Development of a Framework and System for Remote Electronics Experiments*

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The outreach activities organized by the Department of Electrical and Computer Engineering (ECE) at National University of Singapore (NUS) are geared towards bringing interesting engineering projects, workshops, talks and other engaging activities to the students and teachers in the various high schools in Singapore. To expand the scope of the outreach activities, a framework and system to facilitate remote electronics experiments has been developed, utilizing remote virtual instrumentation concepts. Using the proposed setup, the students are able to design electronic circuits and observe/analyze the responses from the circuits to excitation, while being physically distant from the laboratory where the electronic circuits and instrumentation/measurement systems are located.

Keywords: Remote electronics experiment; virtual instrumentation

INTRODUCTION

TO INCREASE THE LINKAGES with students and teachers in various high schools, including junior colleges, and promote their awareness and interests in electrical and computer engineering, the outreach efforts of the Department of ECE at NUS have constantly hosted many interesting engineering projects, workshops, talks and other engaging activities throughout the whole academic year.

One of our recent outreach activities includes engaging prospective students and teachers in their premises through the setup of ECE Corners at selected schools. These schools are selected to serve as a central point to which students from all other schools in the vicinity are invited to participate in the activities at the ECE corners. For demonstration purposes, some portable laboratory equipment showcasing current research directions and other course experiments are displayed. Other more sophisticated and heavy laboratory equipment are not suitable to be set up at these corners as the sites are only temporary (i.e. ranging from a few weeks to a few months). Besides these static display items, workshops are also conducted at these corners during school events. These workshops/sessions offer interesting scientific hands-on experience and demonstrate how scientific principles are used in engineering to develop useful and innovative systems. In general, these practical sessions are concise and focused on an interesting ECE area, so that sessions can be delivered to a large number of keen students. However, there are limits to the

type of portable laboratory equipment which we can bring to the corners. Bulky and complicated laboratory apparatus may pose difficulties in transportation and setting up. To extend the variety of viable setups and activities, leverage on the telecommunication networks can allow students and teachers to access our laboratories at NUS, without leaving their own premises. In this way, difficulties encountered due to bulky and complicated laboratory equipment can be circumvented. No longer constrained by geography, the development of a framework and system for a virtual laboratory [1] is much desired, more so for our outreach activities at the various institutions.

With the rapid advances in engineering and information technology, the powerful integration of computers and telecommunications can bring on near real-time interaction between remote users and resources at the laboratory ([1, 2]). When and where there is a lack of easily accessible laboratory resources, the tools of the virtual laboratory can be harnessed for students to gain a holistic engineering learning experience ([3–22]). Remote and virtual hands-on experiments may be classified into two categories. In the first category are computer simulated and animated versions of the actual experiments. Models of the actual systems are created and used to render a close-to-actual experience [3–5]. An example of such a simulated system is shown in Figure 1 which is a virtual experiment to study the effect of radiation balance as heat sinks and sources are moved relative to each other. The energy exchanges and effects are simulated via computer models.

The second category of virtual experiments involves actual interactions with real laboratory apparatus remotely via virtual instrumentation
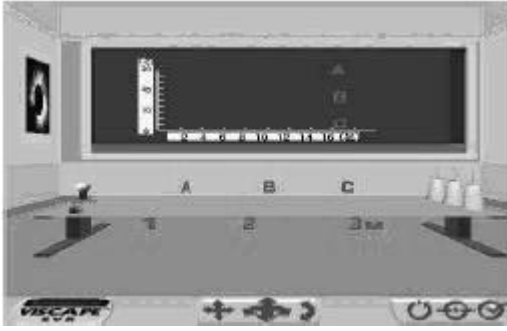
Fig. 1. Virtual experiment on radiation balance.

[10], [14], [15]. These experiments essentially involve actual laboratory apparatus which is pre-wired and setup in advance. The user response can be obtained in real-time via charts or video transmission of the actual systems in operation. Such virtual experiments provide a bridge between remote users and the laboratory, allowing users to gain a realistic feel of controlling the actual laboratory apparatus [16–20].

SETTING UP ECE CORNERS

Through the setup of ECE corners at selected high schools, students can be engaged in outreach activities and projects in their own free time, allowing NUS outreach members to achieve maximum exposure within the school premises. These activities are carefully put together to engage and challenge young minds. Each workshop/session offers interesting scientific hands-on experience and demonstrates how scientific principles are used in engineering to develop useful systems. These sessions range from two hours to half a day to longer-term projects (i.e. three to six months). Sessions are concise and focused on an interesting ECE area, so they can be delivered to a large number of keen students. The corner is also opened to other schools within the same area/region.

Fig. 3. ECE corner with interactive digital media theme.

An ECE corner was setup at one of the colleges as shown in Figure 2. In this case, the theme was control and automation. Students were first introduced to the history and importance of control. They then experienced the difficulties of manually controlling the temperature in a chamber using a handheld controller. Next, they were exposed to virtual instrumentation and had to design a simple automatic controller to control the temperature in the chamber to a desired set-point. The corner housed five sets of this equipment. Three-hour workshops as well as longer-term projects are currently being held at the corner. The number of students in each workshop is 20–30. Other ECE corners include themes on: Interactive Digital Media (Figure 3), Radio Frequency Identification (RFID) (Figure 4), Laser Printing and Perception.

As mentioned above, the development of a virtual laboratory overcomes the difficulties faced by setting up cumbersome and complicated laboratory apparatus at the ECE corners. This is in line with our future plans to extend our outreach activities via remote experimentation. Much time and efforts could be saved up with the development of such a framework. The variety of activities and setups that could be hosted at the ECE corners could be extended as a result. In this paper, the

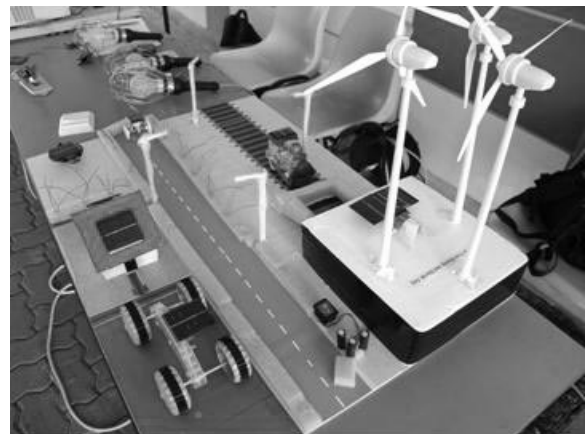Fig. 2. ECE corner at junior college, with temperature control system.

Fig. 4. ECE corner with RFID theme.

development of a remote electronics design experiment is elaborated. A prototype circuit will be used for illustration, although the approach is applicable to full and specific electronic circuits. The user is able to interact with actual electronic components and instruments, including placing and connecting electronic components in a circuit according to her/his design as though the user has physical access to the actual electronics equipment. With such a framework and system in place, many other types of outreach activities involving students' interactions and experiments with the rich resources at NUS can be realized.

With the proposed framework of remotely controlled experiments in place, we can deploy the whole structure in our ECE corners. Before attempting the experiments, webcasts of lectures on the topics related to the experiments are made available for viewing/download via NUS intranet (i.e., http://cit.nus.edu.sg/webcast/). With the theoretical or subject background in mind, the students can then carry out the experiments via the ECE corners or from their home. All the resources (i.e. laboratory manuals and other reading materials) required by the student can also be downloaded from the NUS intranet (i.e. https://ivle.nus.edu.sg/lms/default.aspx).

PROTOTYPE CIRCUIT

A simple prototype circuit is shown in Figure 5. The system developed can be equally applicable to more complicated electronic circuits, involving integrated chips (IC), discrete components (i.e., analogue or digital), switches and other circuit components. Essentially, the student will design this circuit and patch it up on a virtual breadboard according to the guidelines laid out in the laboratory experiment manual provided. Subsequently, the completed design can be uploaded by the student (i.e., who is at a remote location) to a server in the laboratory which also houses all the actual equipment. An actual circuit (i.e. with 'real' electronic components) corresponding to the uploaded design will be automatically configured and realized on an actual breadboard in the laboratory. The student can then choose to input signals or view signals at specific points in the circuit. The signals, arising from a circuit with
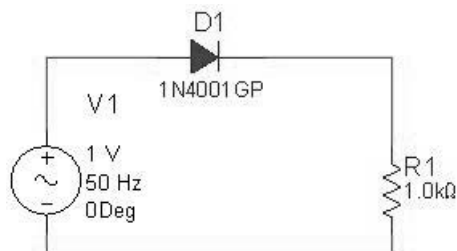
real electronic components, can be transmitted to the student and displayed on her/his computer. In this manner, the student is able to undergo a typical electronics experiment which includes patching up the circuit using electronic components and analyzing the circuit's signals. This can be considered as the next best alternative to being physically present in the laboratory to perform the experiment.

HARDWARE ARCHITECTURE

The overall system is centred on virtual instrumentation [23–25]. A virtual instrument (VI) consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as plug-in boards, and driver software, which together perform the functions of traditional instruments. With virtual instrumentation, engineers use graphical programming software to create user-defined solutions that meet their specific needs. Additionally, virtual instrumentation capitalizes on the ever-increasing performance of personal computers to enable functionalities not possible in traditional instruments. A schematic of the overall system is shown in Figure 6.

Educational Laboratory Virtual Instrumentation Suite (ELVIS)
The ELVIS (Figure 7), developed by National Instruments (NI) is the core piece of apparatus which is used as the platform for the actual electronic circuit to be patched up. ELVIS features twelve integrated instruments that are completely customizable via software, including an oscilloscope, a digital multimeter, a power supply, and a function generator, all of which are common instruments in an electronics laboratory.

PCI eXtensions for Instrumentation (PXI) Chassis
A PCI extension for Instrumentation (PXI) is a PC-based platform for measurement and automation systems [23]. The chassis contains the PXI backplane, which includes the system controller slot, the PCI bus and the timing and triggering buses. For the system controller slot, the controller options include remote controllers from a desktop, workstation, server, a laptop computer or a high-performance embedded controller installed with either a Microsoft operating system (i.e. Windows 2000 or XP) or a real-time (RT) operating system (i.e. NI RT software). The chassis allows customization by integrating different modules to fulfil different experimental requirements. In this system, the PXI chassis (which houses the main controller of the whole hardware architecture) provides commands and instructions to the other devices attached (i.e. ELVIS, data acquisition (DAQ) cards, relay switches and other components). Figure 8 shows the PXI chassis which
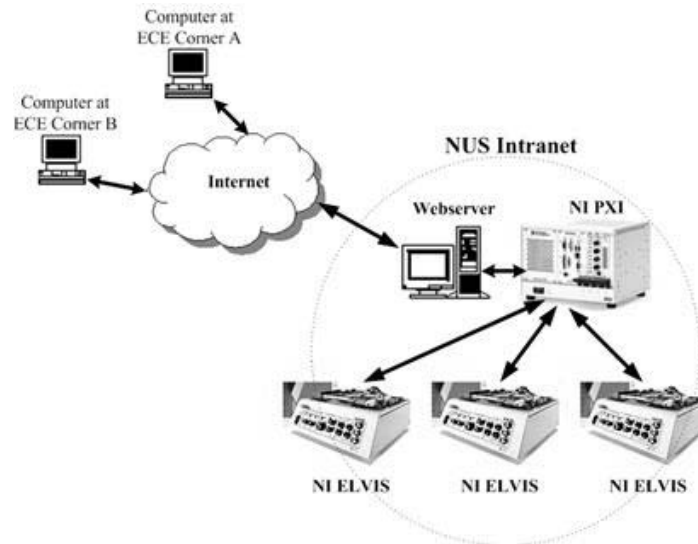
Fig. 5. Prototype circuit.

Fig. 6. Overall schematic of remote electronics experiment structure.
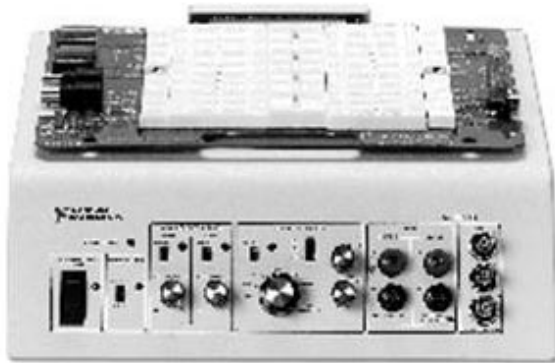

Fig. 7. ELVIS from National Instruments.
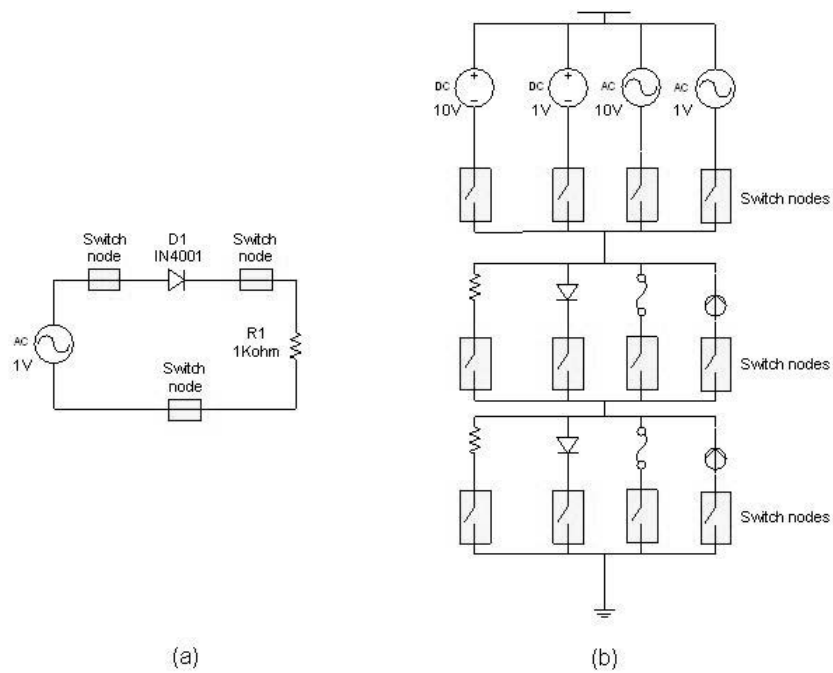

Fig. 8. PXI chassis.

(a)

(b)

Fig. 9. Prototype circuit with switch nodes included.

contains the embedded controller and the slot-in modules.

General purpose relay switch

Relay switches play a critical role in the proposed architecture. They serve as the mechanism that realizes a particular circuit according to the student's design. The connection of the components on the NI ELVIS according to the student's design is enabled through an array of independent switches. Each relay switch contains a normally closed (NC), normally open (NO), and common terminal (COM) and can handle up to 100V of direct current (DC) or of alternating current (AC) or up to 1A of current. The switches are set up at the circuit nodes of the prototype experiment circuit and will be closed or opened according to the uploaded circuit design. Figure 9(a) shows the schematic diagram of the prototype circuit with relay switches at the electronic circuit nodes. The physical diagram layout of the components to realize the prototype circuit is shown in Figure 9(b).

Multifunction data acquisition (DAQ) board

A high-speed DAQ board, optimized for high accuracy at fast sampling rates, provides a channel for the transmission of signals to and from the NI ELVIS. It has an onboard amplifier designed for fast settling times at high scanning rates, ensuring 16-bit accuracy even when measuring all channels at maximum speeds. It has 16 analogue inputs, 24 digital I/O lines, seven programmable input ranges, analogue and digital triggering and two counter/timers.

SOFTWARE ARCHITECTURE

The overall flowchart of the conduct of the remote electronics experiment is shown in Figure 10.

Laboratory Virtual Instrument Engineering Workbench (LabVIEW)

LabVIEW, developed by NI, is a graphical programming language that uses icons instead of lines of text to create applications [24, 25]. It contains a set of tools for acquiring, analyzing, displaying and storing data, as well as tools which help to troubleshoot codes written. With LabVIEW, users can quickly and easily acquire real-world signals, perform analysis to ascertain meaningful data, and communicate or store results through a variety of means. Using LabVIEW, a graphical user interface depicting front panels with controls and indicators can be built. Following the design of the user interface, codes are built using VIs and structures to control the front panel objects. The codes are embedded in block diagrams.

A block diagram contains the program for checking the design circuit, closing the relay switches to complete the experiment circuit
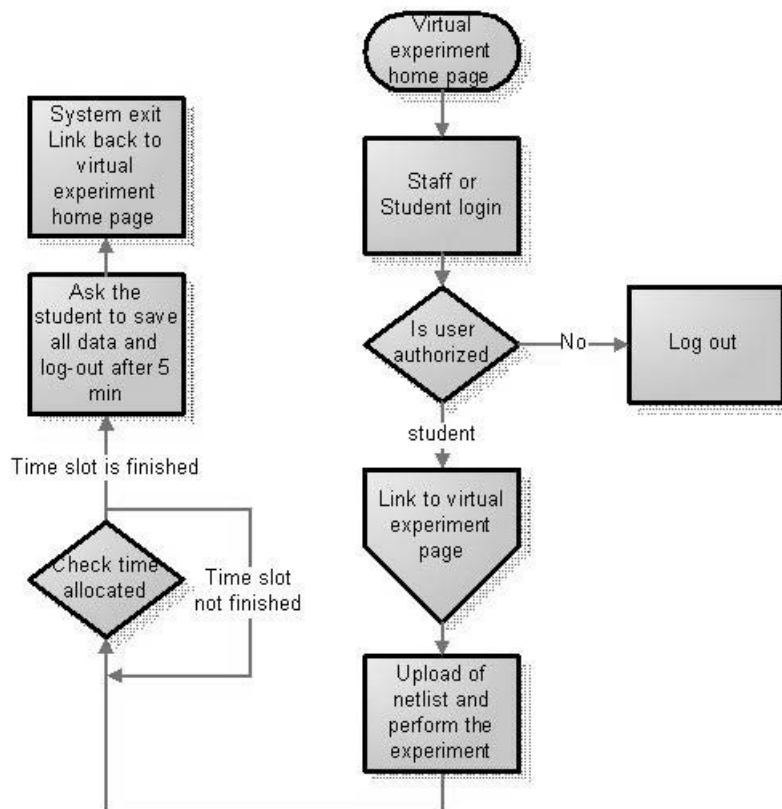

Fig. 10. Software flowchart of system for remote electronics experiment.

Fig. 11. Virtual ELVIS.

Fig. 12. Components on the 3D virtual ELVIS prototyping board.

connection and other additional features, including the verification of hardware functionality and reliability and a text messaging function for communication with the laboratory. The block diagram will only be available for editing and viewing by the administrator, and is transparent to the user.

The VI for remote control and monitoring of the experiment contains the code that executes the reading of the experiment output, the hardware reliability check and the activation of the text messaging function (see below). The VI is saved in the PXI chassis for control of ELVIS, the relay switches and the power supplies. The 'Web Publishing Tool' of LabVIEW allows the VI to be published on the web and. thereafter, the user is able to gain control of the VI via a standard web browser.

Electronic workbench Multisim

Multisim combines intuitive graphical setups with simulation to efficiently design and validate a circuit. With Multisim, a schematic can be built quickly with a comprehensive component library and the circuit behaviour can be emulated using the industry-standard SPICE simulator. Multisim provides an easy-to-use interface to SPICE, ensuring accurate and immediate simulation results. Professional designers can uncover the flaws earlier in the design process, reducing prototype errors and time to market.

In this environment, the student can construct a design circuit using the 'Virtual ELVIS' in Multisim; this is shown in Figure 11 which emulates the behaviour of the actual apparatus, the NI ELVIS. Planning, prototyping and testing of the circuit can be carried out on the virtual version before it is configured on the 'real' ELVIS workstation in the laboratory.

Students at the user end will first place the experiment circuit components on the three dimensional (3D) rendering of the prototyping board of the virtual NI ELVIS, as shown in Figure 12, to complete the circuit design. The zooming and rotating capability of the 3D Virtual ELVIS prototyping board provides an interactive feel for students when they are patching up the circuit on the virtual board. The final circuit design will be converted to the form of a text file which is named as Netlist.
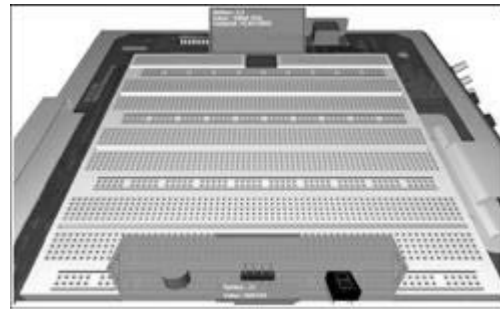
User interface

The user interface provides a frontal instrument panel whereby the user can interact with and control the different functions available in the experiment. This interface determines the user-friendliness of the overall application. The user interface comprises four portions:

1) Experiment output indicators,
2) hardware reliability and netlist checks' indicators,
3) text messaging,
4) experiment flow control.

The user interface developed for the remote control and monitoring of the laboratory experimental setups is shown in Figure 13. Experiment output indicators include numerical and graphical output blocks which display the results of the experiment in numerical format and the graphical format, respectively. These results could be the potential of a point or a current in the circuit. The hardware reliability and netlist checks' indicators are alarm blocks that alert the user in the event of any error or abnormality arising during the course of the experiment. Due to the limited life cycles of electronic components, it is pertinent to eliminate any hardware component failure during the course of the experiment in order to obtain meaningful results. Text messaging controls and indicators are a facility whereby students can communicate with the laboratory administrator. The user controls the initiation and termination of the experiment via a 'Stop' button.

OTHER IMPLEMENTATION ISSUES

As well as the software and hardware considerations during development of the system, there are some pertinent issues to take into consideration to make the whole system more robust and user-friendly.

Pre-experiment hardware check

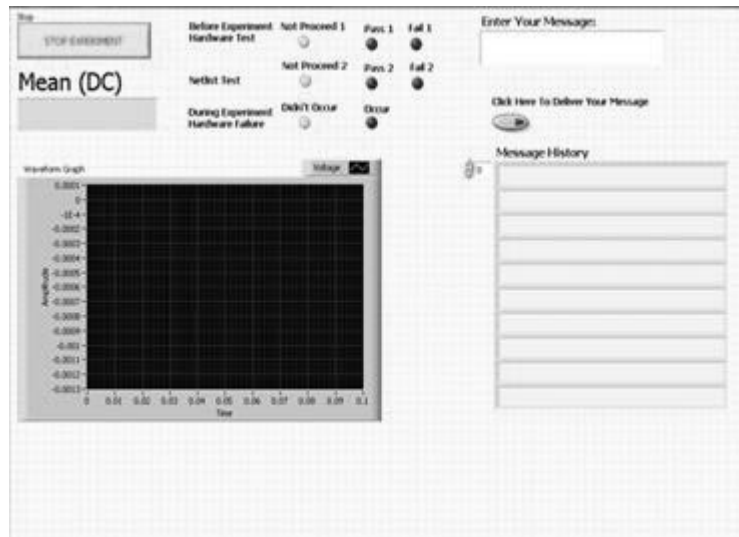One possible limitation of remote control and

Fig. 13. User interface.

monitoring of laboratory experimental setups is that, unlike conventional laboratory experiments, students are not able to physically debug hardware errors. Before the remote experiment, it is thus essential to have some means of checking the functionality and reliability of the hardware components. This is to ensure that meaningful learning can be achieved as students will not be physically present to carry out this aspect of the experiment. In addition, upon completion, the verification status must be shown to the students to inform them whether the experiment can begin. Figure 14 illustrates the result when the pre-experiment hardware check passes. A message 'Before Experiment Hardware Check Pass!' appears to the user and the 'pass' indicator is lighted.

Text messaging function

Another possible limitation of the remote laboratory is the lack of communication channels between the user and the laboratory technicians. In a conventional laboratory, students are able to communicate with tutors or laboratory technicians directly. In view of this shortcoming, a text messaging function has been specially designed for the user. This function is particularly useful for communication when an error occurs during the course of the experiment. In the case when a laboratory
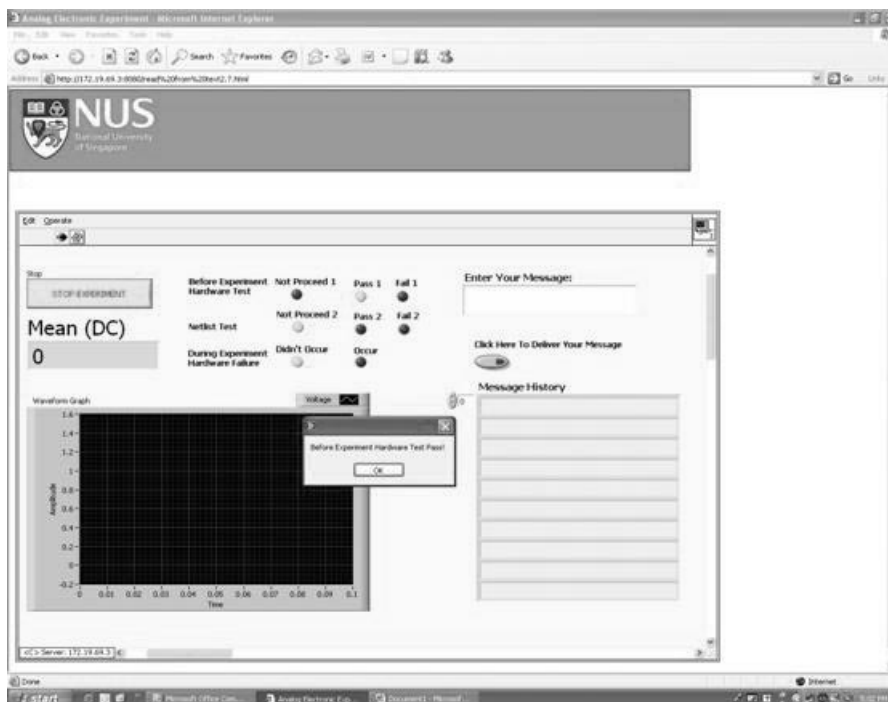

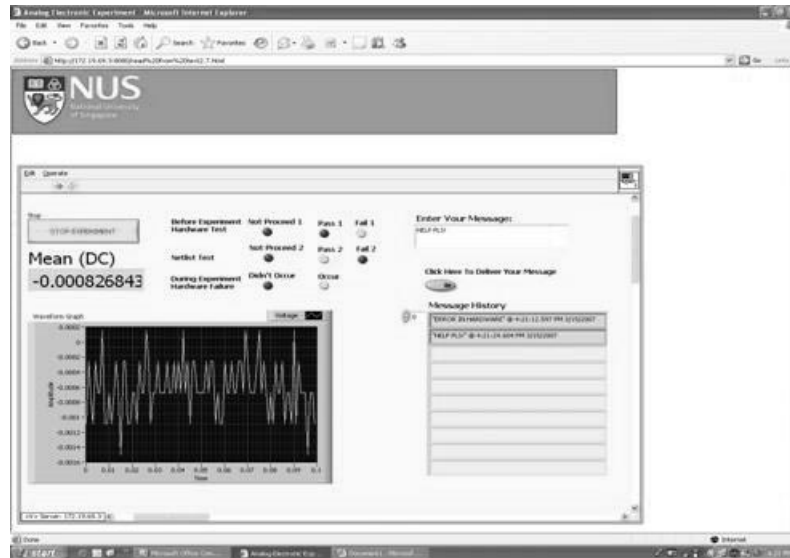Fig. 14. Pre-experiment hardware check.

Fig. 15. Sent messages—client side.

technician is not stationed at the server computer, time and date of the message sent will also be displayed together with the message for tracking. The message history can also be seen as messages sent are stored in the form of an array with each message occupying each element of the array sequentially. Figure 15 shows messages being sent by the user through the text messaging function on the user interface. Messages sent will be indicated at the server interface as shown in Figure 16.

Netlist check

The Netlist corresponding to the student's circuit design is performed by comparing with a signature Netlist which is saved in the server. If the two Netlists match, all the relay switches set up at the circuit nodes will be closed and the exact signature response will be obtained by the user.

If the comparison only matches partially, the switches will be closed according to the student's design and the student will be able to see the corresponding response, based on which a redesign may be done and the process repeated. Indication of the Netlist Check result will also be given to the user. Figure 17 illustrates the result when the Netlist Check passes. A message 'Your Netlist is correct!' is shown and the 'pass' indicator will be lighted.

FIELD STUDY AND SYSTEM EVALUATION

To evaluate the effectiveness and viability of the proposed framework, an electronics experiment testbed named the Integrated Electronics Experi-
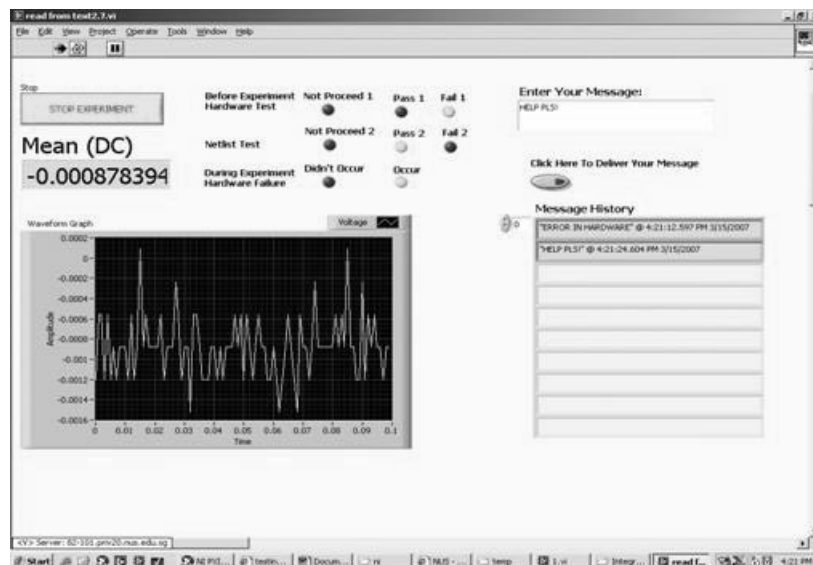
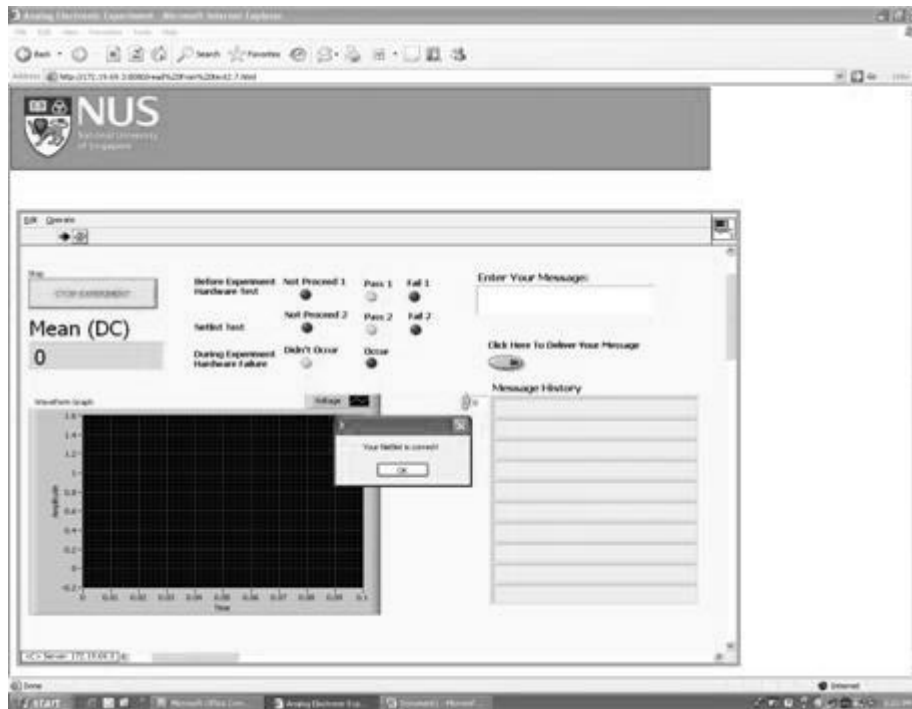

Fig. 16. Sent messages—server side.

Fig. 17. Results when the Netlist Check passes.

ment Workspace (similar to that shown in Figure 6 above) was set up in the Mechatronics and Automation Laboratory in NUS. A 30-minutes talk was given on-site in one of the ECE Corners to a group of 15 junior college students from the science stream (i.e. physics and chemistry were their core subjects). The talk covered the theoretical background of some electrical electronics, like the functions and typical application circuits of some discrete and analogue components. Thereafter, the students were given the procedures of an experiment for them to do at a remote location convenient to them with assigned time slots of two hours each. A brief introduction to the various features of the Integrated Electronics Experiment Workspace was also provided. For deliverables, the participating students had to submit a laboratory report which included a summary of the laboratory procedures, critical observations and results in graphical and tabular formats. In addition, the participating students were given time slots when assistance would be available for interaction remotely when technical help was needed. Some of these students had some experience with conventional electronic circuits design tools, like MATLAB[26], SPICE [27] and C++ [28].

At the end of this trial run, feedback in the form of questionnaires and interview were obtained from a panel of stakeholders, including the participating students and teachers, to evaluate the effectiveness and viability of the proposed testbed (i.e. the Integrated Electronics Experiment Workspace). From this feedback exercise, the suitability of the proposed testbed for prospective students can be determined. The main aim of this study was

not to determine whether the proposed system is better than conventional tools for electronic circuits design. But through this study, the students were exposed to different tools to achieve the same learning objectives. Their choice of tools used in subsequent tasks is of more interest in this study. Furthermore, it is interesting to study the learning experience of designing and implementing electronic circuits without physical contacts with the actual components and equipment, as compared to the conventional way of performing
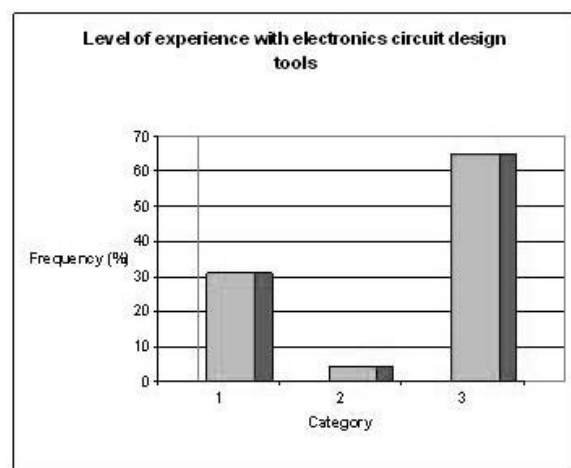

Fig. 18. Results of study to determine the level of experience with electronics circuit design tools. Category 1 refers to those students with prior experience in using electronics circuit design tools. Category 2 refers to those students with prior experience in using NI Multisim and LabVIEW. Category 3 refers to those students with no prior experience in using electronics circuit design tools.
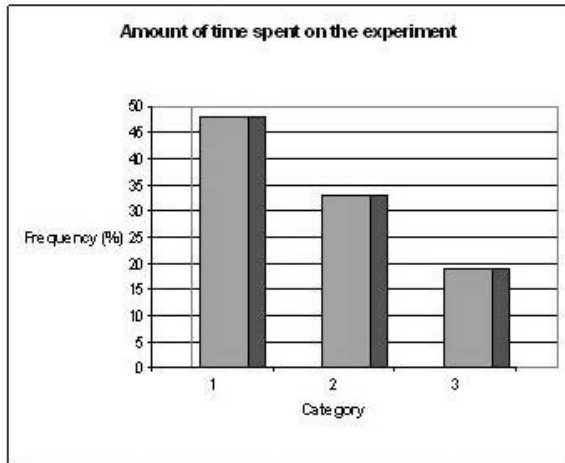
Fig. 19. Results of study to determine the amount of time spent on accessing the Integrated Electronics Experiment Workspace. Category 1 refers to those students who spent more than three hours on using the Integrated Electronics Experiment Workspace. Category 2 refers to those students who spent two to three hours on using the Integrated Electronics Experiment Workspace. Category 3 refers to those students who spent less than two hours on using the Integrated Electronics Experiment Workspace.
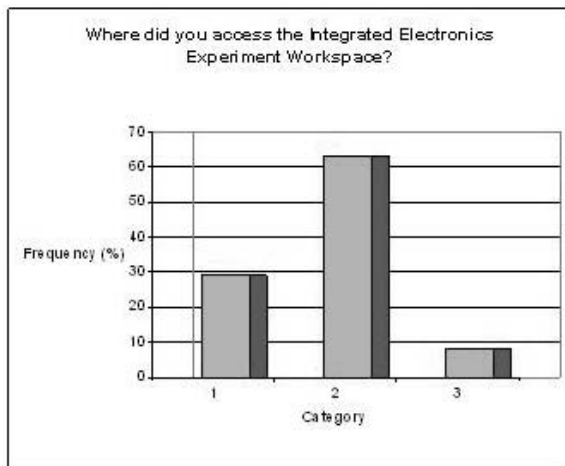

Fig. 20. Results of study to determine where students accessed the Integrated Electronics Experiment Workspace. Category 1 refers to those students who accessed the Integrated Electronics Experiment Workspace from college. Category 2 refers to those students who accessed the Integrated Electronics Experiment Workspace from home. Category 3 refers to those students who accessed the Integrated Electronics Experiment Workspace from other locations.

electronics circuit experiment with hands-on experience using actual components and equipment.

Survey results from the stakeholders (including the group of 15 junior college students who attended the briefing at the ECE corner and five teachers in-charge) are illustrated in Figures 18 to 21. Referring to Figure 18, about 31 per cent of the participating students had prior experience using electronics circuit design tools, like SPICE, MATLAB and C++. Only four per cent of the participating students had prior experience using NI Multisim and LabVIEW. The majority of the
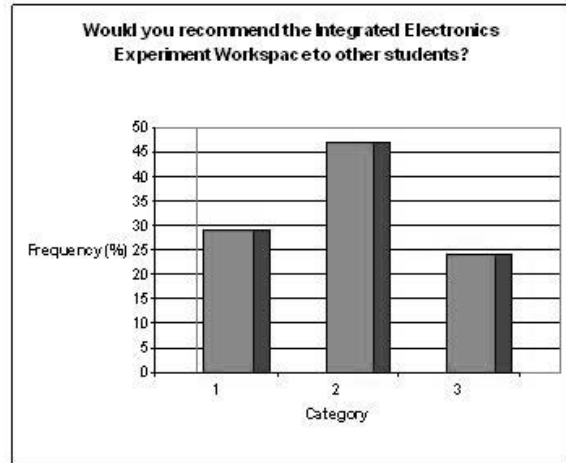

Fig. 21. Results of study to determine whether participating students and teachers prefer the Integrated Electronics Experiment Workspace. Category 1 refers to students and teachers who would recommend the Integrated Electronics Experiment Workspace as their preferred first choice to other students. Category 2 refers to students and teachers who would recommend the Integrated Electronics Experiment Workspace and other electronics circuit design tools to fellow students. Category 3 refers to students and teachers who would not recommend the Integrated Electronics Experiment Workspace to their fellow students.

students (about 65 per cent) had no prior experience with electronics circuit design tools. For those participants with prior experience in using other electronics circuit design tools, they would be able to rate the usability and viability of the proposed approach effectively.

Figure 19 shows the results of the study to determine the amount of time the participating students spent on accessing the Integrated Electronics Experiment Workspace. A majority (81 per cent) spent more than two hours on the assigned experiment. These students had to rebook another time slot to complete their assignments. This came as no surprise as most of the participating students had no prior experience with electronics circuit design tools. Figure 20 shows the results of the study which determines the location where the participating students accessed the Integrated Electronics Experiment Workspace. Most of the students (about 63 per cent) preferred to access it from their homes remotely after official school hours. A small number, about 29 per cent, performed the assigned experiment using the college internet and computer resources. Thus, it could be concluded that most of the students had no difficulty in accessing the Integrated Electronics Experiment Workspace. Figure 21 illustrates the results of the study to determine whether the participating students and teachers' in-charge prefer the Integrated Electronics Experiment Workspace over other electronics circuit design tools available in the market. 29 per cent of them would strongly recommend the Integrated Electronics Experiment Workspace to their fellow students. They replied that they would most

likely use this tool again for future work. About 47 per cent of the participating students and teachers in-charge had a milder response about recommending it as first choice to fellow students. Thus, it could be concluded that the most participants have a positive response after using the Integrated Electronics Experiment Workspace. This study highlights the viability of the proposed system for outreach activities. There are many future plans to implement more remote experiments and demonstrations involving more sophisticated components for the outreach activities at the ECE Corners.

CONCLUSIONS

Development of the framework and system structure which allows the hands-on experience of electronics experiment from a remote location, using virtual instrumentation devices and software, along with their interactions, allow students at home or off-campus to interact with the rich resources at NUS.

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