An Interdisciplinary, LabVIEW Based, Data Acquisition and Measurements Course

James E. Globig
University of Dayton

Abstract
This paper describes an interdisciplinary data acquisition course that teaches the creation of virtual instruments (utilizing LabVIEW) and their application in mechanical, physical, and electro-mechanical measurement systems. It includes pedagogical recommendations on how to teach data acquisition to multiple majors and some tactical recommendations on how to teach LabVIEW to multiple majors. The course follows a combined lecture/laboratory format and is designed for Electronic, Computer, Mechanical, and Manufacturing Engineering Technology students organized into cross-functional teams. The outline of the paper follows the course outline described in TAC of ABET "Self-Study Questionnaire - TC2K Visits" [1]

Introduction
Student
The course is an interdisciplinary course with mixed teams of Mechanical (MET), Manufacturing (MFG), Electronic (EET), and Computer (CET) Engineering Technology students. In general, the course is an integration of LabVIEW-based virtual instrumentation and data acquisition techniques and a physical/mechanical measurements lab [2]. Since the teams contain students from multiple majors, we cultivate a peer-learning environment where the EETs and CETs help the METs and MFGs with the programming and data acquisition and vice versa with the statics, dynamics, strength of materials etc.

Credit Hours
The course is designed to be a two semester hour combined lecture/lab course which meets twice per week for one hour and fifteen minutes.

Computer Usage
The software utilized in the course is approximately 85% LabVIEW, 10% Excel, and 5% MicroSim PSpice. Microsoft Word and PowerPoint are used for report writing and presentation. LabVIEW programs themselves (called VIs) are used extensively in the lecture and homework. Similarly, PSpice is used to teach and demonstrate signal-conditioning principles.

Course Format
The course is designed to be presented in a "dual mode" fashion with one PC (or, if necessary, an overhead) displaying the PowerPoint slides and another PC displaying and running the target software (LabVIEW or PSpice). It is important for the student to be able to see both PowerPoint and LabVIEW programs and data acquisition hardware

simultaneously. The course can be taught with one PC displaying both PowerPoint and LabVIEW windows, however in the author's experience, the window size reduction can be significant enough to prohibit the student from comprehending either window.

In the beginning of the course, the lecture oriented meetings and lab oriented meetings are somewhat segregated. The lecture-oriented meetings focus on the introduction to LabVIEW and data acquisition technique. The lab-oriented meetings focus on the data acquisition principles required if one is to acquire meaningful data. As the course progresses and the student becomes more proficient at creating VIs, the integration of data acquisition technique and data acquisition principles increase, along with the lab content, in each class meeting. Finally, the design component continues to increase as the course progresses when the LabVIEW software and hardware is used to take sensor data from a variety of electro-mechanical arrangements.

For the LabVIEW basics portion of the course, the student is "walked" through each VI as they learn the proper location and integration of the controls, displays, and functions. Using case statements and pseudo-code, the student is then gradually encouraged to design her own VI to implement a simple specification. The specification is presented to the student in Power Point. Each student is then given an appropriate amount of time to implement it in LabVIEW as the instructor answers questions and provides guidance. Each student is required to independently develop the VI's during the LabVIEW intensive class meetings.

Upon the introduction of each of the primary functions, the content of the course progresses to combining the various functions into VIs that implement simulated data acquisition applications. These VIs are thereafter modified and enhanced when the student progresses from the simulated data acquisition to real data acquisition in the lab-based sessions beginning approximately two-thirds through the course. In the lab-based sessions, students are encouraged to work as teams when creating LabVIEW programs and conducting the experiments.

Much of the LabVIEW work is actually done in class creating VIs (Virtual Instrumentation programs). The majority of the homework assigned entails the following: preparing for lab by reviewing the electro-mechanical principles demonstrated by the lab; modifying LabVIEW programs to optimize them for the lab; and creating reports for the labs (procedures, data, conclusions, etc) that were conducted.

The students install the Student Edition of the software on their own PCs. This allows each student to do the majority of homework at home, as opposed to utilizing the School of Engineering labs during no-class times. *A note of caution*: some of the more advanced LabVIEW programs that utilize the hardware for data acquisition will not run properly if created by the Student Edition. Lab assignments are handed out the class period before the lab is conducted. Some of the later lab assignments require the student to design their VIs (LabVIEW programs) using the professional edition software in the SOE labs. Inconvenience is minimized however, since the advanced assignments are few in number

and require the PCI/Signal Accessory hardware (typically not installed in their home PC) to run.

Course Description

Data Acquisition and Measurements – ECT408
The measurement and evaluation of the characteristics of engineering materials, structural mechanics, electromechanical systems and physical systems is introduced with emphasis on data acquisition, signal conditioning and manipulation, and virtual instrumentation.

Prerequisites

- College Composition II – This is a second level course which further develops critical reading and writing skills. Writing skills emphasize writing from sources. At the 400 level, nearly all of UD's Engineering Technology courses have a technical writing component.
- A.C. Circuits and Lab – This course has D.C. Circuits as a prerequisite. Consequently, the student must have successfully completed two circuits courses to take the Data Acquisition and Measurements course.
- C Programming *or* Strength of Materials
  - University of Dayton requires that all EET and CET and students have some programming experience before tackling LabVIEW. At the University of Dayton, C++ is taught in the third year.
  - All MFG and MET students must have Strength of Materials before taking the course

Textbooks and Materials

Texts: LabVIEW 6i Student Edition, National Instruments, Prentice Hall

Electronic Devices and Circuit Theory, Boylestad, Prentice Hall

Laboratory Manual (supplied by the instructor)

Materials: National Instruments LabVIEW 6i Software – Student Edition (included with text)

National Instruments LabVIEW 6i software and associated hardware (supplied in the lab):
  PCI-6024E Multifunction I/O
  DAQ Signal Accessory
  R6868 SCSI-II Cable
  MicroSim Schematics and Pspice

The National Instrument's DAQ Signal Accessory (DSA) is a compact I/O box containing a function generator, noise generator, microphone jack, four LEDs, solid-state relay, thermocouple jack, temperature sensor, digital trigger, two counters, and a quadrature encoder. It connects to the PCI-6024E Multifunction I/O board, (and to many other NI Boards) through a ribbon cable. The DSA is an excellent solution for a low cost, low end Introduction to Data Acquisition lab. If the DSA is used in conjunction with a simple prototyping platform, operational amplifiers and other circuits can be easily interfaced to LabVIEW.

The ideal solution for a course of this type is a new National Instruments product called NI ELVIS (National Instrument's Engineering Laboratory Virtual Instrumentation Suite). It incorporates all of the functionality of the DSA (and much more) but most importantly also incorporates a prototyping area that is protected from damaging the on-board data acquisition electronics through a series of fuses (see Figure 2.1 [3]).
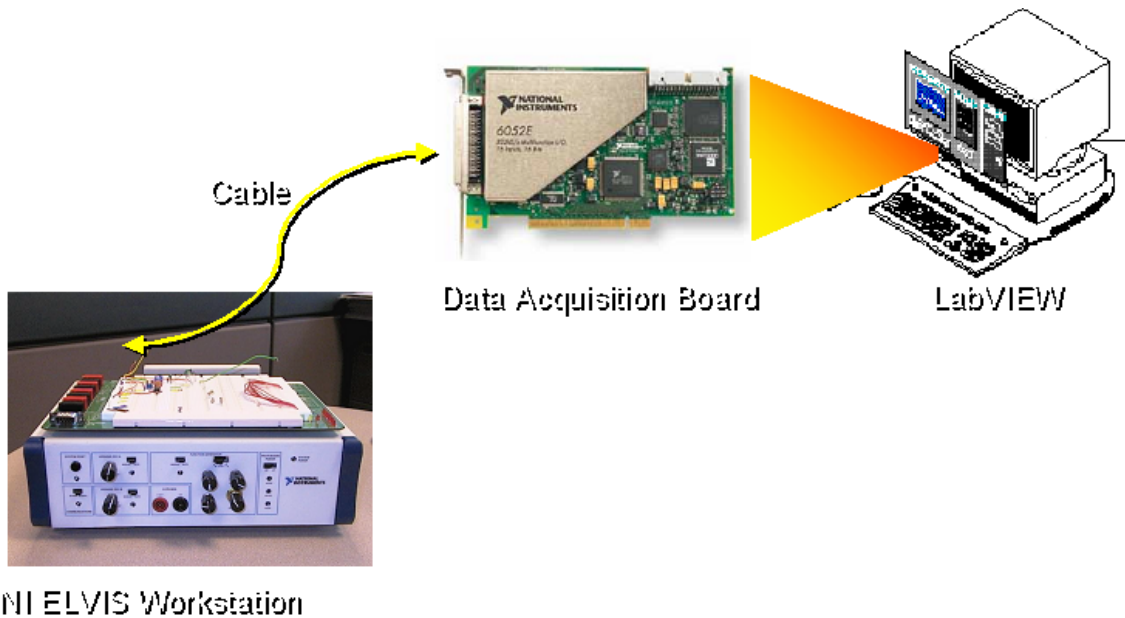

Cable

Data Acquisition Board

LabVIEW

NI ELVIS Workstation

Figure 2.1

Boylestad's text [4] and MicroSim PSpice are referenced while teaching basic signal conditioning principles. All of the students taking this course have previously used PSpice. The op amp based circuits covered in the course are review for the CETs and EETs and are not covered in such depth as to be too intimidating to the MCTs, MFGs and MCTs.

Course Objectives

Upon successful completion of this course, the student will be able to accomplish the following:

1. Increase the comfort level of each student in the other E.T. disciplines;
2. Perform laboratory tests commonly used in measuring the characteristics of engineering materials, structural mechanics, mechanical systems, temperature, pressure, etc;
3. Demonstrate the concepts and advantages of object oriented, graphical software tools;
4. Understand basic software design principles including input, output, data types, pseudo-code, case statements, loops, subroutines, etc;
5. Understand basic signal conditioning techniques employing operational amplifiers;
6. Create and modify data acquisition and control applications and customize them to meet specific needs;
7. Design and implement simple data acquisition and control solutions.

Topics Covered and Class Schedule

Meeting Number	Format of class	Objective(s) Addressed	Subject
1	Lecture	3, 7	**Introduction to the Course; Introduction to LabVIEW, Loading software, Your First VI**

The course begins by outlining the advantages and disadvantages of various levels of programming languages are discussed beginning with assembly/machine language, to high-level languages, to graphical languages. LabVIEW is introduced, a simple VI is created for the class, then the advantages of the LabVIEW (graphical) language are discussed. The LabVIEW example is used to introduce its two windows: The Front Panel, which is the human interface to controlling LabVIEW and the Diagram window, which is the programming interface level.

2	Lab 1 [2]	1, 2	**Experimentation, Statistics, and Probability**

This lab is a review of basic knowledge needed to set up a data acquisition system. The lecture portion of the lab reviews the principles of mean, median, range, standard deviation, types of errors, and probability of occurrence assigned as homework in the previous meeting. A lab comparing the static and dynamic friction between two pieces of steel and two pieces of aluminum, each with dry surfaces and oily surfaces, is conducted. Students take a sufficient number of data points, enter them into Excel, calculate the statistical parameters, and display the frequency distribution of the friction data in bar chart format. Finally, each student determines the data ranges that would be within 50%, 90% and 95% confidence intervals. For each lab, a formal lab report is then created from the procedure, data and conclusions.
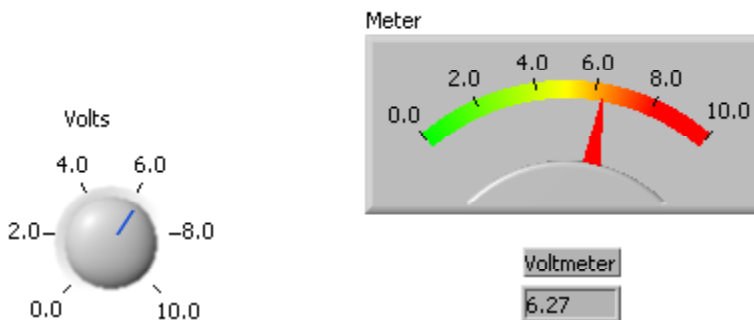
Meeting	Format	Objective(s)	Subject
3	Lect	3, 4, 6	Surfing LabVIEW, Sub VIs

The lecture begins with a hands-on understanding of what an object is and what they look like in LabVIEW. The first hands-on LabVIEW exercise begins by opening LabVIEW and setting it up so that the Front Panel and Diagram windows are displayed simultaneously or at least easily accessible. The students are then shown how to open the Tools (editing, positioning, wiring, and other display manipulation tools) and Controls Palettes (switches, dials, gauges, files, and other indicator/control interface tools) in the Front Panel and then pin them down so they remain visible during programming. Students are also shown how to open and pin down the Functions Palette (loop structures, boolean functions, math functions, arrays, and other data manipulation tools) in the Diagram window.

Next, the class begins assembling their first LabVIEW program (VI). Each student will pick the first object, drag and drop it, label it, and hide or unhide its attributes. This process is repeated copying the instructor's VI until all objects are placed. Finally, the student learns the proper way to wire the objects together (see Figure 3.1). The student then operates the VI and is given a few minutes to experiment with LabVIEW by changing the controls and indicators to create their own VI.

Figure 3.1
The First VI

Front Panel

Diagram

The next subject is how to create a Sub-VI (subroutine). Subroutines are used in LabVIEW, as like any other language, for repetitive or commonly used tasks.

The final portion of the session is devoted to exploring the most commonly used objects in the Front panel and Diagram windows and briefly explaining their functions. The exercise is useful not only to demonstrate the variety and power of LabVIEW, but to allow the student to become comfortable with navigating around.

Meeting	Format	Objective(s)	Subject
4	Lect	3, 4, 6	**Software Structures (For Loops and While Loops), Data Types, and I/O Types**

In LabVIEW, loops are implemented by selecting the loop object (either For, While, Case, or Sequence), placing it in the Diagram window, and stretching it large enough to accommodate the functions the designer wants to repeat. These functions are created by placing objects within the loop and interconnecting them (see Figure 4.1).

Beyon does a particularly good job introducing pseudo-code and demonstrating how to transform pseudo code into a loop-based VI. [5]
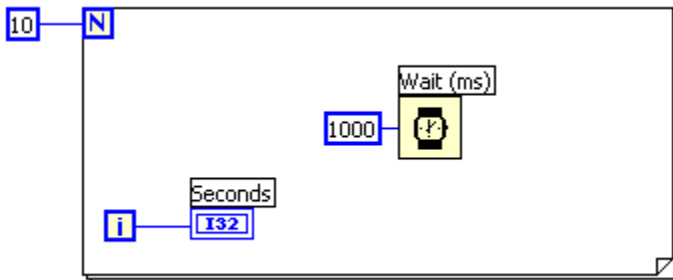
Figure 4.1
From Pseudo Code to Loop

Pseudo Code
1. For I=0 to 9;
2. Display I;
3. Pause 1 second;
4. End;

Front Panel

Diagram

As an extension of the loop exercise, the various data types used by LabVIEW are discussed is some detail using the loop examples. For instance, the color blue is reserved for the I32 data type seen in Figure 4.1 signifying 32-bit integer. Also, the various I/O types are discussed. In LabVIEW, I/O types are distinguished by the border design of the graphical object. For example, thick borders represent input constants. Therefore, a blue thick border is a 32-bit integer input constant.

Meeting	Format	Objective(s)	Subject
5	Lab 3 [2]	1, 2	Curve Fitting

This lab completes the statistics background required for a good understanding of the various treatments of data once it has been acquired. It introduces the concept of using data points to determine a function, in contrast to the previous lab, which compared data points to a known function. The principle of a least squares line is introduced then the student is taught basic regression techniques including the calculation of the Correlation Coefficient. This knowledge is then applied by using regression to determine the spring constant from displacement vs. load data taken from tests conducted on an extension spring.

Meeting	Format	Objective(s)	Subject
6	Lect	3, 4, 6	Case Structures, Sequence Structures

This lecture-based meeting continues the software structures lecture with Case Structures. Case Structures are constructed similarly to the Loop and While structures but have multiple loop planes - one plane for each outcome of a condition test. Each plane can have its own distinct function designed the same way as the other loops.

Sequence Structures are somewhat unique to LabVIEW. Traditional in-line code has a "built in" control for the sequence of execution, however, because of the graphical nature of LabVIEW and because of the characteristics of some of the objects, the Sequence Structure is sometimes required to explicitly control a specific order of execution of a VI. Like the other structures, sequence structures frame the function(s) within them and control the execution order from left to right.

Meeting	Format	Objective(s)	Subject
7	Lab 4 [2]	1, 2	Efficiency of Machines

Lab 7 reviews the principles of linear work, linear power, rotational work, rotational power, and efficiency. Weights are hung from the power screw, ball screw, rack and pinion, bevel gear drive, worm gear drive, and hand drill gear drive machines. Data is then taken on the energy required to raise the weight. Finally, the work performed and the efficiency of the various machines are calculated and conclusions are drawn.

Meeting	Format	Objective(s)	Subject
8	Lect	3, 4, 6	Global and Local Variables, Shift Registers, Formula Nodes

Local Variables are the realization of the "data hiding" principle in object-oriented languages. Local variables are identical copies of the original objects and can be used to read from indicators or write to controls. Local variables are frequently used to simplify the design of a more complex VI. Global Variables can be accessed by different VIs (as opposed to a Local Variable within a VI).

In LabVIEW, Shift Registers perform the same function with large words of data as they do in digital electronics with single bits of data. Their purpose is to dynamically track previous data elements and so, are frequently used as part of a moving average function.
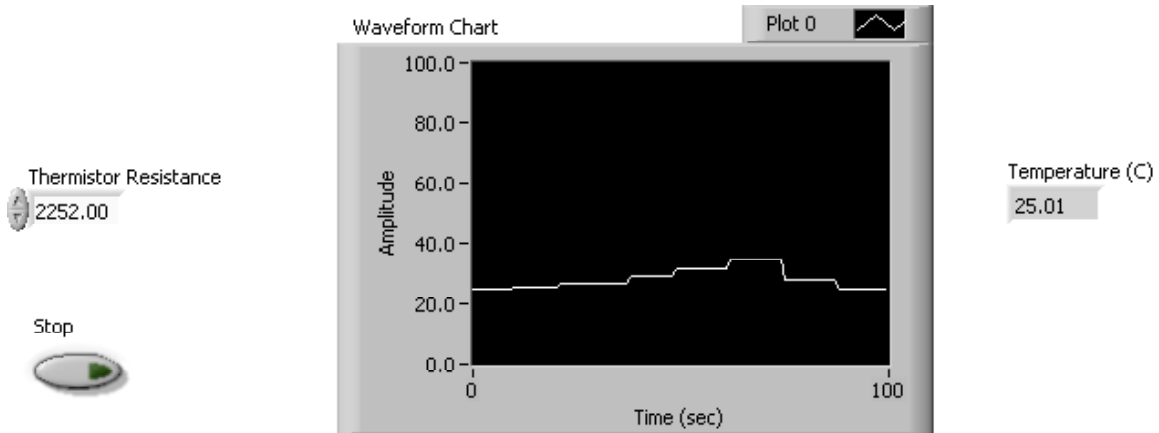
Formula Nodes are objects that execute boolean or mathematical functions, simple or complex, on one to multiple inputs. The example used in the course and assigned as homework, is to implement the Steinhart and Hart equation [6] to transform a thermistor resistance input to a temperature output (see Figure 9.1).

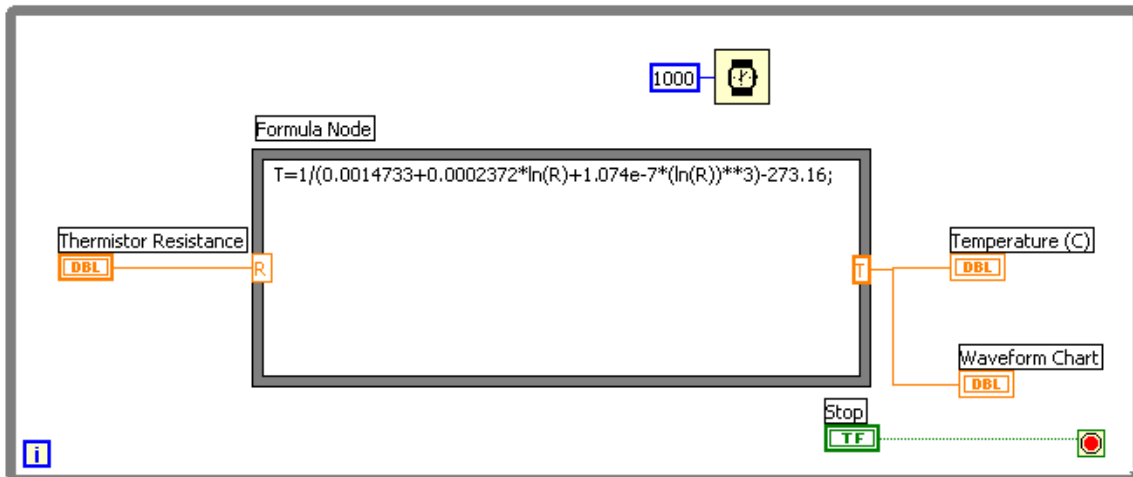| Meeting	Format	Objective(s)	Subject
9	**Lect**	**3, 4, 6**	**Data Display, Property Nodes, Boolean Switch Options**

There are two primary ways to display data: Charts and Graphs. Charts are used for displaying real-time data at relatively low acquisition rates such as temperature. Graphs are used for displaying stored data at a later time. The decision on whether to use a Chart or a Graph to display data is dependent not only upon the type of data but also on its acquisition rate. In other words, the LabVIEW software and associated data acquisition hardware have an upper limit where data can be acquired too rapidly to display in real time. Figures 9.1 and 11.1 show a VI with a Chart and Figure 20.1 shows a VI with a Graph. Note that the Graph-based VI is saving the data in an array, then displaying it.

Figure 9.1
Graphical Data Display and Formula Nodes

Front Panel

Diagram

Formula Node

$$T = 1/(0.0014733 + 0.0002372 * \ln(R) + 1.074e\text{-}7 * (\ln(R))**3) - 273.16;$$

Property Nodes allow the programmer to customize the operational features of an object such as making an indicator blink when data is out of range or manipulating the display mode of Waveform Charts. For example, Boolean Switches have many selectable properties such as blinking, switch action, push button action and latching action. Figure 11.1 shows an Offset property added to the Get Date/ Time in Seconds object.

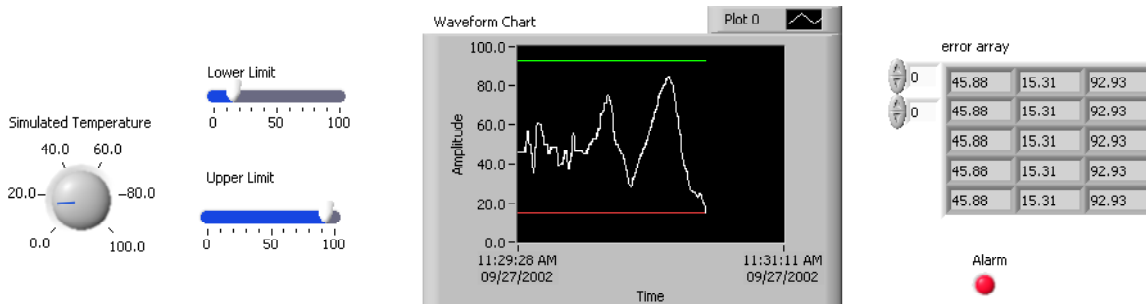| Meeting	Format	Objective(s)	Subject
10	**Lect**	**3, 4, 6**	**Arrays and Clusters**

Arrays and Clusters are data structures within LabVIEW. An array is very similar to an array in other software languages in that it is a collection of data of the *same* type: e.g. an array of numbers, an array of strings, etc. accessed by an index. An array used in association with a loop can be set up to automatically index with each iteration of the loop. A Cluster is like an array but it can contain elements of mixed types e.g. string data mixed with boolean data, mixed with numeric data such as you might find in a set of demographics (name, gender, age …). LabVIEW facilitates the easy export of array and cluster data to a spreadsheet as is shown in Figure 11.1.

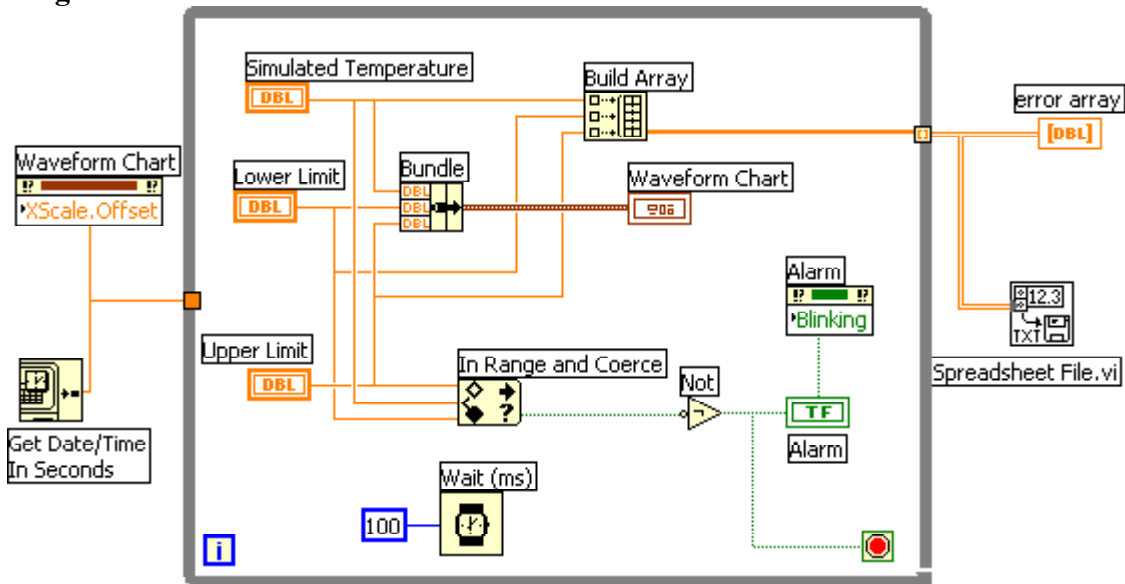|			
11	**Lect**	**3, 4, 6, 7**	**More Array Functions, Waveform Graphs, Multifunction Application**

This is the first session where the student applies many of the LabVIEW principles learned to date in a larger VI. The instructor illustrates the design of a simulated temperature data acquisition system that incorporates set points that, when violated, set off an alarm and write the data to a spread sheet (see Figure 11.1). This VI incorporates the application of the Waveform Chart, the acquisition of time of day, the versatile In Range and Coerce function, properties, arrays, and spreadsheets.

Figure 11.1
Arrays to Spreadsheets

Front Panel

Diagram

Meeting	Format	Objective(s)	Subject
12	Lect / Lab	1, 5, 6, 7	**Components of a Data Acquisition System, Types of I/O Signals, Hardware Installation, Acquiring Real Temperature Data, Enhancing D.C. Data Acquisition**

Bishop has an excellent chapter on the types of signals, types of transducers, good signal transmission and grounding practices, basic signal conditioning including how to select and set up an AD converter, and how to install and utilize a data acquisition board. Bishops treatment of this material is a good review for the electronic and computer student but not so involved as to be confusing to the other majors. Bishop's text, with supplemental material on signal conditioning, is used extensively in this and the next three lectures [7].

Now that the student has learned enough about the software to become a productive LabVIEW programmer, the hardware interface to a data acquisition system is introduced. The complete data acquisition system is now reviewed in more detail. The types of I/O signals are then reviewed: AC, DC, analog, digital, - each with examples of inputs and outputs.

Each team sets up their National Instrument's data acquisition board and creates their first *real* data acquisition channel. The team will configure LabVIEW to acquire data from the DAQ Signal Accessory's Temperature Sensor and display it using the AI Acquire Waveform object and Waveform Chart.

Meeting	Format	Objective(s)	Subject
13	Lect	1, 5	**Transducers and Signal Conditioning – Transducers, Signal to Noise Ratio, Pspice and Comparators**

Bishops treatment of signal conditioning is continued with a discussion of Signal to Noise Ratio and is reinforced by a more technical treatment of operational amplifier and comparator circuits. The utilization of the PSpice tool is reviewed through the design and simulation of a comparator with hystereses circuit.

Meeting	Format	Objective(s)	Subject
14	Lab 5 [2]	1, 5, 6, 7	**Transducers and Signal Conditioning – Displacement Transducers**

A linear displacement potentiometer is interfaced to LabVIEW. The student opens a simple LabVIEW VI created previously and modifies it to fit this application by adding indicators, scaling factors, etc. LabVIEW and Excel are then used to determine the maximum displacement, the displacement constant, the linearity, the repeatability, and the overall accuracy of the transducer.

Meeting	Format	Objective(s)	Subject
15	Lect	1, 5	**Transducers and Signal Conditioning - Amplifiers, Low pass Filters, and Amplifier Noise Reduction, - Differential and Instrumentation Amplifiers**

The design and application of inverting and non-inverting amplifiers, noise reduction and low pass filters, and differential and instrumentation amplifiers is addressed by explaining the principle of the op amp, the purpose of each type of circuit, and the formulas for gain and bandwidth. PSpice is employed to demonstrate the application of each circuit. Also, good operational amplifier design practices are covered in some detail [3].

Meeting	Format	Objective(s)	Subject
16	Lab 6 [2]	1, 6, 7	**Transducers and Signal Conditioning – Force and Torque Transducers**

Load cells in the form of bonded resistance force and torque transducers are mechanically fixtured. A power supply is connected to the excitation leads and the output is connected to the National Instrument's DAQ Signal Accessory. The student then modifies a previously constructed LabVIEW VI to determine accuracy, linearity, and repeatability of their transducer.

Meeting	Format	Objective(s)	Subject
17	Lect	1, 5, 6	**Transducers and Signal Conditioning – Bridge Amplifiers, Grounding and Measurement Systems, A – D Converters, Conclusions**

All of the undergraduates enrolled in the course have analyzed bridge circuits. A brief review of the Wheatstone bridge is followed by the introduction of bridge amplifiers and

their analysis using PSpice. A ground-loop resistance is introduced into the PSpice simulation of a bridge with a remote sensing element. This example is used to illustrate the importance of good grounding practices and the relationships of the amplifier input configuration to the signal source characteristics. A-D Converters are introduced with the primary focus on how to select and configure them to provide optimum range and resolution.
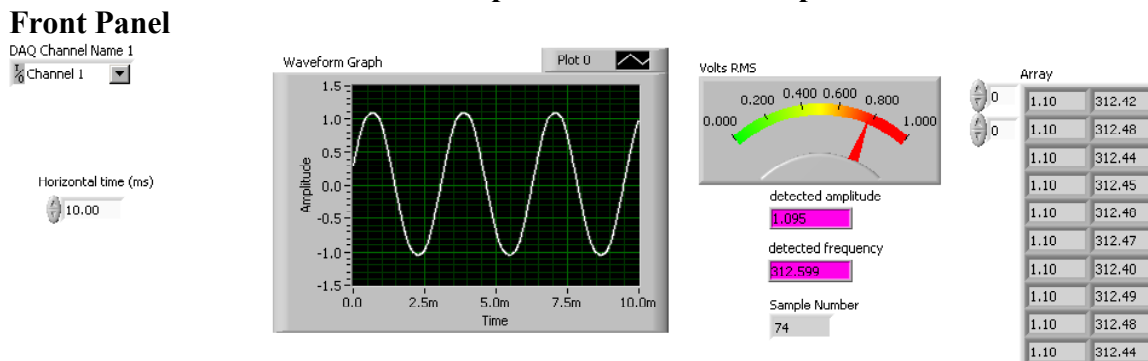
Meeting	Format	Objective(s)	Subject
18	Lab 7 [2]	1, 5, 6, 7	Measuring Strain

In this comprehensive lab, the student connects their learning to date by fastening strain gauges to a beam, constructing a bridge amplifier, connecting the gauges to the amplifier, and feeding the output of the amplifier to the DAQ Signal Accessory and then to a LabVIEW VI. The objectives of the experiment are to design and construct an entire data acquisition system and then determine the experimental vs. theoretical accuracy of strain and stress data as acquired by the system.
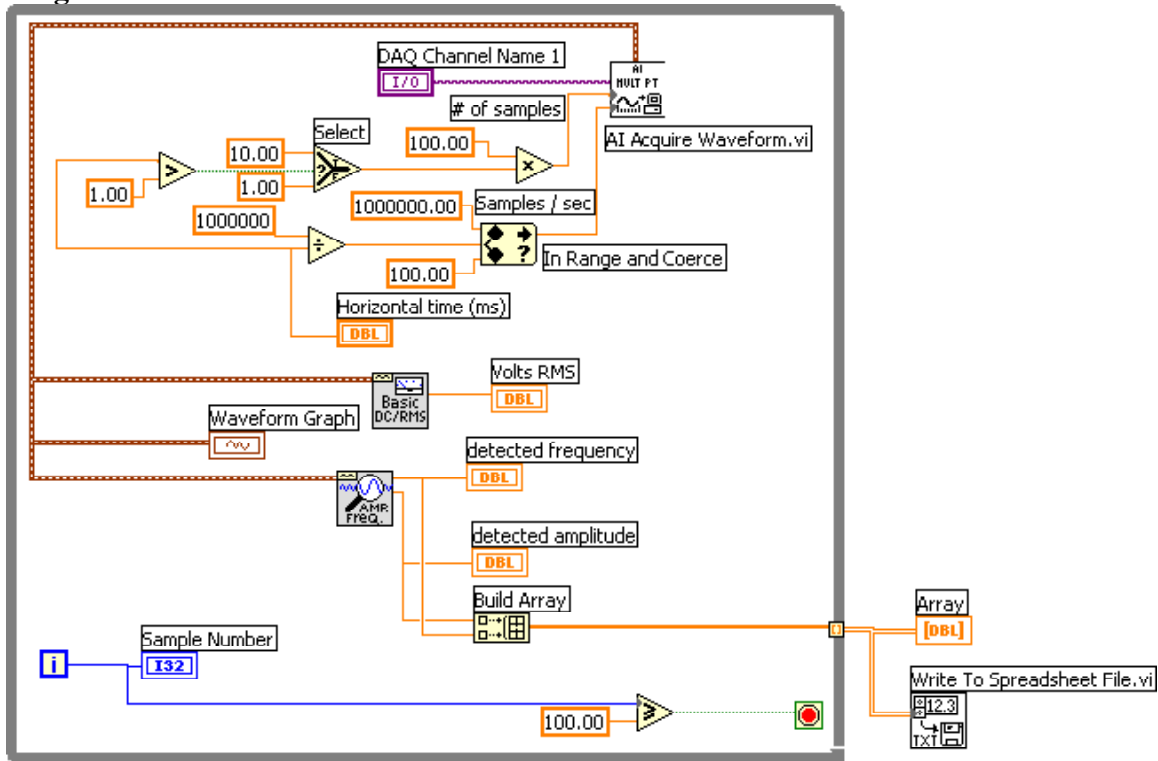
19	Lect / Lab	1, 6, 7	Sine Wave Acquisition, Making an Oscilloscope, Saving Data, RMS Voltage Display

A VI that sets up a new data acquisition channel, acquires a sine wave from the DAQ Signal Accessory, and displays it using Waveform Graph is implemented. At first, the VI is constructed using Waveform Chart but the data rate is too fast for LabVIEW to effectively display. Then the Waveform Chart object is replaced with Waveform Graph. The student will then be able to see that it might be a sine wave. The Sample Rate and Number of Sample inputs to the AI Acquire Wave are manipulated and the Scale and Plot properties of the Waveform Graph are manipulated until a nicely scaled and stabilized sine wave is displayed. A digital representation of the sine wave voltage is created and an array and spreadsheet are created to record and save the data. The final result is a subset of the VI illustrated in Figure 20.1.

Figure 20.1
The Development of an Oscilloscope

Front Panel

Diagram

Meeting	Format	Objective(s)	Subject
20	Lect / Lab	1, 6, 7	**Acquiring Amplitude and Frequency Data**

Session 20 continues the work began in session 19 by adding oscilloscope-like controls to the VI using Mathematical, Boolean and Comparison functions. Frequency counter and voltage amplitude functions are added and logged in an array and spreadsheet. Figure 20.1 is a good example of one of the higher complexity VIs we expect the student to absorb.

Meeting	Format	Objective(s)	Subject
21	Lect / Lab ²	1,4,6,7	**Digital I/O, Data Acquisition and Control**

At this point in the course, the material has been focused on how to properly acquire, display, and save data. In this meeting, the student learns how to create an output to energize a relay from labVIEW. Students are given a design specification that entails turning a motor on by pushing a LabVIEW button, turning the motor off, and as the motor decelerates, counting the revolutions and elapsed time by monitoring the motor's proximity pickup output. Each student begins with the VI they created in the previous meeting illustrated by Figure 20.1, however, during the debugging stage of their design, the student realizes that he is having trouble trying to make the motor control loop complete its execution *before the acquisition loop starts*. With some guided assistance, the student discovers that she can apply a Sequence Structure to make this occur.

Meeting	Format	Objective(s)	Subject
22	Lab 8 [2]	1, 6, 7	Friction

The student connects a motor and its proximity pick-up to the DAQ Signal Accessory. Using VI created in the previous class, the students record rotational velocity data and time-to-stop data in order to calculate deceleration. Given the rotor inertia, the student calculates the frictional torque and, because they acquired rotational velocity data, they can also calculate the power consumed by friction and the overall efficiency of the motor.

Meeting	Format	Objective(s)	Subject
23	Lab 9 [2]	1,5,6,7	Vibration

A steel or aluminum beam is given to the lab team for them to calculate its natural resonant frequencies as a function of the cantilever length. An accelerometer is attached to the beam and it is in turn attached to a vibrator. The input of the accelerometer is connected to a power supply and the output is connected to a bridge amplifier and their modified version of the VI shown in Figure 20.1. When the frequency of the vibrator is varied, mechanical resonance is observed. LabVIEW is then employed to observe and record the resonant frequency. The length of the cantilever is changed and the experiment is repeated.

Meeting	Format	Objective(s)	Subject
24 and 25	Lab 9 & 10 [2]	1, 3, 4, 5, 6, 7	Product Evaluation

For the final two labs, the students are asked to evaluate one of several different electro-mechanical products. Their assignment is to apply their newly acquired electromechanical systems knowledge to evaluate the functionality, speed (or other appropriate performance measure), power requirements, manufacturability, and overall quality of their product. Each team is then asked to identify one area for product improvement, what should be done to improve the product, and to implement a system level design to test their improvement. In the final class meeting, each team is asked to deliver a ten-minute PowerPoint presentation on their evaluation, proposed improvements, and test system.

Conclusion
Pedagogy
The multidisciplinary character of the course presents organizational challenges in addition to the obvious pedagogical challenges. Even after working in teams throughout their time at the University of Dayton, the author finds that the students still want to divide up the work according to their major. A primary objective of the course is to:
1. "increase the comfort level of each student in the other disciplines." As much as possible the course pursues this goal by requiring every student to complete LabVIEW exercises, signal conditioning exercises, and mechanics exercises independently. Further reinforcement, however, may be needed in lab by directing the electronic/computer students to take active roles in setting up the mechanical fixtures and the mechanical/manufacturing students to take active roles in setting up the signal conditioning circuits. The remainder of the course objectives are fulfilled as outlined below:

2. Laboratory tests commonly used in measuring the characteristics of mechanical systems and physical systems are performed throughout the course.

3. The concepts and advantages of object oriented, graphical software tools are contrasted with more conventional tools early in the course. The advantages of object oriented, graphical tools are then developed extensively through the remainder the course.

4. The basic software design principles including input, output, data types, pseudo-code, case statements, loops, subroutines, etc are covered in detail and utilized in the creation of data acquisition and control applications.

5. Signal conditioning techniques employing operational amplifiers are critical to the understanding of not just acquiring data but acquiring *valid* data. These techniques can be learned with a limited class-time investment and without having to fully understand the internal workings of an op-amp. They are then applied in lab.

6. In the later stages of the course, the students customize data acquisition and control applications in order to meet the requirements of electro-mechanical lab assignments.

7. In the last four sessions, the students are designing and implementing simple data acquisition and control solutions which integrate their knowledge of mechanical systems, signal conditioning techniques, and LabVIEW-based data acquisition.

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JAMES E. GLOBIG
Prof. Globig joined the University of Dayton in August 1998. With nearly 20 years of engineering experience in a variety of different product producing organizations, he combines a practical and thorough understanding of the role of the engineer in corporate America. He teaches courses in the Computer, Electronic, Mechanical and Industrial Engineering Technology programs.