

Measurement and Automation: Experiential Learning Opportunity

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I. Introduction

Instrumentation, data acquisition, and analysis of data have become indispensable skills in the engineering marketplace. Process monitoring in factories requires the use of both discrete and analog sensors, as well as computer control of actuators¹. Oil and gas exploration and extraction has become a highly monitored process requiring an understanding of instrumentation and acquisition concepts². Certainly a number of defense-based industries make extensive use of data acquisition and analysis both for product development, as well as test set development for maintenance purposes³. Engineering students undergo a rigorous curriculum that develops the basic theory of sensor and instrumentation technology, but are less exposed to the implementation and application aspect. More recently, incorporating hands-on techniques into lecture classes has gained broad acceptance as a means to enhance retention of key concepts^{4,5}. Although senior capstone classes for a given engineering discipline are geared toward developing a student's ability to synthesize theory into an engineering design, the methods of instrumentation and data acquisition often make project implementation less than satisfactory.

Electrical Engineering programs generally require a course in Signals and Systems that covers the theory of mathematically solving the input-output relationships of systems using the various transform spaces. Implicit in this theoretical study is the notion that engineering systems are modeled with differential equations, though the process of modeling a system is not the focus of typical Signals and Systems textbooks^{6,7}. Consequently, students develop some degree of confidence in manipulating the Laplace or Fourier transform without establishing the connection between the behavior of a physical system and the math. Furthermore, students are exposed to the concept of a signal but rarely have the opportunity to experience the pitfalls of noisy signals, or the incorrect analysis that can occur from under-sampling, nor are they exposed to the concept of transducing a physical phenomenon into an electrical signal that can be acquired and analyzed.

To address these issues, the School of Electrical and Computer Engineering at our University has developed a laboratory-based course that provides an experiential learning opportunity for engineering students. The course, called Measurement and Automation, is cross-listed as a senior-level undergraduate course, and a graduate course. The course is oriented around individual workstations using National Instruments USB-6211 data acquisition devices and the LabVIEW programming environment. Each project during the semester incorporates industry-standard sensors to produce the subject data streams, providing signals rich with both signal-of-interest and noise. The course consists of a mixture of short lectures and extended lab activity. The material covered in this course includes the fundamentals of signal bandwidth, sampling, aliasing, sensor calibration, data manipulation, and external control. This paper explains the prerequisites for the course and the initial content offering as a group of projects with specific goals. The grading process is explored, as well as preliminary assessments of whether the course meets its broader goals and discussion of other possible assessment methods⁸. Finally there is discussion of how the course may act as a test-bed for developing in-class projects for lower-level engineering lecture classes.

The Measurement and Automation course is not a required course in the ECE curriculum. It is popular at the undergraduate level because it provides a wide array of projects that extend the student's base of experience. Graduate students from other disciplines (Chemical Engineering, Civil Engineering, and Mechanical Engineering), who are trying to develop data acquisition and measurement skills for their own research projects, are allowed to enroll in the course with instructor permission. The twenty-four seats in the class have been filled, with a waiting list, each semester the course has been offered. In comparison, the Capstone course typically is designed to give students project experience with a single engineering focus. The capstone course provides a vertical project experience, giving the students exposure to project management, design review, prototyping, and budgeting.

II. Prerequisites

A. Engineering Course Requirement

The Measurement and Automation course requires Electrical and Computer Engineering (ECE) students to have completed a Signals and Systems course. The rationale for this prerequisite is straightforward. Students who have completed a Signals and Systems class have been exposed to the transform spaces, the solution of differential equations using transforms, and sampling theory. Developing skills in the Laplace and Fourier transforms, filter assessment through frequency-domain behavior, and solving ordinary differential equations are key elements needed to understand signal acquisition and analysis. No specific math requirements are listed because the Signals and Systems requirement incorporates the relevant math. The course is primarily designed to accommodate ECE students, but its appeal has expanded to graduate students in several engineering disciplines whose research involves a significant amount of instrumentation (e.g. a Chemical Engineering student pursuing his doctorate needed to become conversant with monitoring system parameters toward process control of a chemical reaction, or a Civil Engineer studying bridge deterioration for his thesis who needed to specify and acquire appropriate accelerometers, and then acquire vibration data). In order to accommodate a broader selection of engineering students, the instructor can override the Signals and Systems prerequisite if the student has had another course in her discipline, of sufficient depth, that studies the methods of solving differential equation models of systems.

B. Programming Requirement

The LabVIEW software environment is used in the course for both acquisition and analysis of data streams. Previous knowledge of LabVIEW is not required, but some fundamental programming course is required to ensure that the students understand the basics of program construction. As an example, the student may not know how to implement a WHILE loop in LabVIEW at the beginning of the semester, but should certainly understand what a WHILE loop is, and the conditional nature of its continued execution.

III. Laboratory Hardware and Layout

The laboratory course has 24 individual workstations. Each workstation runs on the Windows operating system and has both LabVIEW and the Microsoft Office Suite installed. The workstations all have Internet access through the main university domain, and students log into the computers using their standard university login. This allows them to access their network drive and store ongoing project work where it can be accessed outside the lab if desired. Each

workstation has a National Instruments USB-6211 attached via USB cable (see Figure 1). The USB-6211 has 16 single-ended, or 8 differential 16-bit data acquisition channels with an aggregate sample rate of 250 kS/s and a dynamic range of +/- 10 volts. There are two analog-out channels with 16-bit resolution, four digital inputs, and four digital outputs. Each USB-6211 has a custom-designed interface board that allows a common signal source to be delivered to all workstations (see Figure 2).



Figure 1: Individual workstation with National Instruments USB-6211 and protoboard.

The projects all rely on dissemination of one set of signals from a unique origin. Sensor signals are connected to a distribution panel that fans out the signal to the 24 student positions. This is possible because the sensors are externally powered and the USB-6211 has input impedances greater than 10 G Ω . Therefore, there is minimal loading of the signal source. A common signal-of-interest has the advantage of providing the instructor with an expected result across all students. Furthermore, the instructor controls what sensors are connected at the distribution point, allowing the instructor to keep the coursework moving forward through the semester. The instructor's computer is connected to a projector and has its own USB-6211 and interface. This allows the instructor to demonstrate theory, or programming techniques, while the students can visualize it and implement the same thing themselves. Furthermore, this arrangement allows the instructor to use his workstation to retrieve and grade the assignments. The result of all but one project is a LabVIEW program, so the instructor can test each student's code with the same signal source used by the student.

Finally, there are extra project setups available for the graduate students. In order to differentiate the course requirements, graduate students are given extra independent projects that require more investigation and implementation effort. In these instances, the graduate students are grouped in

teams of two or three students; a typical specification write-up is presented to each group. The team is responsible for treating the instructor as the “client,” deciding if they need clarification on any issue, determining what sensor suite is available for the project, and is expected to provide the client with design review to ensure that the ultimate product meets the client’s needs.



Figure 2: National Instruments USB-6211 data acquisition with attached protoboard, showing the common data source connection

IV. Common Course Projects

The course is designated as worth three semester-hour credits and meets once each week. The once weekly meeting time is intentional because it provides time to develop an idea with a short lecture, and then time for the students to pursue their understanding of that idea while the instructor is available for guidance. This ensures that the students do not procrastinate in executing their project assignments. The course follows a building-block approach toward developing the student skills. Preliminary lectures are devoted almost entirely to a review of programming concepts, and the LabVIEW-specific constructs used to implement the programming concepts. The initial project develops the student’s basic LabVIEW skills, and does not require any data acquisition. Subsequent projects acquire and analyze data, and act on the analysis results. The projects become increasingly more challenging through the semester as the student gains knowledge and skill. Table 1 describes the progression of course projects.

Table 1: Course Projects with Specific Goals

Project	Task	Goal
1	Create a User Interface that acts as an account login with name, ID, and PIN	Develop LabVIEW skill in both user interface design and block diagram development. The student will learn to create conditions that allow the program to run continuously until shut down is selected. The project also requires the student to read and write data files, acquire user input, manipulate arrays, and display dynamic information.
2	Create a program that monitors pressure sensors on two tanks to detect losses in each tank, and set an alarm if the loss exceeds a certain value	This task is designed to help the student learn to acquire data through the LabVIEW tools. Two channels of low-bandwidth data are present, and the student must track the data over time to detect signal trends. The program must also use a digital output channel to control an external warning device when a loss condition occurs.
3	Acquire two channels of audio data, provide live spectrum plot, and use the frequency content of the audio signal to control dancing lights. Develop creative user interface.	This project requires students to research audio bandwidth, and acquire stereo (two) audio channels at an appropriate sampling rate. Live spectrum data is displayed, and the students are expected to design a set of bandpass filters that divide the signal in a way that allows them to control four colored lights, based on the power in each frequency band. The light behavior is expected to be stable regardless of the volume level.
4	Acquire single channel of data, use this data to create a math model of an unknown physical system	Students acquire data from an accelerometer attached to a bouncing toy. The toy has a decaying oscillation, and the students solve the motion equations based on the accelerometer data.
5	Develop a user-friendly weather station	Acquire five channels of weather sensor data. The students are given the model number of each sensor and required to research the calibration factors for each sensor so that the user display is in standard units for each parameter (wind speed, temperature, etc.). The students create a user-friendly, informative display.
6	Count change on a light tray from a camera image	Acquire network camera images to determine the amount of change on a platform; develop understanding of image processing tools such as color extraction, open, close, threshold, etc.

A. Project 1

The first project does not require any data acquisition, and is designed to enhance the student's programming skills. The assignment requires the students to develop a secured entry program that expects a user to type in a name, student number, and personal identification number (PIN) for access. The program specification requires that it run continuously and read the potential list of users from a comma-separated-variable (CSV) file that can be edited by an administrator. Furthermore, the program must log successful and failed entry attempts in separate CSV files. The user interface must be informative and easy to use, and must inform the user of the results of the login attempt. The Entry Access project helps the student become familiar with LabVIEW, further develop understanding of programming constructs, and gain exposure to file input-output (IO) in a broadly accepted format that crosses hardware and software platforms.

B. Project 2

The second project is preceded by a lecture reviewing data acquisition. The students are encouraged to work along with the instructor in acquiring the initial periodic waveform, facilitating an experiential analysis of sampling and aliasing. Discrete Fourier Transform theory is reviewed showing that an ever-increasing frequency will continue to produce a discrete spectrum that falls within the half-sampling rate limit. The data acquisition discussion also includes an explanation of dynamic range and bit sensitivity. After the lecture, the students are asked to acquire signals from two pressure transducers that indicate fluid level in two tanks, based on the calibration given in the project specification. The students are required to monitor and display the fluid levels, in gallons, detect any leakage at a rate greater than what is specified, and activate an external alarm when the leak condition occurs. The project must also reset its monitored level when fluid is added to the tanks. This project is the fundamental exercise used to expose the student to data acquisition. The transducer changes are relatively slow so that students can focus on multi-channel acquisition, dynamic range, and monitoring. The concept of storing previous samples for future comparison is a key element to successful completion of the project. The student is also required to produce a visually ergonomic user interface.

C. Project 3

The third project is an audio processing project that is preceded by a discussion of basic filters: low pass, band pass/stop, and high pass. Filter theory is a complex field requiring courses devoted to its development, but the use of digital filters is so prevalent that many engineers need to understand the effects of filter order and cutoff frequency with respect to sampling rate and timing. After discussing filters in the context of the frequency spectrum of a signal, students are asked to acquire two channels of stereo audio data, provide a near-real-time visual assessment of the spectral content (i.e., the data acquisition should collect enough samples for each access of the data bus such that the program can compute a reasonably accurate spectrum), and control a set of four colored lights based on frequency content—disco lights. The lecture material informs the students that there is a standard sampling rate for audio, but requires the students to investigate that on their own; further they generally find that a division of the audio bandwidth into four equal bands does not produce effective control of the lights, requiring further exploration into frequency content of audio signals. An extended component of the exercise is to ensure that the behavior of the disco lights due to frequency content is independent of volume. In other words, if the volume is turned down, the lights should not just stop blinking on and off,

nor should they stay on continuously if the volume is significantly increased. Finally, the user interface for this project is weighted more heavily, as the students are asked to put in the effort to produce a stereo-system-like display.

D. Project 4

A fourth project utilizes a single channel of data from an accelerometer. In the previous exercises the students have become comfortable with the concepts of data acquisition—dynamic range, bandwidth, filtering. The fourth project is designed to expose the student to the idea of determining system behavior based on analysis of sensor data, rather than analyzing the system from its fundamental elements. This type of black-box approach is often encountered in industry. The project lecture expounds on a basic second-order differential equation with a bouncing toy as the physical realization of the model. This exercise is the only one in the course that steps through the process of developing a mathematical model of a physical process. A helicopter toy with an accelerometer attached to the bottom is suspended from the ceiling by a spring. The toy can be displaced by some amount and released, causing a decaying oscillation. With a tape measure extending next to the toy, the students are asked to provide the fundamental equation of motion. This project is unique within the course, in that the product turned in by the student is not a functional LabVIEW program, but a report detailing their methodology and results. The free-body diagram is developed and the initial Laplace equation describing the system is found to be:

$$\frac{d^2x(t)}{dt^2} + \frac{D}{M} \frac{dx(t)}{dt} + \frac{C}{M} x(t) = 0$$
$$\Downarrow$$
$$s^2 + \frac{D}{M} s + \frac{C}{M} = 0$$

where M is the mass, D is the damping constant, and C is the spring constant. The students are not given the M , D , or C , and are not required to find them. In this case, the roots of the Laplace equation are either real, or complex. With complex conjugate roots, the fundamental motion is modeled by the equation:

$$x(t) = Ae^{-\alpha t} \cos(\omega t + \varphi)$$

where A is the initial displacement, α is the decay time constant, ω is the single-mode oscillation frequency, and φ is the initial phase. It is noteworthy that α and ω are the same for position, velocity, and acceleration. However, if the initial displacement is the maximum displacement, then φ can be set to zero, and A can be visually measured prior to release. The problem resolves itself to measuring the accelerometer data and determining α and ω .

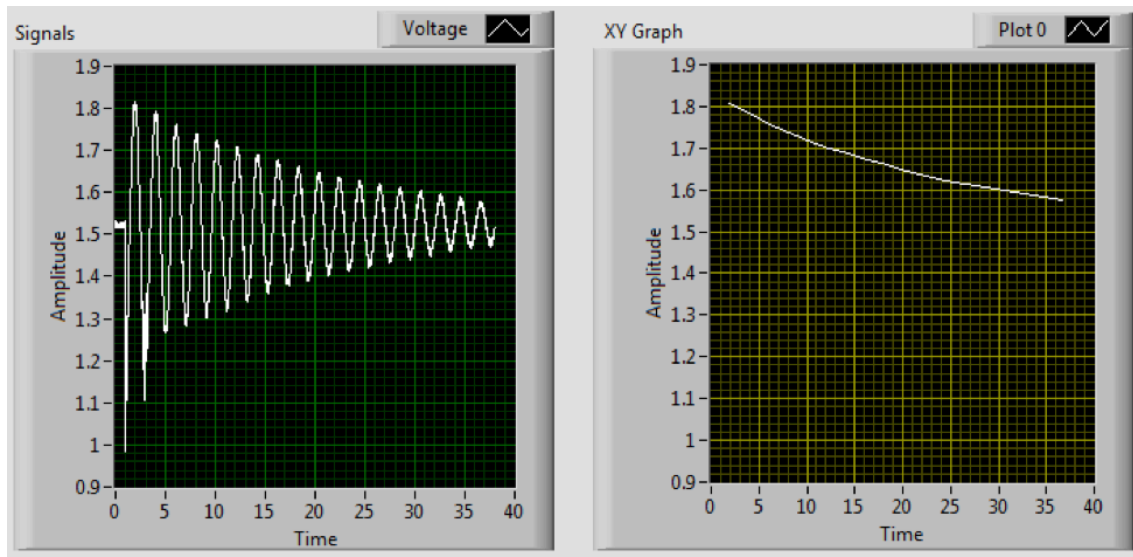


Figure 3: Program display of accelerometer output (left) and plot of peak points (right) for decaying oscillation of toy helicopter.

The graded product for this project is a thorough paper that clearly describes the relationship between the physical system and its mathematical model, how the data were acquired (including an explanation of how the dynamic range and sampling rate were determined), the method of extracting the decay curve and frequency of oscillation, and how these acceleration values relate to the desired position formula. The paper is expected to be much like a typical white paper in industry, and grammar, syntax, and spelling are graded in addition to the engineering content.

E. Project 5

The fifth project requires five-channel data acquisition from meteorological sensors. Two instrument sets exist: one set in the lab, and an identical set on the roof of the building. There is no lecture for this project. The students are told the model numbers of the sensors and expected to find the calibration values themselves. At this point in the semester most students are comfortable with using Internet searches to find user manuals and specification sheets. Once the students have developed an initial program to acquire and display weather data, the sensor stream is changed to the outside source. For this project, part of the grade is determined by how closely the student's weather information matches the nearby airport weather observation system. Students are given the dial-up number for the system in order to refine their program. The user interface, ability to change between units for temperature, wind speed, and barometric pressure, and accuracy of the data are all part of the assessment for this project.

F. Project 6

The final project delves into vision-based systems. The underlying theory of image processing, like filter theory, commands its own graduate level course. However, image acquisition and analysis are frequently encountered in factory automated testing and analysis and a fundamental understanding of image analysis tools is useful to a broad selection of engineers. The vision project provides the student with access to a network camera pointed at a platform with a selection of change in random locations within the field of view. The student is required to count the change and present the user with an amount of money, as well as a breakdown of the coin types and quantity. The change is frequently shuffled to new positions to ensure that the results

are robust. Students are exposed to different image constructs (RGB, HSV, YUV) and determine the best construct and plane extraction for their purposes. A key element is the student discovering the critical role of lighting to vision-related tasks.

G. Graduate Projects

Graduate projects go beyond the common assignments in that the students are given a specification for the desired result and very little other information about the system or project setup. Graduate projects are performed in addition to the common project set so that the graduate students have a greater work-load. The two fundamental graduate projects are a tank level-control project, and a carnival weighing-station project. These projects both use National Instruments Compact DAQ devices.

- 1. Tank Control:** In this project, the students are given a vertical, cylindrical tank with a pressure sensor located at the bottom. A water spigot is mounted in the side, at the bottom. The lab water tap is attached a control valve, and the outlet of the control valve is inserted into the top of the tank. Students are given the model number of the pressure sensor and a tape measure. The requirement is to maintain the tank at a specified number of gallons when a leak is introduced. The project involves measuring the pressure sensor, accounting for calibration factors, tracking the values over time, and controlling the water valve at the inlet to maintain the specified volume of water. The leak is variable, controlled by the water spigot at the bottom of the tank. The control valve has a fixed flow (under the assumption that the tap is fully open). The water valve is digitally controlled, while the sensor input is an analog acquisition. The students are told that overflowing the tank is considered a complete failure. The desired accuracy is +/- 0.25 gallons.
- 2. Weighing Station:** In the weigh-station project, the students have access to a heavy steel beam with a strain gauge attached at the center. The strain gauge model number is given to them. The steel beam is suspended off the floor at each end, and has a fixed distance between the supports. The specification requires a system that weighs a subject standing on the beam and reports the weight with audio commentary. The user interface is required to have a zeroing function and a calibration mode not available to the regular user. Two standard weights are available for calibration. Accuracy is specified to be within 1% for weights between 90-300 pounds.

V. Course Grading

A. Program-Based Assignments

Assessment of student performance is accomplished through two basic methods. Most projects require a LabVIEW program to be turned in as the final product for grading. The first method of grading is based on assessment of the programs that are turned in for each assignment. The functionality of the LabVIEW program, how well it meets the project requirements, the level of code commenting and error handling, and the overall appearance of the user screens are all part of the grading rubric. Functionality and meeting the project requirements are graded more heavily, accounting for 70% of a project grade. Commenting and error-handling account for 20% of the grade, and user interface accounts for the final 10% of the project grade. Although the students are not expected to produce ergonomically analyzed and tested interfaces they are

encouraged through grading to put some effort into developing user-friendly interfaces. An example of well-executed code and poorly executed code is shown in Figure 4 below. The upper panel shows poorly organized, non-functional code. Furthermore, the student did not write the code so that it would execute until the user terminated it, something all the coding assignments required since monitoring data streams is a fundamental aspect of the course. On the other hand, the lower panel represents well-documented, functional code with an organized and easily readable layout. This student actually implemented a state machine for the project, though that was not a specific requirement. Although the concept of a state machine is presented as the preferred method of flow control in a LabVIEW program, the implementation of a state machine is a more advanced skill that few of the students master during the semester.

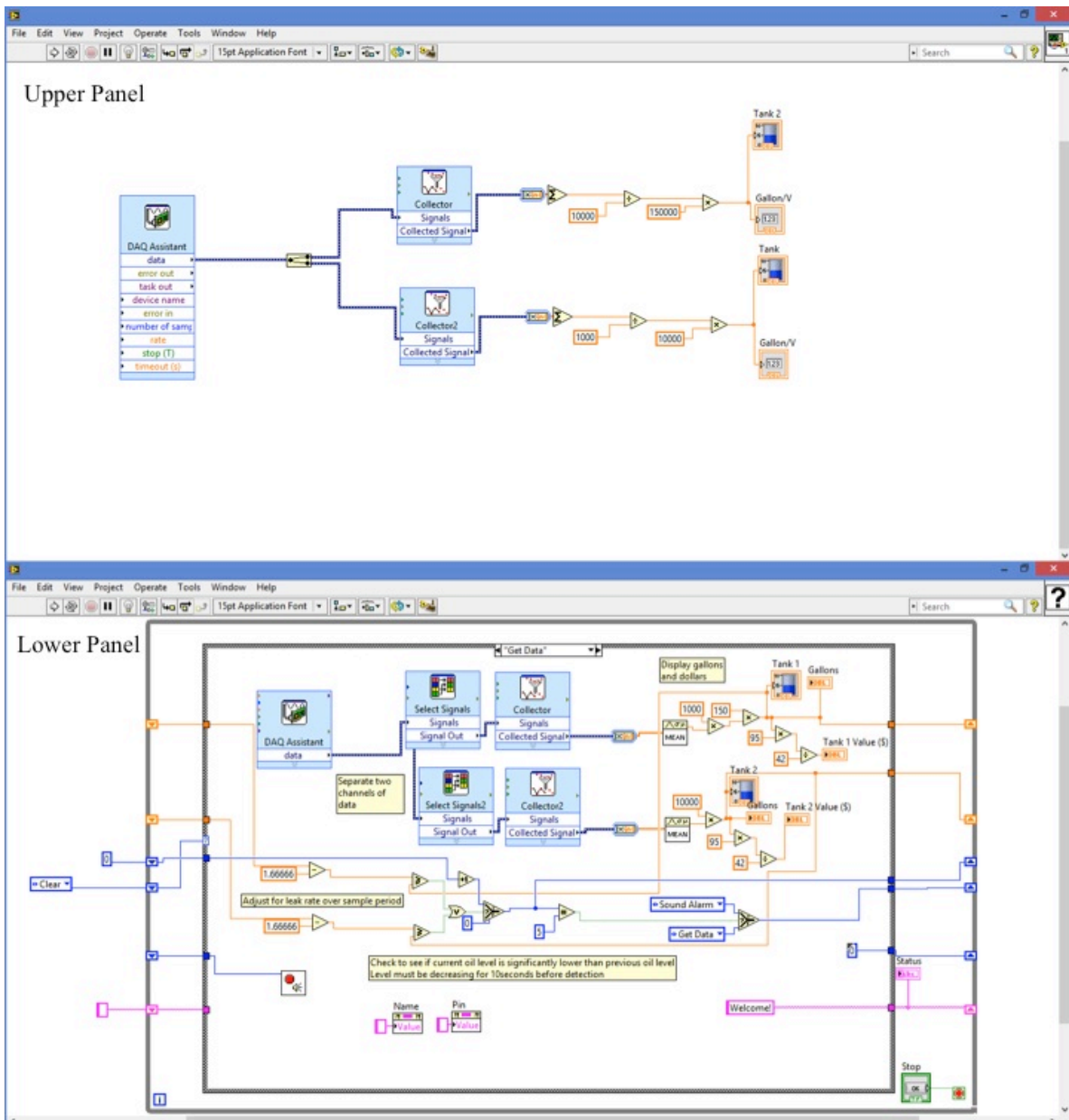


Figure 4: Two implementations of LabVIEW code for a project. Upper panel received a failing grade; lower panel received high marks.

B. Report-based Assignment

The motion-equation project requires the student to write a white paper explaining the problem to be solved, the method of data acquisition, and the results achieved. The project does not require a LabVIEW program to be turned in. The grade for this project is based on the student's ability to adequately explain the math model, relative to the physical system, the student's method of acquiring data for analysis, the analysis methodology, and the results. Key elements that are expected include a mathematical derivation that demonstrates why the accelerometer data can be used to infer the position equation, an analysis of signal bandwidth and expected sample rate, noise mitigation techniques, and data analysis method. A frequent misstep resulting from this project is double numerical integration of the accelerometer data, which the student often finds leads to unexpected results. Another pitfall is experienced with oversampling. The oscillation frequency is about $\frac{1}{2}$ hertz, yet some students choose to sample at high acquisition rates, such as 2000 Hz, or even higher. This generally leads to an extra discussion of the tradeoff between frequency and time resolution when choosing a sampling rate. Meeting the Nyquist criterion is not the only consideration. A secondary focus of this project is to help develop writing skills in engineers, so the students receive significant feedback about fundamental grammar, syntax, and spelling. The final report is expected to include plots of the acceleration, and a definitive statement of $x(t)$ that inserts the proper values for α and ω .

C. Total Grade

All of the projects account for 85% of the final grade. The remaining 15% is accounted for from the results of the student taking the Certified LabVIEW Associate Developer (CLAD) exam at the end of the semester. This exam is used as a final exam. Although teaching LabVIEW as the sole purpose of the course is not within the purview of the university, it is used extensively in the course. This is analogous to the use of MATLAB in many Signals and Systems, and Digital Signal Processing courses. Using the CLAD as a final exam gives the students the added benefit of potentially having a CLAD certificate on their resume as they begin their job hunt. A score of 70% or better is required to pass the CLAD exam. However, the passing score is not required to pass the Measurement and Automation course. Rather the exam score is distributed over the remaining 15% allotted for the final exam in the course.

Significantly, the ABET assessment process, initially conducted in the spring of 2013, indicates that students who struggle in the course have systemic math and physics deficits. Previous courses have not enabled these students to bridge the divide between the math and physics concepts on paper and the application to actual, physical systems. In this area, the course may prove useful in producing evidence for needed curriculum adjustments in lower-level courses. Application of theory is the hallmark of the engineering profession, and students should expect to have some developing skill in application by the time they graduate from an engineering degree program.

VI. Course Objectives

The goal of the Measurement and Automation course is to provide the students with an experiential learning environment that promotes retention of the ideas covered and the skills to continue the self-learning process throughout their respective engineering careers. Because the course has only recently been moved in this direction, there is insufficient current data available

to measure whether those objectives have been met. Future assessment will be based on surveys of graduated students in industry, as well as the subset of students who take the course as undergraduates, but continue on to graduate studies at the university. Those surveys will initially begin after the spring 2014 semester. Also under review is a paired pre-survey and post-survey for students taking the course, which will assess the immediate impression of the student regarding the understanding and retention benefits of the course. The assessment will address perceived understanding of key topics at the beginning of the course, and at the end. Pending approval, the in-course survey will be implemented in the fall 2014 semester.

Some preliminary evidence shows that the Measurement and Automation class assists students by helping them to achieve a greater proficiency in LabVIEW. 21 senior or graduate ECE students were surveyed in another ECE course that was assessing LabView proficiency and the three students that had completed Measurement and Automation responded 74% higher when asked to rate their competency in LabVIEW. The end-of-course survey by the university elicited the relevant responses shown in Table 2:

Table 2: Relevant Assessment from University Course Evaluation

Course concept	Average Response (out of 5)	College Rank (%)
Class work contributed to learning of material	4.7	71
Course material related to professional practice	4.8	81
Course methodology helped develop analysis and design abilities	4.5	75
Assignments contributed to learning the material	4.5	70

Currently, only standard end-of-semester student evaluation data are available for assessing the course. The popularity of the course, however, will provide an excellent opportunity create assessments that more thoroughly quantify whether the objectives are being met.

VII. Discussion

The Measurement and Automation course at our university is a young course in its development. Although laboratory-based courses in engineering are not a novel concept, this course is unique in the lab design. The signals are universally taken from actual sensors, rather than from simulators. These sensors have band limits, noise figures, and sensitivity figures, which can affect the data acquisition process. Furthermore, the broad array of physically realized signal sources provides the students with a wide exposure to signal amplitudes and bandwidths, requiring preliminary analysis and understanding of the signal-of-interest—a key aspect of proper engineering analysis. The distribution system within the lab also helps reduce infrastructure costs because the project setups only need to be realized once. Rather than 24 accelerometers, 24 toy helicopters, 24 springs, and 24 tape measures, a single set up generates the data used by the entire class. This also has the salutary benefit of promoting a sense of esprit de corps and cooperation within the class as they work together to decide when to operate lab equipment, or when to reset it. While each student is expected to turn in his or her own work, this type of cooperative environment gives students a feel for the group work environment seen frequently in industry.

Another interesting result of this course is collaboration with instructors at the lower-division course level. For example, the University has a Digital Signals and Filters course geared toward the sophomore level, which introduces the students to the Z-transform, FIR filters, and the concept of sampling. The in-class lecture and experiment in aliasing constitute an excellent physical example for the students. The instructor is able to produce a sine wave, acquire it with the USB-6211 and a LabVIEW program, and display the instantaneous spectrum. With the sampling rate set at 1000 samples per second, the sine wave frequency is increased slowly beginning at 100 Hz. The spectrum shows a single peak at 100 Hz, but as the sine wave begins to exceed 500 Hz, the peak on the spectrum plot simply marches backward from 500 Hz. At a frequency of about 1000 Hz, the sine wave produces a peak near DC, and then increases again. In the first test of this in-class project, students were very interested to note that the peak kept ranging between 0 and 500 Hz, regardless of how high the function generator frequency was set. Based on the success of this preliminary project, an effort is being developed to define a set of projects across the curriculum that would require the students to purchase a reduced data acquisition device as part of their basic undergraduate experience. The target device is the National Instruments myDAQ, which has two data acquisition channels, two analog-out channels, digital IO, and has a student cost on par with an engineering textbook. In summary, the Measurement and Automation course is also acting as a testing ground for developing experiential projects for lower-level engineering coursework.

VIII. Conclusion

The developing Measurement and Automation course at the University of Oklahoma provides students with hands-on projects that are designed to reinforce understanding of signals and system theory, and the underlying math. Each project relies on a common-source data stream distributed to each individual workstation, giving the instructor an expected outcome upon which to grade the student effort. The course has received positive reviews amongst recent alumni in post-graduate surveys. New course-specific surveys are being developed in an effort to more thoroughly and accurately assess whether, from the student perspective, the course is meeting its stated goals.

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