance of the depicted instrument. The available interfaces are as follows:

- a DMM (Fluke 23),
- a function generator (HP 33120A),
- an oscilloscope (Agilent 54622A),
- a DC power supply (E3631A),
- the default PXI-instruments interfaces from National Instruments, and
- a traditional breadboard.

After choosing the instrument interfaces, the user starts to design and wire her circuit on a simulated breadboard by clicking and dragging the simulated components and wires with her PC-mouse, as shown in Fig. 8. Once the user gets her circuit ready, with all the instrument values adjusted, and clicks on the "perform experiment" button. The experiment client sends the designed circuit with all the adjustments and the configurations to the "measurement server" (see the next section) through the experiment protocol.

The experiment protocol is an XML-based protocol that uses either XML Socket or HTTP (the actual configuration) over the TCP/IP model to transport the requested data to the "measurement server." For instance, an experiment protocol request sent by a function generator could look as that shown in Fig. 9. The experiment protocol describes which settings and functions each instrument type can perform, independent of hardware manufacturer. Thus, it is possible to select an instrument simulated interface independently of the manufacturer and to create new interfaces of instruments that do not exist in the current set.

4.3 Measurement Server

The measurement server is a software application written for Microsoft Windows in Microsoft Visual C++. Thus, the

```
<functiongenerator>
<fg_waveform value="sine" />
<fg_amplidute value="1000.0" />
<fg_frequency value="1000.0" />
<fg_offset value="0.0" />
<fg_startphase value="0.0" />
<fg_triggermode value="continuous" />
<fg_triggersource value="immediate" />
<fg_burstcount value="0" />
<fg_dutycycle value="0.5" />
<fg_userdefinedwave length="20" encod-
ing="BASE64">ABCD1234ABCD1234ABCD
</fg_userdefinedwave>
</functiongenerator>.
```

Fig. 9. A message based on the experiment protocol to describe the functions of a function generator.

Microsoft runtime libraries (Microsoft Visual C++ Redistributable Package) should be installed before running it. It receives the measurement requests from the experiment client in separate TCP sessions and through the port 2324. Thus, connect and disconnect are required for every request made to the server. The requests/responses should not exceed 64 kB in size.

The role of the measurement server can be defined in the following steps:

Authentication. At each request, it verifies that the client is a valid user by validating the client cookie generated by the webserver with the database.

Verification. It acts as a virtual instructor. It compares the received circuit data with the "max lists" before sending it to be executed on the real instruments, to avoid hazardous circuits or any damage that may be caused to the real instruments. A "max list" is a file created by the teacher to define the permitted values of the components and the instruments in a certain experiment. This enables the teacher to be the sole person responsible for any damage. The "max lists" of all the available experiments are inserted inside the folder of the measurement server software. The max list of an experiment determines which connections the experiment is permitted to have. For instance, if the max list states that the anode of the power supply is connected to the node A while the cathode is connected to GND, the user would receive an error if she connects the anode to GND.

Queuing. It can handle requests from 16 simultaneous clients in less than a second (1/16 second is the maximum time for each request) by queuing all the simultaneous requests and performing them sequentially with regard to the priority, reservation, and so on.

Proxy Server. After validating and queuing the requests, it starts to send the requests sequentially in separate TCP sessions over TCP/IP through the port 5001 to the "equipment server" (see the next section). The measurement server acts as a gateway and could serve more than one equipment server.

4.4 Equipment Server

The equipment server consists of the PXI platform and the relay switching matrix. The equipment server software is installed in the NI PXI-controller (or in a separate PC instead). It is a software application for instrumentation control developed by LabVIEW. The equipment server software receives validated sequential experiment protocol requests from the measurement server in separate TCP
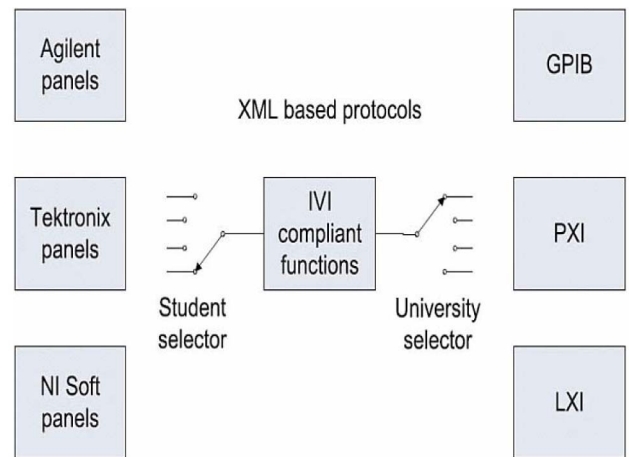

Fig. 10. The flexibility provided by IVI standardization [3].

sessions over TCP/IP through the port 5001, and it executes it through the connected instruments. After that, the results return back to the client PC-screen with the same sequence. The results are represented in the form of measurements on the simulated instruments.

Most of the undergraduate electronics laboratories of all the universities around the world have common equipment (oscilloscopes, function generators, DMMs, DC power supplies, and breadboards) regardless of their model and manufacturer. The current VISIR supports PXI; however, other universities would like to use another platform such as LXI or GPIB. To enable interchangeability between workbenches and different grid nodes (different universities), VISIR recommends the functions and attributes defined by the IVI Foundation to be used to describe the base class capabilities and the class extension capabilities of the lab hardware. In fact, all the instrument drivers installed in the equipment server are Interchangeable Virtual Instruments (IVI) compliant. Accordingly, it is possible to create a standardized approach, as described in Fig. 10, which is easy to adopt. The base capabilities of an IVI-complaint instrument are the functions of its class that are common to most of the instruments available in the class. For instance, for an oscilloscope the base capabilities mean edge triggering only but other triggering methods are defined as extension capabilities. The functions supported by the VISIR oscilloscope are listed in Table 4. The goal of the IVI Foundation (www.ivifoundation.org) is to support 95 percent of the instruments in a particular class. The Virtual Instrument System Architecture (VISA) standard is accepted too, but the instrument functions should be those defined by the IVI standard.

The component list file of the relay matrix is inserted inside the equipment server software folder to define the available components to the software. The whole operation cycle can be summarized, as shown in Fig. 11.

5 INSTALLATION AND START-UP

In this section, the key configurations of VISIR implementation and adoption are highlighted. However, a step-by-step installation manual (VISIR Installation and Start-up Guide) from the project released documents is available and distributed within the SIG VISIR mailing list. Moreover, a

TABLE 4
Base and Extension Capabilities of an Oscilloscope

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

wiki page is assigned for the installation and the software development is available at http://svn.openlabs.bth.se/trac.

The user interface uses HTTPS, which receives HTTP over an encrypted Secure Sockets Layer (SSL) to provide a secured and protected communication. Thus, the HTTPS virtual host must be properly configured and enabled on the Apache server. The NI drivers of the PXI devices and the relay switching matrix must be defined and should appear in the "Measurement and Automation Explorer" of the LabVIEW platform. The relay switching matrix driver is an ".ini" file that is distributed with the matrix. The "EquipmentSer-ver.vi" file is used to configure the instruments slots in the NI PXI-chassis, the communication port of the equipment server, and the component types. The "measure server.conf" file is used to configure the communication ports of the measurement server, the log level, and the database connections. The "config.php" file adapts the user interface source on the local hosting machine characteristics (boot-strapping), and it must be modified to be directing to the accurate directories and root paths of the local machine. The "config.xml" file adjusts the experiment client setting and connection with the measurement server. The "Library.xml" file contains all the available simulated components in the experiment client,and defines the characteristics of each of them (number of pins, image, rotation, etc.), and it must be updated with the available components in the component list in order to appear to the user.

6 DEPLOYMENT FEEDBACKS AND THE ENCOUNTERED DRAWBACKS

VISIR has been successfully implemented and deployed in the undergraduate engineering practices at ISEP, University of Deusto, and UNED [7]. The overall results were satisfactory. Several electronic circuits practices have been carried out by VISIR without any inconvenient. These practices include

- Half-wave rectifier with and without a filter.
- Inverter and noninverter operational amplifier.
- Regulator with zener diode.
- Common emitter and common collector BJT.

At ISEP, VISIR has been deployed in a course of more than 270 students enrolled without many irregularities. The students stated that they did not feel that it helped with their motivation but that they would like to extend its utilization to other subjects. They also felt that a formal tutorial could have been helpful. At University of Deusto, VISIR was accepted among the students as a useful tool for
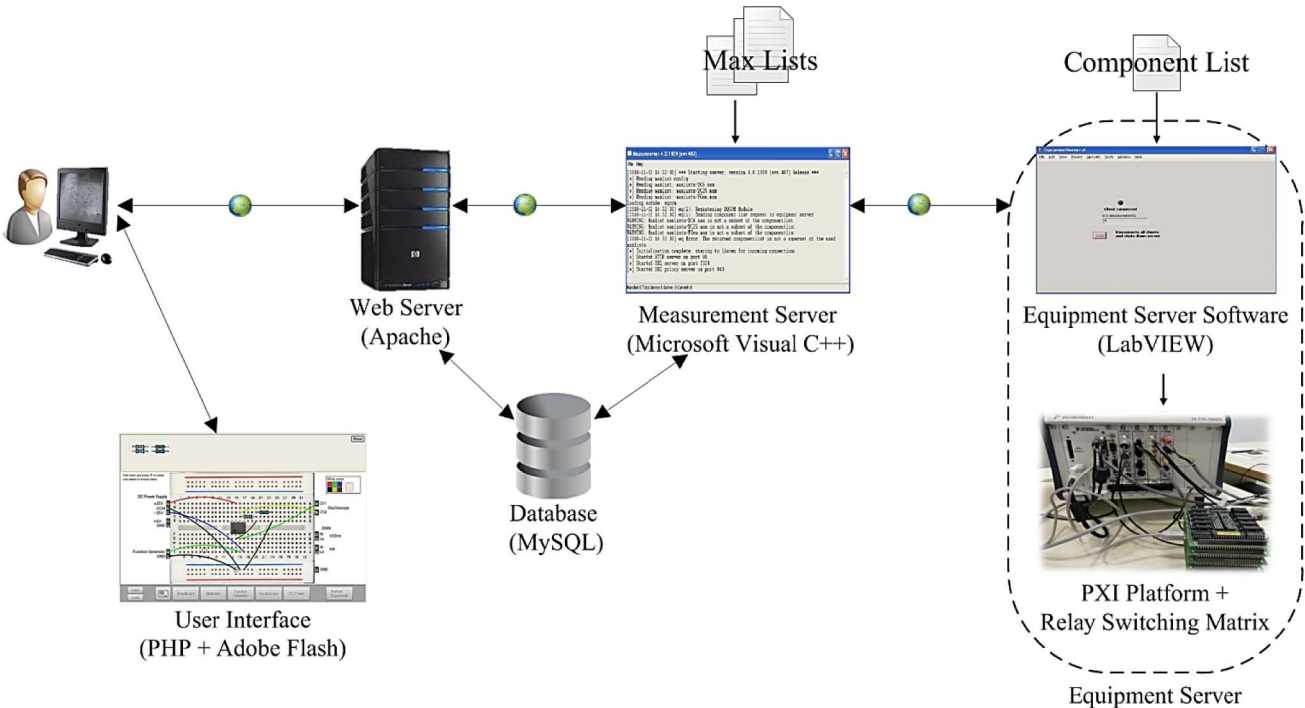

Fig. 11. The overall operation cycle of VISIR [17].

TABLE 5
Survey on VISIR Deployment at UNED (2010/2011)

	Question	Score (out of 5)	Average (%)
Feasibility	Q.1. It helped me to understand the subject contents?	3.76	
	Q.2. It was useful for trying many circuits without any fear of errors?	4.82	
	Q.3. I recommend it to be used in other subjects?	3.05	**77.53**
Sense of reality	Q.4. I felt that I was working with a real laboratory environment and not a simulation?	3.69	
			73.8
Performance	Q.5. It was responding without time delay?	4.49	
	Q.6. There were no software bugs or access errors?	4.11	
			86

Fig. 12. An amplifier circuit that requires two AC source and DC sources.

practical sessions; the students who had used it gained more self-confidence when they started using the real lab, even though, their first time was through a remote lab. On the other hand, the students considered it as a support tool, not a total substitution for real labs.

At UNED, during the academic year 2009/2010, the students of the subject "Electronic Circuits and Components," a first-year subject of the Technical Industrial Engineering career in Spain, used the VISIR installed at University of Deusto, thanks to an agreement between both universities. The goal was to evaluate the system performance and to check its accuracy and sustain ability when it comes to real-time deployment. About 40 enrolled students were using the VISIR of Deusto during two entire days without any problems or inconvenience. The students could repeat their experiments varying the values all the time they needed during the two days. In other words, the results were very satisfactory and the system was proven to be sustainable. Many of these students stated that they would like to use VISIR for electronic circuit practices of other subjects. Many students also stated that it would be better to use VISIR to make the first approach toward the instruments and, afterward, repeat the same practices in the real laboratory. Owing to this positive perception, the Electrical and Computer Engineering Department at UNED decided to install its own VISIR for the undergraduate electronic circuits practices. The department installed a VISIR in December of 2010. The system was in operation starting from the academic year 2010/2011 and was used as a mandatory pre-laboratory work for students of the subject, "Foundations on Electronic Engineering"—a subject within the new Electronic Engineering grade of Bologna that was recently applied in Spain. The goal was to use VISIR to take the first approach to the instruments and the typical ways of work in a real electronics laboratory. Afterward, the students would repeat the same practices in the real laboratory at the department. This procedure allowed the
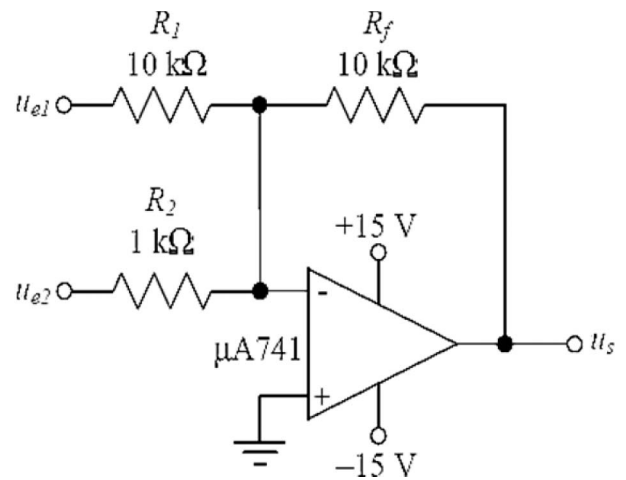
students to gain more efficient experimentation skills during their first electronics practices. At the end of the course, a survey was conducted among all the enrolled students (64 students) in that subject. The survey encompassed questions in terms of learning outcomes, sense of reality, and performance. The survey results are shown in Table 5. As shown in the table, the performance of the system is notably high. The sense of reality could be better—this may owe to the lack of live view (webcam) of the equipment, since in VISIR student only see the simulated workbench even though she is manipulating a real one—but it is still relatively high for being a remote laboratory. In general terms, VISIR was definitely feasible and students enjoyed the experience and gained a higher motivation for learning.

On the other hand, much feedback has been gathered from administrators and teachers, from universities within the VISIR community, who have been working with VISIR. In addition to the common positive perception, some drawbacks and limits have been addressed, which are reviewed in the following points:

Lack of assessment and evaluation. VISIR does not provide a tracking service. Thus, the teacher cannot assess students' work. The system provides a strong scheme of security to avoid hazard circuits but it does not allow the student design to be assessed afterward by the teacher. The system registers only the student login, which is not sufficient to evaluate student work. A solution to this problem is to integrate VISIR with an LMS, which is will be discussed in the next section.

Limitation of the relay switching matrix. As mentioned earlier, the relay switching matrix is limited to 16 component boards, and it is only developed at BTH (it is not commercially available). This has reduced the flexibility of VISIR and has hindered its deployment in many subjects, limiting its utilization to a certain ongoing course, since the practices of each course would require a different component design on the relay switching matrix. A solution to this problem is to substitute the current relay switching matrix with a commercial one, which is will be discussed in the next section.

Limitation of the instruments. VISIR comprises most of the instruments used for undergraduate electronic circuit practices. However, some circuits require two prototypes of a single instrument. For instance, Fig. 12 shows an

Fig. 13. VISIR-LXI instrumentation [13].

amplifier circuit with two AC and DC sources, which could not be constructed by VISIR. The solution to this problem is to increase the capacity of VISIR by adding several PXI modules, which means an increase in cost. In addition, the entire software code must be modified and rewritten in order to include the extra instruments in the virtual workbench.

7 CHALLENGES AND FUTURE WORKS

Further developments are being done within the community to enhance the VISIR architecture and to allow a better implementation in engineering education. Next, a brief discussion on each initiative is presented.

7.1 VISIR LXI

As mentioned earlier, VISIR provides the flexibility to choose another platform technology based on IVI drivers. Thus, a new VISIR system based on LXI platform is being developed at University of Deusto [18]. All the instrumentation is from Agilent, as shown in Fig. 13. It consists of a power supply (N5746A), an oscilloscope (DSO5012A), a signal generator (33220A), a DMM (34410A), and a switch (34980A) equipped with two dual 4×16 matrixes (34932A) that replace the current proprietary relay switching matrix. To reduce the number of components in complex circuits, a single component can be placed in multiple nodes. A standard Ethernet connection is applied between the server and the instruments with a specific IP address for each instrument to identify it. The aim is to reduce the cost of the PXI platform and the proprietary relay switching matrix, and to increase the system flexibility. Moreover, this architecture will allow wrapping the system in WebLab-Deusto [19].

The drawbacks of this solution are that it allows only circuits with single polarization (because the chosen power supply does not provide negative voltage), it is limited by 52 components of two leads, the maximum allowed frequency is 30 MHz, and finally, owing to the delayed time response, it could be less scalable.

7.2 Integration with iLab

The iLab project (http://ilab.mit.edu/wiki) [20], [21], [22], developed by the Massachusetts Institute of Technology (MIT), provides a middleware infrastructure based on web services and developed by Microsoft .NET technology, known as iLab Shared Architecture (ISA). ISA provides an

efficient management framework that can support administration and access to a wide variety of online laboratories at multiple institutions independently of their developed platform. It is a pioneer architecture that provides administration, access, and sharing of heterogeneous remote laboratories among institutions. The System Engineering Department at Carinthia University of Applied Science is currently working on integrating VISIR into ISA framework [23], [24] to take the advantages of ISA. This integration will allow sharing of VISIR with a high load capacity in an efficient way.

7.3 Integration with LMS

UNED is the second largest distance learning university in Europe after the Open University of United Kingdom with 205,931 [25] enrolled students. LMS is the main tool implemented at UNED in the learning process to provide online classrooms education. WebCT (www.blackboard.com) and dotLRN (www.openacs.org) are the actual implemented LMSs. However, the provision of practical laboratory sessions online under a feasible implementation [26] is still being a major concern of the university. With the advent of remote laboratory technologies, the Electrical and Computer Engineering Department (DIEEC) at UNED has embarked on researching into e-learning technologies [27], [28], [29], [30] and into the possibilities of integrating remote laboratories within LMSs [31] to afford the provision of practical knowledge online. In addition, this integration will introduce services that are not provided by VISIR such as user track on and assessment.

Currently, the department is researching the integration of the common services provided by the VISIR interface with those provided by LMSs. A similar approach has been realized at ISEP [32] in order to provide a common access to VISIR through an open source LMS, known as Moodle. However, in such an approach, users will be required to enter their login credentials in order to be directed to the related experiment. Thus, it does not provide a complete integration in the way that the user could access to VISIR through the LMS with a single sign-on and every account type in the LMS (teacher, student, administrator, etc.) would have the same privileges of its equivalent account type in VISIR interface. This would allow the utilization of the services provided by LMSs, such as synchronous and asynchronous communication tools, and user assessment [33], along with the lab work to create a rich integral online educational platform.

7.4 VISIR Open Lab Platform 5.0

As mentioned earlier, mounting components on the relay switching matrix is limited due to the limited number of nodes and component boards. However, the project founders proposed a brilliant solution that aims to interconnect all VISIR systems, installed at all the universities and institutions within the community, with each other in order to create a grid laboratory shared and accessed by all the participants. This would allow expanding the application range; each university could install certain circuits on its own VISIR and utilize another type of circuits installed on a VISIR of other universities and vice versa [3].

The next version of the VISIR open lab platform (5.0) will provide a cloud that supports a federation of VISIR laboratories and includes a free-access repository for sharing learning resources. Members of this cloud will be the VISIR community partners and they should contribute with one or more workbenches followed by their own policy of access. A teacher may reserve any workbench within the cloud for a particular time period. It would also be possible for organization without VISIR to participate. However, they should be granted access to a particular workbench through prior negotiation with the providers [34].

8 CONCLUSION

VISIR has proven to be an outstanding learning technology for electronic circuits practices. The system has been deployed at several universities in undergraduate engineering practices with satisfactory results either relying on it totally or using it partially along with the hands-on practices. In this paper, a wide overview on the system construction and functionality has been provided. This paper has discussed all the features provided by VISIR for its implementation and deployment in engineering education along with feedback from the universities that had deployed it in their learning curricula. This paper has also discussed the limitations and drawbacks of VISIR and has addressed the ongoing and future works carried out within the VISIR community in order to overcome the mentioned drawbacks and enhance the system. Last but not least, further concerns are being discussed within the community to extend its support capacity, scalability, and its application range to include other types of circuits, e.g., logic circuits. VISIR, indeed, is a step forward toward a new generation of captivating learning technologies that can be feasibly implemented in engineering education.

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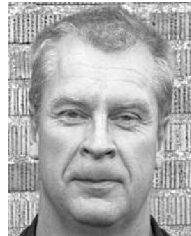
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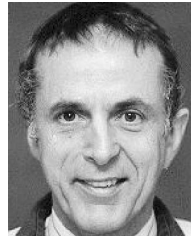
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