Development of an Online Analog Signal Processing Lab using LabVIEW

Nathaniel Hakes, Yang Zheng, Jesse Chen, David Munson
Department of Electrical and Computer Engineering
University of Illinois at Urbana Champaign

Abhay Samant
National Instruments Corporation, Austin, TX

Abstract

In this paper, we will discuss the development of a computer-based laboratory course using National Instruments LabVIEW and data acquisition products. The techniques presented in this paper are general purpose and can be used to develop any lab that requires simulation, hands-on experience, and the ability to run the lab over a network of computers. As a case study, we have chosen an analog signal processing course, ECE 210, taught by the department of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign. In this paper, we will describe how we developed the physical lab and the prelab using LabVIEW and how we provided students with tools to remotely access the lab.

Introduction

In recent years, teaching methods have gone through a number of changes. Significant among these changes is an increased use of technology. Professors now frequently deliver instruction with the aid of computers rather than through the traditional lecture approach. Students sometimes access and complete homework over the Internet, as computers easily grade the fill-in-the-blank or multiple-choice format questions. The next logical step is to use computers to teach the lab section of a class. Students can use computers to acquire real-world signals, perform advanced analysis and present the results. However, only a limited number of instructors have made use of this technology, in part because of the perception that the use of computers will compromise the traditional hands-on focus of the lab. In reality, students will still be required to set up the experiment. They can use computers to "speed up" manual measurements made in the lab, thus allowing them to collect more real-world data than what was possible by hand. This will leave students with time to delve into a more detailed and complex analysis of the concepts addressed by the lab. The use of computers also allows students who do not have access to a physical lab to monitor and control experiments over the Internet. The networking capability of computers allows "virtual" access to a real-world lab by students at a remote location, facilitating distance learning. These students can also use a computer simulation of an experiment as a pre-lab assignment, thus allowing them to have a better understanding of the behavior of the experiment. For students without access to a physical lab, the simulation pre-lab can provide a valuable learning experience that would not be available otherwise. In essence, computers can enhance, not compromise, the value of the hands-on lab experience and expand its availability to students.

In the first section of this paper, we will provide a brief introduction to LabVIEW and its capabilities. In the second section, we will discuss how these capabilities can be used to develop a computer-based laboratory course. In the third section, we will describe an analog signal processing course and use one of the labs from this course as an example to demonstrate the development of an online analog signal processing lab using LabVIEW.

National Instruments LabVIEW and DataSocket Technology

LabVIEW is a graphical programming language based on the concept of data flow programming. Many engineers and scientists in industry and academia have adopted LabVIEW for data acquisition and instrument control applications. Functions in LabVIEW are referred to as VIs (Virtual Instruments). LabVIEW has VIs for data acquisition, data analysis, and data visualization and presentation. The data acquisition VIs allow you to acquire data from a real-world source. Consider an experimental setup in which you connect a thermocouple, measuring the temperature of the room, to one of the channels of a data acquisition board. You can use one of the data acquisition VIs to acquire the temperature signal and then easily connect it to a graph to visualize the temperature readings. You can also perform calculations on the data using VIs such as the Mean and Standard Deviation. These VIs are part of the Advanced Analysis library in LabVIEW. The VIs in this library allow you to use classical digital signal processing and numerical analysis algorithms without writing a single line of code. We have listed some of these VIs below:

- Signal Generation contains functions for generating sine wave, square wave, chirp signals, Gaussian White noise, and other types of signals.
- Digital Signal Processing contains functions for Fast Fourier Transform (FFT), correlation, convolution, and power spectrum.
- Smoothing Windows contains functions for implementing Hanning, Hamming, Blackman, Exponential, Flat Top and other types of windows.
- Curve Fitting contains functions for Linear Fit, Exponential Fit, General Polynomial Fit and General Least Squares Fit.
- Linear Algebra contains functions for basic matrix operations, matrix multiplication, matrix inversion, and eigenvalue and eigenvector calculation.

LabVIEW also provides tools such as the VI Server and DataSocket to allow distribution of experiments over a network of computers. The VI Server allows one machine, which runs LabVIEW and VIs for different labs, to act as the server. Students can access experiments from their home computer or any other computer connected to the network. Their computers, which need not have LabVIEW installed, will have standalone executables that connect to the server using the TCP protocol and run the requested VI. Students can control the experimental setup from their computers and analyze the results. More than one student can access and execute the VI on the main server simultaneously.

National Instruments, the developers of LabVIEW, also provide DataSocket, which is a programming tool that reads, writes, and shares data among applications and/or different data sources and targets. You can access the DataSocket functionality from LabVIEW. Imagine a scenario in a lab with one computer that acquires data from an experimental setup and a second computer that acts as a server for the lab. The acquisition computer maintains one connection to the server and distributes data to students who are working from home or from other computers on the network. The student computers will have Web pages containing DataSocket reader components that connect to the server and read data. The acquisition can be restarted or the measurement computer rebooted without having to reconnect all the student computers. The latter stay connected to the server and receive new measurements as soon as the acquisition restarts and new data is sent to the server.

LabVIEW Implementation of a Laboratory Course

Instructors can use LabVIEW's features described in the previous section to develop a lab course. They can use the advanced analysis functions to develop VIs that simulate the behavior of a particular lab. They can use these VIs for a pre-lab or a homework assignment. Students will be required to run the VI and study the simulation results before they come to the main lab. They can also change parameters of the experiment simulation and observe the resulting changes. Such a pre-lab will prepare students for the actual lab class as it will give them a good mental reference of what to expect while performing the experiment. Instructors can use LabVIEW's VI Server capability to make the prelabs easily accessible to the students. They can set up the simulation VI on a server computer, which will have LabVIEW installed. Instructors can build an executable file in LabVIEW that has the same graphical user interface as the simulation VI and connects to the server using TCP protocol. This executable file can be built for a variety of operating systems such as UNIX, Windows 2000, NT, 95/98, and MacOS. Students can download and run this executable file on their computer. For the actual lab, instructors can develop a VI similar to the simulation VI. The only difference is that the simulated data will be replaced by real-world data. Students will be required to set up the experiment and connect measurement probes to the data acquisition board installed on the PC. They can use LabVIEW to collect real-time data during the experiment and make measurements. They can plot data in graphs and charts or export data to a spreadsheet, HTML file, or other document for their lab report.

In the next section we will use a specific example of an analog signal processing course, ECE 210, as an illustration of a lab implementation using LabVIEW.

ECE 210 – Analog Signal Processing Course

ECE 210, Analog Signal Processing, is an undergraduate electrical/computer engineering course taught at the University of Illinois at Urbana-Champaign. The course provides an introduction to analog signal processing with an emphasis on underlying concepts from circuit and system analysis. Topics presented in the course include the following:

- Resistive circuit analysis
- Signal arithmetic and calculus with circuits
- Circuits in sinusoidal steady-state
- Fourier series and circuit response to periodic power signals
- Fourier transforms and circuit response to energy signals
- Signal modulation and AM radio
- LTI systems and Laplace transforms
- Analog filter design
- Signal sampling

The course also includes five laboratory sessions, which cover the following topics:

- RC Circuits: examine frequency response of series RC circuits.
- Operational Amplifiers: design and construct operational amplifier circuits, build inverting amplifier, integrating amplifier, and first-order active filter.
- Impulse Response and Convolution
- Bandpass Filtering and Fourier Series
- Fourier Transform and Superheterodyne AM Radio Receiver: Examine Fourier Transform theory by constructing an AM radio receiver.

The objective of the laboratory portion is to reinforce the concepts taught during the course. Students complete a pre-lab before the lab period. The pre-lab consists of answering questions covering concepts to be examined in the lab session and solving problems based upon theory covered in the lectures and readings. The instructor or the lab teaching assistant then assigns two students to each lab station, which contains instruments such as an oscilloscope, function generator, linear power supply, multimeter, and a computer. Students use the lab period to build and analyze a particular circuit. They input signals of different frequencies and compare the circuit response to the theoretical response that they had learned in the class. They perform certain measurements and then prepare a lab report.

The feedback we received from some students is that they hardly have enough time to build the circuit as intended, so they are unable to fully explore the objectives of the lab. Of those students who do successfully complete the lab, many do not have enough time to experiment further with changing certain parameters of the circuit and analyzing the results. According to the students, the most time-consuming aspects of the lab were building and debugging the circuit and copying the waveforms displayed on the oscilloscope into the lab notebook. To address some of these issues and to enhance the laboratory experience for the students, we implemented a computer-based version of the course using National Instruments LabVIEW and data acquisition products. We developed all five labs using the techniques described in the previous section. We will now use one of these labs as an example to demonstrate our approach.

Example: Bandpass Filtering and Fourier Series

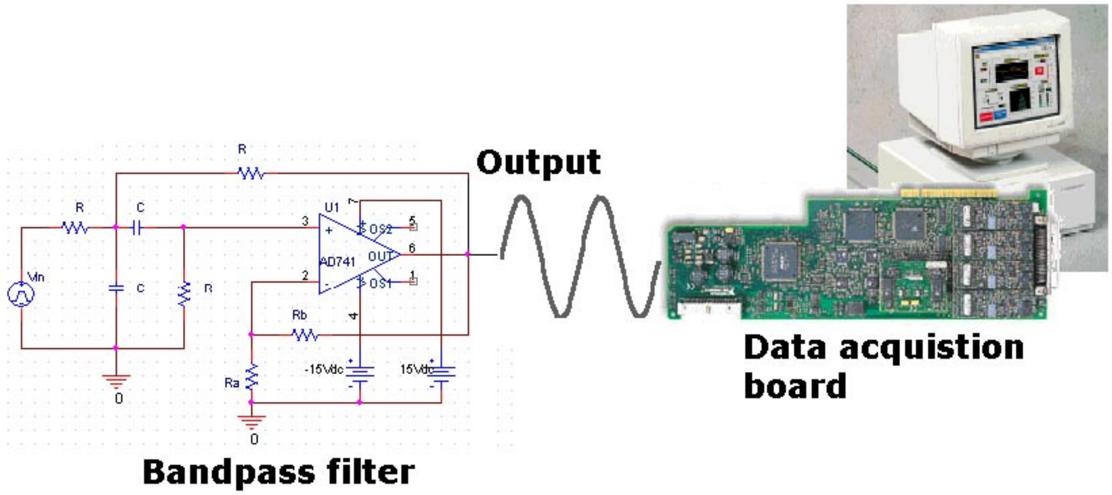
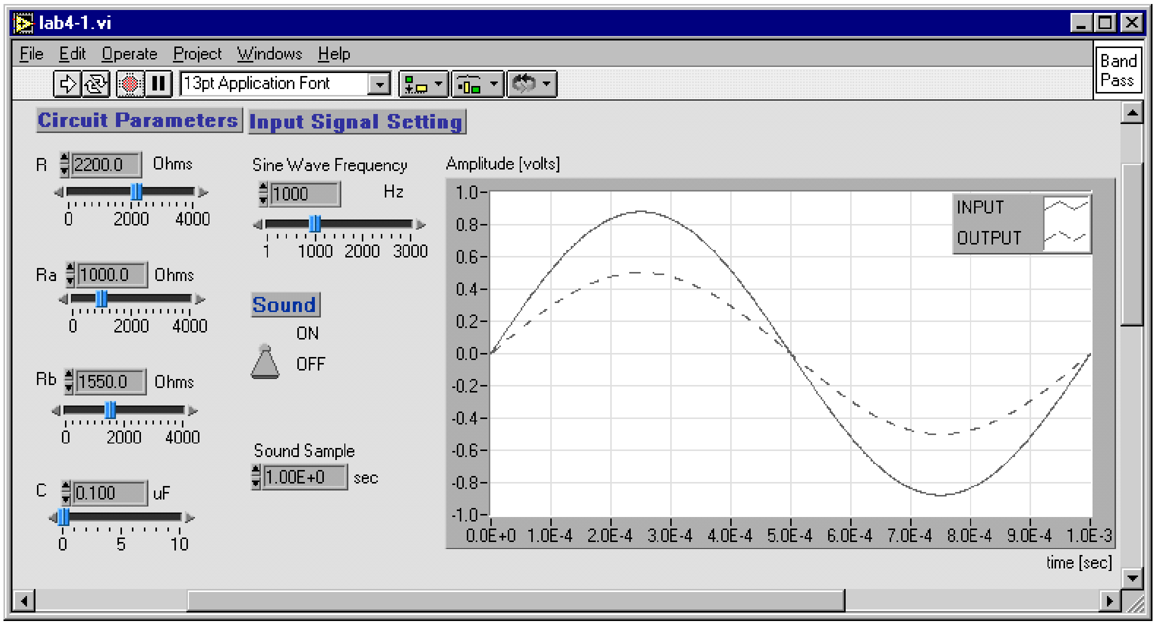


Figure 1: Circuit schematic of a bandpass filter with the output connected to a data acquisition board.

In this lab, students build a bandpass filter circuit with an op-amp, resistors, and capacitors. Figure 1 shows the circuit schematic, which is laid out on a breadboard. They connect the output of the circuit to a data acquisition board installed in the lab computer. They then use LabVIEW to determine the response of the filter by sweeping the frequency of a sinusoidal input. They also input a periodic waveform and measure its fundamental frequency and harmonics. They experiment with different values of capacitors, resistors, and input signal frequencies. They can send the output waveform to a graph or the PC soundcard, allowing them to see or hear the changing amplitude of the output for different frequency input signals. They then print the graphs and data and attach it to the lab report, which can be in the form of an Excel spreadsheet or an HTML file.

For the pre-lab, we developed a LabVIEW VI which simulates the behavior of the lab using transfer functions representing the circuit's response to input waveforms. Figure 2 shows the front panel of the VI.



R 2200.0 Ohms
Ra 1000.0 Ohms
Rb 1550.0 Ohms
C 0.100 uF
Sine Wave Frequency 1000 Hz
Sound Sample 1.00E+0 sec

Figure 2: Front panel of a LabVIEW VI that simulates the behavior of a bandpass filter.

Students can adjust the values of the resistors and capacitors for the bandpass filter circuit. The VI calculates the transfer function and displays the input and output waveforms on the graph. The student thus receives immediate feedback regarding the characteristics of the output waveform caused by the different value resistors and capacitors. We also made these simulation VIs easily accessible over the Internet using LabVIEW's VI Server capability. We developed executables that students can download and use to remotely access the simulation VIs from their home or dorm computer.

Summary

With the ever-increasing use of computers in education, the ability of computers to increase the efficiency of lab instruction is a benefit that must be exploited. Computer-based measurement can reduce certain drawbacks of labs such as the need to manually record, analyze, and display data in a report. It is also important to enable students at a remote location to have access to experiments that were unavailable before due to lack of laboratory resources. LabVIEW is a tool that offers all of these features today. Easy to program and network, LabVIEW allows both real-time connectivity to and simulation of existing labs. In this paper, we described the implementation of an analog signal processing lab using LabVIEW. Although this paper concentrated upon a lab implementation specific to electrical engineering, one can apply the same techniques to various applications, such as other engineering disciplines or the physical sciences.