

Re-Engaging Engineering Students in Hands-On Education

Abstract

This paper presents the technologies and implementation activities that are under development to re-engage students in “hands-on”, in and out of class exploration, experimentation and design to aid students’ understanding of the “big ideas” in electrical engineering. It describes (while the presentation will demonstrate) the Mobile Laboratory hardware and software (developed by Rensselaer) which, when connected to the PC via a USB port, provides similar functionality to an oscilloscope (with a full 50KHz bandwidth), 2 function generators, a multimeter and bipolar power supplies (for less than the cost of a typical textbook – approximately \$75). With the advent of this mobile instrumentation studio PC-based laboratory, many instrumentation-based course offerings can now be held in normal classrooms rather than in specially outfitted facilities. In addition, students are asked to perform hands-on experiments outside of the classroom anywhere/anytime, thus facilitating new opportunities for them to “tinker,” to gain valuable insight through practical experience and to rekindle the passion for solving problems – potentially attracting/retaining a significantly larger fraction of the best students.

Rationale

Today’s students are computer-savvy, exhibit a diminished attention span, and have tremendous demands upon their time. Educational research has shown that humans retain perhaps 10% of what they hear someone else tell them, but retain as much as 90% of what they learn by doing. Mobile studios with Tablet-based Laboratory equipment setups (TabLabs) can be set-up and removed in minutes, allowing for greater efficiencies in space utilization, scheduling (over a period of 24 hours/day), maintenance & support, enhanced student-teacher engagement and ultimately, improved student learning.

Engineering students are typically running multiple applications while simultaneously using browsers, instant messaging and search engines on their computers. This results in competition for the user’s attention and impedes the ability to focus – with the notable exception of the engrossment involved with a computer game. Consequently, the shortened attention spans, lowered tolerance for repetition, and dependence on computers seriously challenges educators to provide information in more dynamic, compelling, thorough, and interactive ways.

As electronic designs have become increasingly complex, today’s products require engineers with advanced skills and greater intuition in science, math, engineering and technology than prior generations exhibited. Shortened attention spans hinder students from staying engaged and focused in technical classrooms, resulting in poorer performance and diminished interest in pursuing technical careers. Notwithstanding the recent advances in educational technology, we need to incorporate more dynamic, hands-

on opportunities to reach and motivate more diverse populations. Today's engineering students don't enter college with the same amount of hands-on experience that prior generations had.

Project Overview

The "Mobile Studio" project is developing pedagogy and hardware/software with support from both Analog Devices and HP which, when connected to a PC (via USB), provides similar functionality to that of the laboratory equipment (scope, function generator, power supplies, DMM, etc.) currently associated with an instrumented studio classroom. Our goal is to further expand the studio pedagogy (pioneered by Rensselaer with the help of HP) to have students learn with technology in mobile environments that are no longer limited by network access and equipment issues. Our aim is to: develop and use educational technology to eliminate the boundaries between theories provided in a lecture and practice; apply concepts in directed problem sessions; and enable/encourage our students' "hands-on" exploration of engineering principles, devices, and systems that have historically been restricted to specific laboratory facilities.

Hardware

The Mobile Laboratory hardware is based upon a small (11.3 in²) proprietary printed circuit board. This board contains all the components required to implement the system, as well as limited processing power to take some of the load off the user's PC. A majority of the devices on the board can be attributed to one of several main functionalities: power, digital input/output, analog input, analog output, waveform output, and daughterboard connectivity.

Power

One of the advantages of using USB for communications between the hardware and a PC is the 5V power supply provided by the PC on the same connector as the USB data. A device can draw up to 500mA, which is more than enough for this hardware. This eliminates the need for students to carry around a bulky wall transformer, and also eliminates clutter by having only one required connection into the board. On the board, various regulators and an inverter provide power to the digital and analog components of the system.

Digital Input/Output

The board has 16 digital channels, each of which can be individually selected as an input or an output. When a channel is set as an output, it can output a high voltage level of 3.3V (standard CMOS logic), and drive up to 1.6mA. When selected as an input, the channel is 5V tolerant, which allows interfacing to TTL logic families. In addition to simple control and monitoring applications, these digital pins can be used for various output modulation schemes, such as Pulse-Width Modulation (PWM), or as a logic analyzer when in input mode, among other uses.

Analog Input

At the heart of the analog input system is a 1MSps, 12-bit analog-to-digital converter. The ADC is multiplexed to 12 channels, seven of which are available to the user via a screw terminal mounted on the board. Channels 3 through 7 are able to read voltages between 0 and positive 2.5V. Channels 1 and 2 are enhanced, in order to more closely match a commercial oscilloscope's input capabilities (though any analog channel can be used in oscilloscope mode). On these two channels, the input range is -10V to +10V. To provide this range, a digitally-adjustable gain front end is implemented. These enhanced channels can be operated in single-ended or differential mode, and offer a high-impedance input to minimize the effects of the hardware on the circuit under test. Many of the standard oscilloscope features traditionally implemented in hardware, such as AC coupling, are implemented in firmware or software to reduce costs.

Analog Output

To compliment the analog input capabilities of the hardware, four independent digital-to-analog converters are supplied. The output range of the DACs is 0 to 2.5V, with 12-bit resolution. These can be used to provide a DC voltage to an external circuit, or an AC voltage in an arbitrary waveform generator configuration. All four channels are internally tied to analog input channels to allow monitoring of the DAC output.

Waveform Output

In addition to the DAC outputs, two independent function generator channels are provided on the board. These are capable of generating sine, triangle, and square waves at frequencies between 0.004 Hz and 500 kHz. Similar to a bench top function generator, these channels have adjustable DC offset and adjustable amplitude. The phase of each channel can be varied, allowing the channels to be put in phase, out of phase, or anywhere in between relative to the other channel. As with the DAC channels, these two channels are internally tied to analog input channels to monitor the output of each function generator without tying up user accessible channels.

Daughterboards

In addition to providing all of the aforementioned features, the hardware is also set up to act as a base for additional features. Three vertical headers provide access for a daughterboard to interact with nearly all the capabilities of the board. For daughterboards with low power requirements, power is also supplied via the headers. A daughterboard can supply or monitor analog and digital signals to/from the main board, as well as communicate with the main processor, thus allowing a daughterboard to communicate with the user's PC. At this time, a sensor daughterboard has been developed which adds a large collection of sensors commonly used in circuits and physics classes.

Software

The PC software suite is designed to allow a collection of different features to easily communicate with a variety of hardware. All the components of the suite can be placed in one of three categories: framework, hardware interfaces, and feature displays.

Framework

The framework is the main application of the suite, and provides a foundation for the other components. The application dynamically loads any features and interfaces that are available on a users system, allowing for seamless addition and upgrading of components in the future. This makes the system very flexible, and able to easily change to meet the expanding needs of the users and hardware in the future. To make this possible, both the feature displays and the hardware interfaces abide by a set of “rules” which makes the interface between the two possible. With this configuration, each feature display need not know the specifics of each hardware variant. Instead, it simply sends standardized commands to the framework, which then decides which hardware interface should be used to relay those commands.

The hardware interfaces take the standard commands, and re-process them into a form that their specific hardware understands, and transmits those commands to the hardware. Both the hardware interfaces and feature displays are implemented as DLLs and the framework is implemented as an executable application. The framework cannot provide any useful functions without hardware interfaces and feature displays, and conversely, the feature displays cannot function without being loaded into the framework application (although the Hardware Interfaces can be used by other applications). Once combined, however, the system is a powerful suite that allows virtually limitless expansion on both the hardware and software side.

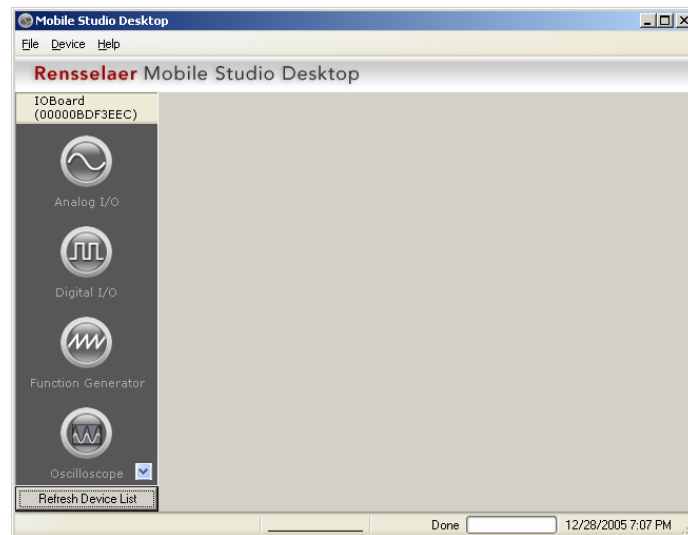


Figure 1: The Framework Application

In addition, the framework application manages the list of currently connected hardware, as the software can connect to multiple devices simultaneously, and provides the graphical interface for the user to select which features they want to use with which hardware, as show in

Figure 1. The application also manages the windows for each feature, so that several features can be open at the same time, either from the same hardware or from different hardware.

Hardware Interfaces

A major goal when designing the software suite was to allow the feature displays to communicate with a variety of hardware, both hardware that exists now and hardware which is yet to be realized. The individual hardware interfaces provide this ability to the software suite. Each provides an identical interface to the rest of the suite, however the way in which each hardware interface handles the data is very different. The interfaces take the data provided to them from the feature displays and format it into the equivalent command which their specific hardware understands. The same is done in reverse for data coming from the hardware destined for a feature display. Separating the hardware interfacing from the rest of the software yields a number of advantages. First, numerous communications interfaces can be used.

While the current hardware communicates over USB, the hardware interfaces are equally as capable at handling a device which communicates over, for example, serial or TCP/IP. A second advantage to the hardware interface system is that a feature display can be written, without any knowledge of future hardware, and as long as the required devices are still available on future hardware, the feature will still work. This works in reverse too, as new feature displays can be developed that work with both new and older hardware, without any additional development time. In addition to providing services to the software suite, the hardware interfaces can be used by 3rd party applications to create software tailored to a specific task.

Feature Displays

The feature displays are the part of the software with which the user interacts. They provide a graphical interface tailored to a specific functionality that the hardware can perform. For example, the Oscilloscope Feature Display provides the user with a screen that mimics a standalone oscilloscope, and the controls react as they would on their bench top counterpart. Five feature displays have been developed at this time, namely Analog I/O, Digital I/O, Function Generator, Oscilloscope, and Spectrum Analyzer.

The Analog I/O display provides a voltmeter-like display for analog inputs. All of the available analog channels can be selected, and the readout updates at rates similar to those of a mid-range multimeter (10 Hz). For analog output, a slider and readout are available for each DAC channel, which allows for setting a DC output voltage between 0 and 2.5V. The slider provides an easy interface method for users either on standard mouse-and-keyboard PC or a pen-based (tablet) PC. The readout provides a digital

display of the value currently being output. The voltmeter display can be set to show the output of a DAC channel at the same time the user is changing the DAC output, in order to verify that the expected output is indeed the actual output.

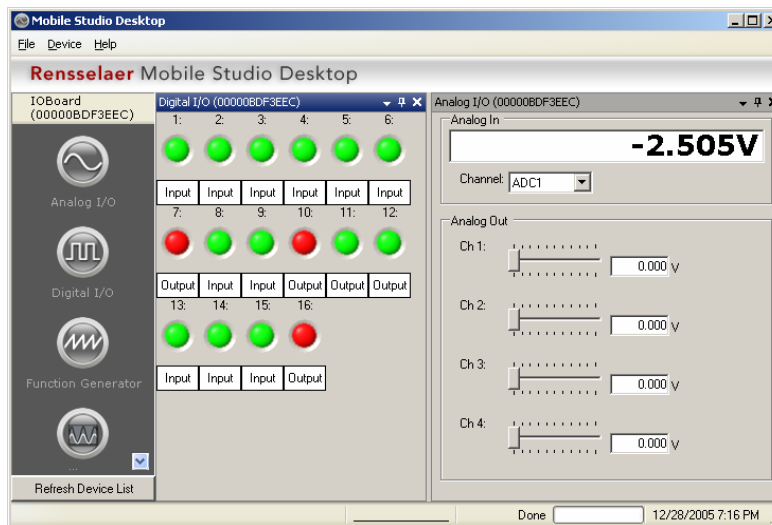


Figure 2: The Digital I/O and Analog I/O Displays

The Digital I/O page provides a very basic interface to set the direction of each digital pin, as well as set the state for output pins and view the current state via a virtual LED/logic probe display. In the future, this display will be upgraded to include digital modulation schemes such as PWM, as well as other digital options.

Included in the Function Generator display is the ability to set the frequency, phase, waveform type, offset, and peak-peak level for each channel available on the connected hardware. Future improvements include the ability to sweep the frequency and amplitude, among others.

Both the oscilloscope and spectrum analyzer displays are designed to mimic the actual instruments as much as possible, while still exploiting the enormous advantage that a dynamic user interface on a PC provides compared to the fixed interface of a bench top instrument. Although you may “click” something on screen instead of turning a knob, the intent is that a user who becomes proficient with this PC based scope will be able to then use a bench top scope with little or no re-learning.

The oscilloscope display is set up as a color, dual-channel oscilloscope with a math channel. Triggering options include: Single-Shot, Normal, where the display is only updated when the trigger condition is met, and Auto, where the display is updated un-triggered when no trigger condition is met for a set amount of time. For viewing non-cyclical signals, the user also has the option of turning off triggering. The trigger source can be selected as Channel 1, Channel 2, or any one of the digital input pins, similar to an “external trigger” option. The slope of the trigger (rising or falling) as well as the trigger voltage level is selectable. An option to set the trigger to 50% of the current signal is

available, and a future upgrade will include an “Autoset” button that will determine an appropriate volts/div, time/div, and trigger level without any user interaction.

The analog input can be selected for both of the oscilloscope channels. For example, analog input pin 5 could be assigned to Channel 1, while the second function generator’s output could be assigned to Channel 2; offering flexibility that is not typically found in bench top instruments. This allows the user to have a large collection of signals connected to the hardware at the same time, and then easily select which input to observe. The software automatically adjusts the display to account for the differences between the various analog inputs. In addition to the standard volts versus time display, the oscilloscope also includes a Channel 1 versus Channel 2, commonly referred to as an X-Y display.

As with most digital oscilloscopes, the oscilloscope feature display includes a number of additions to aid the user in measuring a signal. A Measurements panel provides the user with the Frequency, Period, and Peak-Peak, RMS, and Mean voltage of either Channel 1 or Channel 2. Both time and voltage cursors are also available, in case the user wishes to measure something not covered in the Measurements panel.

The Spectrum Analyzer Feature Display presents the user with a screen that mimics an entry-level bench top spectrum analyzer. The user has the option of selecting a center frequency and span for displaying, or a start and end frequency. The vertical scale can be set manually or put into Auto mode. As with the oscilloscope feature, the user can select any available analog channel as the input source. User controlled cursors are implemented, along with automatically placed peak markers. A simple time-domain view is available to allow the user to ensure the input signal is what they expect. Two separate collection modes are available. The first uses the hardware’s maximum sample rate. The downside of selecting the high-speed mode is that the buffer size is limited to 1k, as the buffer is implemented in hardware. This mode is good when a user wishes to see a wide spectrum of frequencies, but is not as concerned about resolution. The second mode uses a lower sample rate, but allows for much larger buffers. Since this buffer is implemented in software, the user can select how large they wish the buffer to be. This mode allows far greater resolution, with the disadvantage of a lower maximum frequency.

Implementation

We have observed that by simultaneously stimulating a student’s multiple senses, we can improve the student’s understanding of the educational concepts – which leads to greater retention and application of the acquired knowledge. In addition, the Mobile Studio has changed the way students make measurements; allowing for a nearly instantaneous comparison between theoretical predictions, virtual simulations and actual hands-on experimental results. Students can again “tinker” with the hardware aspects of engineering and science, providing open-ended opportunities to explore ideas – as prior generations did.

Student access to user-friendly, computer-controlled instrumentation and data analysis techniques offers immediate scaffolding of principles and concepts by obtaining experimental results – from the Mobile Studio hardware & software. Current collaborations (student-student, student-teacher) in classes are typically limited to using static 2D data (e.g. on paper) and constrained problems. This project implements the utilization of dynamic data, graphical collaboration techniques, and in-class design scenarios to further engage students. For example, team results from the development of a treble circuit project are presented and distributed via the mobile studio's A/V system.

The Mobile Studio provides students with the equipment to grasp the fundamental concepts associated with engineering education by acquiring, utilizing and controlling real world phenomena (e.g. voltage, current, resistance, position, temperature, intensity, etc.); moving objects to precise locations; and developing systems to monitor, process & manipulate electrical signals and events. The project's outcomes are intended to enable students to take measurements (using a scope, function generator, etc.) and test prototype designs from anywhere at anytime.

For example, students are given a statement of the problem to be explored ($V=IR$) or the quantities to be measured (voltage, current and resistance) and are asked to both devise and conduct experiments and techniques to acquire the data using the instrumentation card. They use the interactive learning modules and technologies in a manner where they aren't fully guided through prescribed laboratory activities. Take-home activities for Physics I, Physics II, Circuits and Electronics courses have been developed and implemented that have students designing and performing experiments that illustrate the theory – in contrast to the educational sequence historically used to present related concepts (theory – problem solving – experimentation).

Pilot Assessment

The assessment of the pilot efforts included a review of the educational technology, interviews with faculty, classroom observations, student evaluation surveys/interviews, and conventional student performance metrics (course work, HW, exams, etc.). Student performance on design-oriented problems by those using the Mobile Studio's TabLab instrumentation was significantly better than the group that did not participate in the Mobile Studio sessions - in contrast with analysis-oriented problems, in which similar results were achieved by both groups. The Mobile Studio allowed faculty to better present course concepts and foster student interactivity & collaboration.

Additional outreach activities were carried out with 4th grade science teachers from the Niskayuna School District (@Craig Elementary School). Tablet PCs were used to explore interactive modules (developed by Rensselaer's Academy of Electronic Media) with the Mobile Studio hardware/software to aid the students' understanding of electrical connectivity, resistance and circuit testing. A subset of the Mobile Studio Tablet PCs was also used in an interactive session at Lansingburg High School (Troy, NY), which incorporated hands-on activities to demonstrate the impact that electronics had on music. Each of these efforts had a huge positive impact on the students involved; including a

significant improvement on the corresponding section (focused on electrical concepts) of NY State's standard 4th grade exams.

One Year Ago

Even with the more engaging studio environments, student learning is still impeded by space constraints, insufficient time for laboratory activities (particularly to do the in-depth probing that leads to an intuitive feel for system design), and poorly designed equipment that takes up a great deal of space – and can't be brought home for individual study. Lab-equipped classrooms are both in high demand and in extremely short supply.

Today

Configuring a studio facility typically requires a large equipment allocation/expense and a specific space utilization plan. Renovation of existing facilities is currently cost-prohibitive for many schools, thus limiting the potential to leverage the advantages of the studio format. The hardware is being piloted in five courses at Rensselaer and Howard - providing studio classrooms for curricula that used to offer courses in lecture only formats; currently involving Electrical Engineering, Computer Engineering, Physics and Rensselaer's core engineering program. As a wonderful testament to the project's achievements, Jason Coutermarsh (the undergraduate student developing the instrumentation board hardware) won first prize at Rensselaer's 2005 Undergraduate Education/Research Project Competition.

One Year from Now

We will use the advanced mobile technologies to produce a new generation of classrooms that are more adaptive and less reliant on the construction of large facilities, allowing studio pedagogy to be readily deployed at a dramatically reduced cost. We plan to infuse the TabLab technology and pedagogy into Rensselaer's Physics and ECSE departments' large enrollment courses and expand the utilization of mobile studio classrooms campus-wide. Ultimately, we will develop the Mobile Studio practices and the TabLab technology into a model that can be readily adopted by home-schooling providers, community colleges, universities, and K-12 institutions – to significantly impact student learning on a national scale. It is anticipated that the Mobile Studio hardware will be readily available for others at an estimated cost of less than \$100/board; while the software will be made available to interested parties via Rensselaer's Academy of Electronic Media website.

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