LabVIEW in the Undergraduate EE Classroom - The Rebirth of the Measurements Lab

Mark H. McKinney[1]

Abstract

The traditional measurements lab has all but disappeared from most electrical engineering curricula. Incongruously, computer based measurement and automation has become an integral part of industrial research and development. As a result, it is becoming increasingly important to teach students these technologies in an undergraduate EE curriculum. At the Citadel, a course in measurements coupled with a lab focusing on computer based measurement and instrumentation utilizing LabVIEW has been developed. This paper will present the establishment of a senior level LabVIEW based measurement and instrumentation laboratory course. The course covers topics ranging from basic LabVIEW programming to process control using computer-based instrumentation.

Introduction

As the field of electrical engineering continues to expand and become more complex, departments are faced with the dilemma of how to fit new material into the curriculum. Instead of eliminating material, many departments choose to combine courses or integrate the material from one course into others. With this solution, students are exposed to more topics, but certain areas of the discipline are not covered in as much depth as they once were. Instrumentation and measurements (I&M) and is one such area.

Once a cornerstone of an undergraduate engineering education, instrumentation and measurements has been divided up and integrated into several other courses. Much of the statistical analysis has moved to a probability and statistics course where it is often not taught within the context of measurement systems. The instrumentation aspects are given a cursory overview as part of a freshman or sophomore level introductory lab course, seldom consisting of much more than how to use the equipment at hand. Finally, the process control aspects have either been eliminated or moved to a controls laboratory. While ABET considers instrumentation abilities to be one of the primary objectives of completing an undergraduate engineering education[1], a decline of the students' abilities in areas relating to measurement science has been observed.[2]

In contrast, measurement, automation, and instrumentation systems have become increasingly sophisticated and powerful. With the move to computer-based instrumentation, artificial intelligence systems have allowed the I&M systems to become an integral part of design and analysis of systems.[3] While they were once considered a supplement to existing technologies, they have evolved into their own area of specialization.

A state-of-the-art I&M system can replace an entire bank of measurement equipment with a single chassis, be programmed for system monitoring and process control, and even program embedded controllers and programmable logic devices.[4] The specifications of computer-based instruments are now comparable or superior to that of traditional instruments. As a result, more and more of industry is moving towards computer-based systems for nearly every aspect of engineering. It is of critical importance to provide the

1 Department of Electrical Engineering, The Citadel, 171 Moultrie Street, Charleston, SC 29409.

skill and knowledge to design, program, and utilize this rapidly developing technology to graduates of undergraduate electrical engineering programs

The Citadel's Department of Electrical and Computer Engineering has recently developed a course that covers traditional measurements topics with an accompanying lab dealing exclusively with computer based measurements and instrumentation utilizing a LabVIEW programming environment with data acquisition and IEEE 488.2 communication protocol capabilities.

In a previous paper[5], the introduction of a measurement and instrumentation system in a junior level electronics class was discussed. Due to the success of this integration, it was decided to resurrect the traditional measurements course as a computer-based measurement and instrumentation laboratory coupled with a traditional measurements course.

The Course

The primary exposure students have to measurement and instrumentation techniques and analysis is in a first or second year introductory laboratory course. This exposure is usually handled in less than one class meeting and is very limited in scope. From an instrumentation standpoint, it is typically limited to basic operation of function generators, oscilloscopes, power supplies, and multimeters. From a measurements standpoint, it is usually concerned with little more than the accuracy of the meters and calculating error. Other typical measurement topics may be covered in a statistics course or subsequent lab classes, but this material is either not directly related back to measurements or is learned with very little rigor.

The measurements course developed was intended to build upon and expand the students' existing knowledge of measurements and instrumentation. It was loosely divided into the following two broad categories:

Measurement techniques and interference

This section served partially as a review as well as delving deeper into the topics pertaining to measuring physical quantities. In addition to basic signal analysis techniques, types and sources of error were discussed as well as methods of curve fitting to account for errors inherent in the measurement system. Interference sources and shielding techniques were also discussed.

Sensors and transducers, instrumentation amplifiers, and signal conditioning

Various types of sensors and transducers to measure temperature, pressure, strain, pH, flow, level, and light intensity were discussed. Each student was assigned one type of sensor and was required to give a presentation to the class on the operation of that particular sensor. Particular attention was paid to whether the sensor was active or passive, any signal conditioning that was necessary, and the usable range and sensitivity of the device. In addition, various types of differential and instrumentation amplifiers were discussed, analyzed, and designed.

The Lab

The goals of the laboratory portion of the sequence were to enable the students to design and utilize computer based measurement and instrumentation systems. As shown in figure 1, the hardware utilized for the lab included various pieces of test and measurement equipment connected to a computer via a GPIB, or IEEE 488.2 bus and a PC running LabVIEW with a data acquisition (DAQ) card installed. Note that the system under investigation is connected to both the laboratory instruments as well as the DAQ card. The data acquisition card has input as well as output capabilities, thus allowing it to provide a stimulus for the system as well as acquire data; this configuration allows for maximum flexibility.

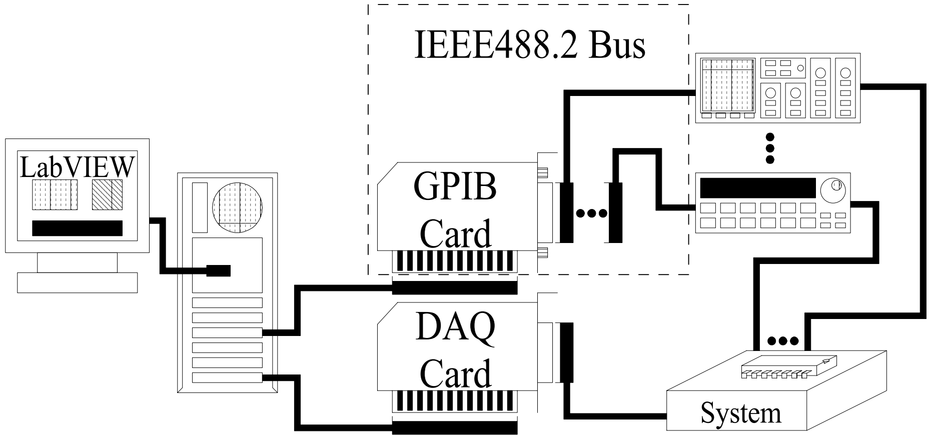

Figure 1 - Hardware set-up for computer-based measurement and instrumentation system

In order to set up an automated PC-based measurement system, the computer needs to know not only how to communicate with and control the laboratory instruments and the DAQ card, but must also have a program designed to make the required measurements. There are several packages on the market designed to control instrumentation devices and acquire data. The most widely utilized is National Instrument's LabVIEW. LabVIEW is ideally suited for this type of application in an undergraduate engineering lab because of its modularity and graphical programming interface.

LabVIEW is a graphical programming language tailored for data acquisition and instrumentation control. As can be seen from the small example program in Figure 2, there are two programming windows; the first displays the actual graphical code while the other allows the design of a graphical user interface (GUI). Together, these make up what is referred to as a virtual instrument, or VI. Additionally, a VI can be configured such that a higher-level VI can call it. When a VI is used in this manner, it is referred to as a subVI. This hierarchic programming structure allows specialized functions to be coded as subVIs, thus creating powerful blocks of reusable code.

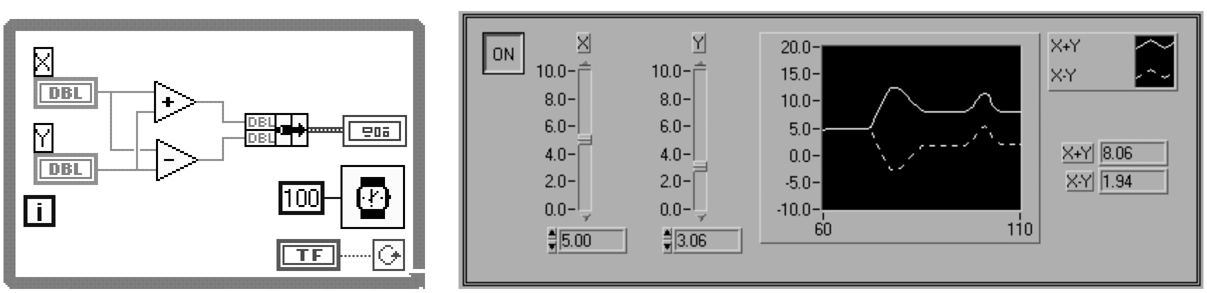

Figure 2 - Diagram and Front Panel for Simple VI

While graphical in nature, LabVIEW is a true programming language and must be learned as such. Students must have a firm background in control structures (for, while, if-then-else, etc…) and structured programming techniques in order to be proficient LabVIEW programmers. The students in this lab had experience with C++ and MATLAB, so minimal time was spent on the basics of structured programming.

Lab Structure

The lab was divided into essentially four sections: a section on learning the LabVIEW programming language, a section on utilizing the DAQ cards to send data to and receive data from the outside world, a section on controlling test and measurement instruments via the GPIB bus, and a section on using the I&M system for process control.

One of LabVIEW's fundamental strengths is its modularity through subVIs. The course was therefore designed such that the students worked on small projects that were then compiled into a larger project. This taught the students a powerful programming technique of combining small manageable programs instead of trying to program an application from the ground up - as is usually the case in an undergraduate programming course. For each topic, this top-down approach was utilized as will be discussed in the following sections.

Learning LabVIEW

The first portion of the semester was dedicated to learning the basics of the LabVIEW programming language. For this portion of the lab, a minimal amount of class time was spent on explaining the individual commands used in LabVIEW. Instead, projects were given that required the students to utilize the commands in useful ways. A few small projects were assigned to familiarize the students with the language and its capabilities. The students were required to select a significantly complex programming project that interested them.

This technique allowed the students to learn LabVIEW in their accomplishment of the task they set for themselves. As these exercises were designed to teach the programming language itself and not computer-based instrumentation, the only stipulation was the project could not communicate with the outside world.

This goal-oriented method of teaching a programming language was very effective and by the end of this portion of the course, nearly all of the students had a working knowledge of LabVIEW programming.

Communicating with the outside world via the DAQ card

Once the students had a fundamental understanding of LabVIEW programming, the projects focused on writing data to and receiving data from the outside world via the DAQ card. The first project dealing with the DAQ card was a temperature monitoring system. Initially, the students were required to write a program that would accept a user input for temperature with user selectable maximum and minimum temperatures. The program was required to give a visual warning if the temperature was outside the bounds set by the user. This program was then compiled as a subVI and the students were required to connect a thermocouple to the DAQ card and read the actual temperature. The program had to display the actual temperature as well as indicate whether the temperature was too high, too low or fell within the user specified range.

The second DAQ project was to create a rudimentary function generator using the output capabilities of the DAQ card. The first step in this project was to create a subVI that would display a waveform to the GUI. The user had to have the capability of selecting which type of waveform to display (sine wave, square wave, or triangle wave) and its amplitude. As the frequency of the signal depends on the loop execution time of the VI, frequency control was not required.

By integrating this subVI into a larger program, the students utilized the output capabilities of the DAQ card and output the waveform to an oscilloscope. The program also monitored two voltage inputs to determine which type of waveform to output and its amplitude.

Communicating with test and measurement equipment

Once the input and output capabilities of the DAQ card had been explored, the students were introduced to the IEEE 488.2 interface protocols for communicating with external test and measurement (T&M) equipment connected to a GPIB bus. The instruments used in this lab all had GPIB bus connections and are equipped to respond to IEEE 488.2 command protocols.

The IEEE 488.2 standard is a set of commands for communication with instruments connected to a GPIB bus. Below is the description for the IEEE 488.2 standard:

A set of codes and formats to be used by devices connected via the IEEE 488.1 bus is specified. This standard also defines communication protocols that are necessary to effect application-independent and device- dependent message exchanges, and further defines common commands and characteristics useful in instrument system applications. It is intended to apply to small-scale to medium-scale instrument systems comprised mainly of measurement, stimulus, and interconnect devices with an instrumentation controller.[6]

Because many high-level subVIs that handle the low-level IEEE 488.2 commands are readily available for most T&M equipment, LabVIEW programmers can successfully control instruments without explicit knowledge of the base commands. To introduce the students to the base-level commands inherent in instrumentation control, they were initially required to control a function generator using the raw IEEE 488.2 commands. This allowed them to understand the operation of the higher-level subVIs utilized throughout the remainder of the course.

Figure 3 shows typical subVIs available for T&M instruments (a function generator and a multimeter). As can be seen, there are inputs available for all front panel controls. This allows for the creation of a GUI that includes only the parameters needed from several pieces of measurement equipment. In addition to these configuration subVIs, there are initialization and close subVIs for most instruments. This basic setup allows for straightforward control of most laboratory equipment.

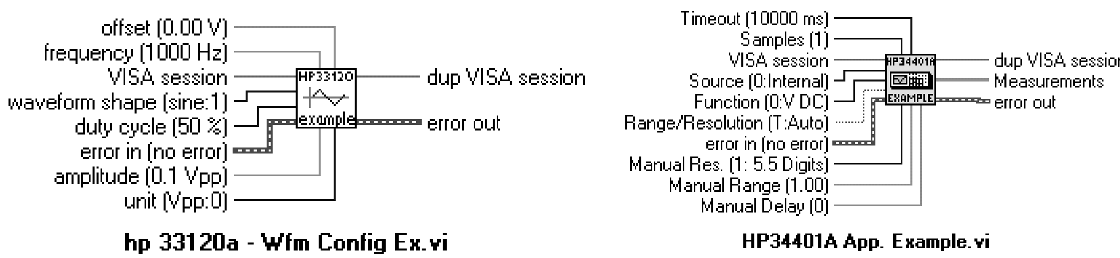

Figure 3 - Function Generator and DMM SubVIs

The main project utilizing GPIB control of instrumentation was an expansion of the spectrum analyzer project described in detail in a previous paper.[5] The basic operation of the spectrum analyzer is outlined in the flowchart in Figure 4. Prior to any program execution, communication is established with the equipment. The frequency parameters, inputted from the front panel, are used to cause the function generator to produce a sine wave at the selected frequency. This sine wave is applied to a test circuit and the multimeter measures the RMS voltage at the output of the circuit. If the current frequency is less than the stop frequency, the next frequency is selected and the last two steps repeat until the stop frequency is exceeded. At this point, the data collected are converted to dB and the gain and frequency data are output to a file. The communication channels to the measurement equipment are then closed.

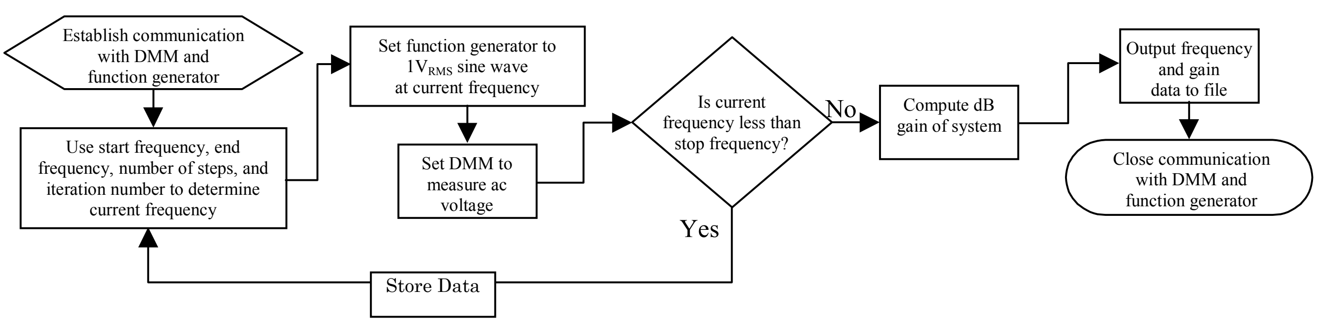

Figure 4 - Flowchart for Spectrum Analyzer VI

The students were first required to create two subVIs: one that logarithmically swept through a given frequency range and another that measured the RMS value from the multimeter and converted it into a dB gain given an applied voltage. These two subVIs were integrated into a larger program that allowed the two subVIs to work together and output the data to both the screen and a file.

The second project utilizing GPIB instrumentation control combined both DAQ card output capabilities and GPIB instrumentation control to make a rudimentary system analyzer. The basic requirements of this project were to design a system that would transmit a single cycle of a given frequency square wave from a function generator, apply it to an unknown system and display both the input and output waveforms received from an oscilloscope. Additional requirements were that the VI should utilize an output channel on the DAQ card to trigger the function generator and that the VI should set the oscilloscope in the appropriate triggering mode with appropriately scaled time base and voltage sensitivity.

Process Control

The final project of the semester involved utilizing a temperature reading to control the output of a heater. The project required the students to monitor the temperature of a heater block and control its temperature to a user input set point. Figure 5 shows the hardware configuration for the project. The program was required to use a pulse width modulation (PWM) scheme to control the heater and a thermocouple was used to monitor temperature. The duty cycle of the control signal was varied based on the input from the thermocouple.

As with other projects throughout the semester, this project was also broken down into smaller, manageable tasks. The first task was to utilize the subVI created earlier in the semester to read temperature and generate outputs for in-range, over temperature and under temperature conditions. The second task was to create a PWM control for the heater elements. This subVI was to have inputs for duty cycle and period. Once this subVI was developed it was integrated with the previously developed temperature-monitoring program. The final step was to create a control algorithm. This step involved characterizing the heater, determining an error based on the set point and actual temperature, and determining the appropriate duty cycle for the heater based on the error. A simple proportional control algorithm with a dead-band was utilized.

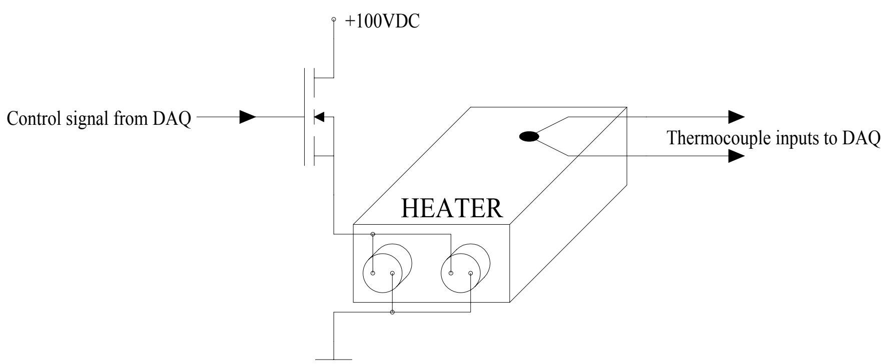

Figure 5 - Set-up for process control project

Student response and conclusions

When discussing our curriculum with parents and engineers, the idea of teaching computer-based I&M systems invariably brings praise and comments about the marketability of engineers with LabVIEW experience. The students also recognize that computer -based instrumentation and measurement systems are a valuable method of quickly creating powerful measurement and process control applications.

The response to the LabVIEW material was uniformly positive from the students. They appreciated the "hands-on" aspects of the course and while initially intimidated by the graphical programming language found it exciting to be able to quickly create professional looking and powerful applications. Many of the students appreciated the fact that the material in both the course and lab brought several topics from the rest of their undergraduate career together in a way that they could directly apply in the real world.

Measurements and instrumentation is a rapidly changing field and is nearly completely disassociated with the "traditional" measurements of a few decades ago. Current, state-of-the-art I&M systems consist of a single chassis and instrumentation modules that fit into the chassis. The modules have specifications that meet or, in many cases, exceed those of traditional bench-top units and are controlled exclusively through an instrumentation specialized programming language such as LabVIEW. These systems offer a flexibility, compactness, and power impossible with traditional instrumentation. As these sophisticated systems become more prevalent, our graduates will be required to know how to operate and program them.

Utilizing a top-down approach to teaching an I&M specialized programming language, data acquisition, instrumentation control, and process control, students obtained the skills necessary to set up a sophisticated I&M system. When taught in this manner, students are faced with the real-world challenges of learning how to solve a problem with the tools at hand. The methods presented proved effective in motivating the students to learn these increasingly important skills.

References

1. Feisel, Lyle D. and George D. Peterson (2002) “The Challenge of the Laboratory in Engineering Education,” *Journal of Engineering Education*, American Society for Engineering Education, Washington, DC.

2. Morawaski, Roman Z. (2002) “Are Measurement-Oriented Courses Getting too Difficult for Polish Students?” *Measurement*, Elsevier Science Ltd., Oxford, UK.

3. Finkelstein, L., M. El-ham and R. Ginger (1998) “Conceptual Design of Instrument Systems Utilising Physical Laws,” *Measurement*, Elsevier Science Ltd., Oxford, UK.

4. http://sine.ni.com/apps/we/nioc.vp?cid=11784&lang=US

5. McKinney, M. (2001) “LabVIEW™ in the Electronics Lab,” *Proceedings of the 2001 ASEE Southeastern Section Conference*, American Society for Engineering Education, Washington, DC.

6. IEEE Standard codes, formats, protocols and common commands for use with IEEE Std. 488.1-1987, *IEEE Std. 488.2-1987*, The Institute of Electrical and Electronics Engineers, Inc., New York, NY.

Mark McKinney

Mark McKinney received his B.S., M.E, and Ph.D. degrees in Electrical Engineering from The University of South Carolina. He is an assistant professor of electrical engineering at The Citadel, The Military College of South Carolina, where he has taught for five years. He has worked on projects for the Naval Surface Warfare Center on current limiting polymer protection devices and on LabVIEW sub-degree temperature control systems for the cooling of electronic components for KryoTech.