A Low-cost, Interdisciplinary, Engineering Instrumentation Laboratory Course

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Abstract

A question often asked of engineering deans is the following:

"Dean, how can I conduct a meaningful engineering instrumentation laboratory course with such a small budget?"

This paper reports the results of efforts to provide such a course at the School of Engineering, Christian Brothers University.

The course is interdisciplinary in that the students are exposed to experiments and instructors from different disciplines. This is considered desirable in that the students are exposed to a greater breadth of viewpoint and wider background of the instructors as well as being exposed to a wider range of physical measurements. There are significant budgetary advantages of the interdisciplinary nature of the course in that the cost of equipment can be distributed across the budgets of more than a single department.

Equipment cost for the course is relatively low. Several factors are involved in this. Extended use is made of general purpose test equipment such as digital multimeters, oscilloscopes, and signal generators. Low cost sensors, electronics at the component level, student strain gages, etc., are used. Large special purpose systems are avoided and simple systems are constructed on site from the component level.

Senior-level professors teach the course. In using senior professors to teach small sections, salary expenditure is relatively high, but such an arrangement is compatible with desires of a small school of engineering to provide an unusual amount of personal attention and close supervision to each student.

Within the text of the paper, typical experiments are described. Details of the experiments are made available. Typical equipment costs are made available. Some surprises have been experienced and are discussed.

Introduction

The engineering instrumentation course at Christian Brothers University is designed to instruct students in the theory and use of various instruments and transducers. While emphasis is placed on the acquisition, analysis and reporting of data, the course relies heavily on experiments that demonstrate the interdisciplinary nature of instrumentation.

The senior-level professors who teach the course have diverse backgrounds in electrical, computer, mechanical, and aeronautical engineering with significant instrumentation experience in each area. The professors have had industrial experience in these areas and each have functioned as members of interdisciplinary teams.

This course is designed to introduce students to the conversation that frequently takes place between disciplines as part of any engineering project. As such, each lecture and laboratory section is normally attended by faculty from both the mechanical and electrical engineering departments.

Descriptions of Some of the Experiments

Voltage Division

In some semesters, the first experiment performed involves voltage division in a simple series dc circuit consisting of a dc source of voltage and two resistors. The output is taken as the voltage across one of the resistors using a high-resistance voltmeter. Only a small number of measurements (one or two, typically) are made. Knowledge of the possible variations in input voltage, resistances of resistors, and voltmeter resistance is made available. There are two main goals. The first goal is to observe the effects of instrument loading in the circuit when the circuit resistors have resistances several orders of magnitude smaller than that of the voltmeter and compare with the case when the resistors have resistances comparable to that of the voltmeter. The second goal is to determine if the measured output voltage lies within the bounds predicted by knowledge of the functional relationship between the voltage output, the circuit resistances, and the possible variations in the circuit resistances.

Temperature Measurement

An experiment done recently involves a small thermal process and temperature measurement. The process consists of a beaker of water that is heated by a resistance heater connected to a standard 120-volt ac electrical supply. The temperature of the water is measured by an immersed mercury laboratory thermometer and also by an integrated circuit (LM34DZ) temperature transducer externally attached to the beaker. The first main goal of this experiment is to observe the operation of two methods of temperature measurement and to calibrate the electrical measurement against the thermometer measurement. The second goal is to obtain the RC time constant (T) of the process from the free response of the temperature and to estimate the effective thermal resistance (R) from knowledge of the time constant (T) and computation of the thermal capacitance (C) of the process.

Data Conversion

Another experiment involves data conversion in instrumentation with the goal of showing the equivalence between the analog and digital representations of measurements. There are two parts of the experiment as described below.

Analog to digital conversion is studied after discussion of the need to convert process measurements (usually analog) to digital form for operator guidance or direct entry into a digital computer for control purposes. An integrated circuit A/D converter (e.g., ADC 0804 LCN) is connected to measure a 0-5 volt dc input and convert it to 8-bit binary form. The converter is calibrated by plotting digital output (as a fraction) versus analog input voltage.

Digital to analog conversion is studied after discussion of the need to convert digital data (e.g., from a computer) to analog form as required at the input of most physical devices. An integrated circuit D/A converter (e.g., DAC 08 CP) is connected with an operational amplifier to accept 8-bit binary input data and provide an analog output voltage of 0-5 volts dc. The conversion is calibrated by plotting the analog output in volts versus the digital input value (as a fraction).

Measurement of Airspeed

This experiment utilizes CBU's low-speed wind tunnel to introduce the students to the procedure for measuring the speed of an incompressible, flowing gas. For perhaps the first time, students apply the Bernoulli equation in a practical fashion. The concepts of static, dynamic and total pressure are introduced for perhaps the first time to the ECE students, and given a concrete meaning to the ME students. Measurement of a pressure difference in inches of water, using a precision manometer, is a concept with which most students are familiar but have not had the opportunity to apply in practical experiment.

A three-phase motor using a variable frequency controller drives the wind tunnel. Students are first required to calibrate the controller with the tunnel speed through use of a pitot-static tube connected to the precision manometer. Secondly, by rotating the pitot-static tube to various angles of attack, they determine the error in dynamic pressure introduced by misaligning the tube with the flow.

Flame Temperature Measurement

This rather simple experiment has proven to be a great learning experience for the students. The materials consist only of various grades of thermocouple wire, a digital multimeter (DMM), a disposable butane lighter, an acetylene torch, and a bucket of ice water.

Students are told they are to measure the flame temperature of a butane-air mixture and a fuel-rich acetylene-air mixture. They must then choose the appropriate thermocouple wire for the expected temperatures. The students form the thermocouple junctions using the acetylene torch and connect the instrumentation in preparation for temperature measurements.

The butane lighter is first utilized, and students find that the temperature varies depending on where the junction is held within the flame. Next the acetylene torch is used to generate a fuel-rich mixture. As with the butane lighter, they note that the temperature again depends on the position of the junction within the flame. At this point, similarity to the initial butane temperature measurement ends. The students are puzzled when the measured temperature begins to drop. Typically the students suspect that a junction has failed, the DMM is broken, or various other instrumentation failures. A moment of enlightenment occurs when they are instructed to remove the junction from the flame and examine it. Many are surprised to note the junction appears to have significantly grown in size. The instructor then explains how the fuel-rich mixture has resulted in solid carbon being deposited on the junction, increasing it's apparent size, but, more importantly, acting as an insulator and giving the false impression that the flame temperature decreases with time.

Construction and Testing of a Pressure Vessel

The application and use of strain gages are the main points of focus in this experiment. Again, the materials utilized are simple and inexpensive: student strain gages; various diameters of PVC pipe with end caps; a strain indicator, which is the only equipment of significant cost; and an air line fitting.

Each student group is assigned a specific diameter of pipe from which to construct a two-foot long pressure vessel. One end cap is drilled and tapped to accept an air line fitting to enable pressurization. Before construction, students are asked to calculate the forces expected on the end caps so that they gain an appreciation of the magnitude of forces applied during the pressurization process. This leads to a lecture on appropriate construction techniques and the enhanced need for safety awareness during this experiment.

Once the vessels are constructed, the students apply the strain gages after an initial demonstration by the instructor. Each vessel is then pressurized to approximately 100 psig with the students taking strain readings in 10 psig increments. The pressure is then decreased back to 0 psig with strain readings again taken in 10 psig increments. Finally the instructor applies a pressure, unknown to the students, which they must determine based upon the calibration curves they generate.

This is the only experiment where the students have gained first-hand experience into the necessity of safety precautions. Although each group is instructed to assemble their pressure vessel using techniques approved by the instructor, one group recently ignored this advice. This group had a third party assemble their vessel with dramatic consequences. One of the end caps departed, because of inadequate preparation and adhesive application, during an early stage of pressurization. No injuries occurred because of adherence to proper safety protocols.

Fast Fourier Transform Applications

Since both mechanical and electrical engineers are required to understand frequency response and resonance behavior, each semester an experiment is performed specifically to introduce frequency analysis using histograms and the FFT. Because of the placement of the course in the curriculum, most of the students have not been formally introduced to the mathematical basis of either the Fourier series or the Fourier transform. Therefore, the experiment is performed using standard mathematical software and test cases to insure the students are using the software appropriately. Therefore, the first part of each semester's experiment involves plotting an known sinusoidal signal in the time domain, and after taking the FFT, verifying that the signal peak appears at the correct location on the frequency histogram. If there is any doubt in the student's minds about the appropriate usage of the software, they are encouraged to verify their procedures using additional known simple sinusoids and/or sums of sinusoids. After the students understand the basics of mathematical analysis using FFT software, they are presented a real world problem that emphasizes frequency behavior. The specific experiment performed during a particular semester depends upon the percentage of ECE majors versus the number of ME majors. Regardless of the student composition, the experiments are designed to emphasize analysis of frequency behavior in real applications. Specific examples follow.

AM Sideband Analysis

For classes composed primarily of ECE majors, the FFT experiment is used to introduce the concept of amplitude modulation. In this case, after the students have completed the section using known sinusoids, they are presented with a data file with unknown contents. Actually this file contains a series of data samples from a single sinusoidal source which is amplitude modulated by another single sinusoid. The students are required to plot the signal in the time domain and then using this plot, determine the frequency of the carrier signal, the modulating signal and the modulation depth. Next, they are required to use the FFT to determine the frequency spectrum of the modulated signal. Based upon the information acquired in the time domain and from the histogram, the students are required to determine the formula which specifies the locations of the upper and lower sidebands of the modulated signal.

Mechanical Oscillation Analysis

For classes composed primarily of ME majors, the FFT experiment is used to introduce frequency analysis of mechanical systems. In this case, the students are required to mount an accelerometer on a mechanical shaker table. Each group is allowed to take data using an automated data acquisition system. Then the students are required to use both time domain and frequency domain analysis to determine the primary and secondary oscillatory frequencies of the table.

Sonar Data Analysis.

For mixed classes, the FFT experiment can be used to simulate military sonar applications. The students are introduced to two basic concepts of sonar analysis; namely, that frequency is proportional to the rotational frequency of the propellers and that amplitude is inversely proportional to the distance between the vessels. The students are provided with a sample data set that contains several low frequency sinusoidal signals which vary in amplitude over time period of several minutes. Based upon the available information, the students are required to determine the relative distances and speed of the vessels in the sample. In addition, the students are required to determine the relative change in position over time.

Cost Estimates

The basic general-purpose lab equipment assumed for each workstation consists of a variable power supply (PS), a digital cathode ray oscilloscope (CRO), a digital multimeter (DMM), a signal generator (SG), a circuit board (CB), appropriate leads for each instrument, and assorted leads for connection of components on the circuit board and for connection of the circuit board to external devices. The cost of the basic equipment for each workstation is estimated at 3000 dollars. The required replacement time is estimated at 10 years. Costs beyond those of the general-purpose equipment above are small, in general. For example, the components used in the voltage division experiment cost less than one dollar total. In the temperature measurement experiment, the integrated circuit transducers cost about one dollar each, and the laboratory thermometers cost about 75 dollars each. In the data conversion experiment, cost of the integrated circuit converters is in the range of two or three dollars each, the operational amplifiers less than one dollar each, and the cost of the resistors a few cents each. An outstanding advantage of the interdisciplinary offering of the course is that the cost of the basic general-purpose equipment can be shared among departments. In addition, each department may contribute use of "inherited" equipment acquired over a long period of time, such as the shaker table and wind tunnel discussed above.

Conclusions

A low-cost engineering instrumentation course of interdisciplinary nature can be offered successfully, given proper cooperation and support among participating departments. Moderate costs can be obtained by using general-purpose laboratory equipment, avoiding special-purpose systems, and obtaining transducers and other components from component suppliers rather than from system suppliers. Using instructors from two or more departments increases both the width and depth of the student lab experiences. Cost sharing among departments is an outstanding advantage. Some surprises have been experienced. Among these is the discovery that student performance in either electrical, computer, or mechanical experiments does not correlate strongly with the department of the student, and that students tend to pair off in lab groups by relative abilities rather than by department affiliations.

Biographical Information

DR. ROBERT L. DRAKE is a professor of electrical and computer engineering at Christian Brothers University. He has a number of years experience in teaching and practice of control systems, industrial electronics, and instrumentation.

DR. MARK A. DRIVER is an associate professor and the chairman of the Mechanical Engineering Department at Christian Brothers University. He has significant experience in ICBM flight test, jet engine design, and the varied instrumentation requirements in aeronautical systems testing.

DR. ERIC B. WELCH is an associate professor and chairman of the Electrical and Computer Engineering Department at Christian Brothers University. His background includes work in biological and aeronautical instrumentation as well as computer systems.