An Instrumentation and Data Acquisition Course for Electronics Engineering Technology Students

Biswajit Ray
Dept. of Physics & Engineering Technology
Bloomsburg University of Pennsylvania
Bloomsburg, PA 17815

Abstract

Design of an instrumentation and data acquisition course for sophomore level electronics engineering technology students is presented. The course incorporates experiment design and problem-based learning as pedagogical tools. An assessment-verification-improvement process was implemented to incorporate class dynamics into the teaching/learning process. The course has defined learning and teaching objectives within the constraints of a project-oriented course. The major objective of the course is effective integration of hardware and software in designing computer controlled processes and/or systems with the aid of sensors, transducers, data acquisition board, and instrument control.

Introduction

The ability to conduct and design experiments is rated as one of the highest desirable technical skills of engineering and engineering technology graduates[1,2]. Specifically, the survey indicates that employers want graduates with a working knowledge of data acquisition, analysis and interpretation; an ability to formulate a range of alternative problem solutions; and computer literacy specific to their profession. The Industrial Advisory Board of the EET program at Bloomsburg University of Pennsylvania recently reinforced the above need. Additionally, the advisory board wanted our students to be introduced to such experimental techniques and tools before they venture out for their first full-time semester-long coop experience. Potential employers of our graduates are in the automated manufacturing and testing sector of the industry; and that motivated the creation of an instrumentation and data acquisition course for the EET students. This course is offered during the fourth semester of the B.S. program, well before their first coop experience during the sixth semester.

For pedagogical reason, the problem-based learning (PBL)[3,4] was adopted for this course. With PBL, students are empowered to self-direct their educational experience by designing experimental systems and/or subsystems against given specifications. It is an instructional method, which uses real-world problems to facilitate students' critical thinking and problem solving skills while accomplishing the course objectives. Students get involved and take responsibility for their learning experience; and instructor becomes a resource. Instructor role changes to that of a consultant, mediator, counselor, and resident technical expert. The purpose of implementing PBL is to motivate the student to integrate and utilize knowledge rather than to re-involve the student into the learning process after an extended period of inactive listening. In the instrumentation and data acquisition course, PBL is applied to industrial projects within the context of a laboratory.

The instrumentation and data acquisition course development reported herein is offered to B.S. EET majors during their fourth semester in the program. Students have had circuit analysis, analog electronics, and electrical machines before registering for this course, and they take digital electronics concurrently. In developing this experiment-based data-acquisition-supported instrumentation course, a detailed literature survey[2, 5-11] was conducted. A freshmen-level course[2] for mechanical engineering students covered LabVIEW[12] software integrated with three experimental modules (tank level, temperature, and force). A junior-level instrumentation and experimental methods course[5] for mechanical engineering students also integrated the use of LabVIEW software with temperature, pressure, strain gage, and vibration measurement systems. Developments of similar courses were reported in recent years for agricultural and biological engineering students[6], mechanical and industrial engineering students[7], and engineering technology students[8-11] of various disciplines.

The course developed at Bloomsburg University incorporates the experiences reported in above referenced institutions in relation to experiment design concepts and integration of software and hardware in developing modern automated instrumentation systems. Use of instrument control was not reported in the referenced papers; however, at the suggestion of local industries, this topic was incorporated into the course. Since this course is for EET students who have already taken courses in analog and digital electronics, instrument control was integrated smoothly and provided a significant boost to student’s ability to develop truly automated systems.

The following sections present a summary of course-level assessment approach, curriculum and laboratory format, sample laboratory experiences, and student feedback.

Course Assessment

A course-level assessment-improvement-verification feedback process[13,14] was implemented for students’ classroom learning experience. Traditionally, assessments for measuring students’ learning experience are performed only once at the end of each semester utilizing standardized institutional survey. This approach leads to long turn-around times in the assessment-improvement feedback loop. Assessment, improvement, and then verification that changes made to improve the learning experience were indeed effective can take up to two years for classes taught annually. Additionally, end of semester assessment results are specific to the group of students participating in the assessment. Since the learning experience can be very subjective, and class dynamics varies significantly from semester to semester, course changes to improve learning experience which were based on an assessment taken at the end of a course may not be beneficial to students in future offerings. Finally, because traditional assessments are often based on an institutional standard, they do not address the students learning experience in light of course-specific educational objectives.

The shortcomings of using standardized end of semester assessments can be overcome by using a series of multiple short assessments during a semester, in which assessments are designed specifically for the course and the student body. This assessment-improvement feedback process flowchart is shown in Figure 1. This process substantially reduces the assessment-improvement-verification turn-around time (i.e., improves bandwidth), making it easier to evaluate the effectiveness of teaching or curriculum changes on the learning experience. The process also addresses the problem of varying class dynamics since changes in course curriculum or the teaching style directly benefit those students participating in the assessment.

The learning and teaching objectives for the course are listed in the next page. A list of questions was prepared based on the stated objectives, and the survey was conducted during the third, ninth, and fifteenth week of the semester.

Course Format

This three-credit course meets for two one-hour lectures and one three-hour laboratory per week. The first three weeks of the fifteen-week semester are primarily devoted to LabVIEW programming. During the next eight weeks, the concepts and integration of sensor and transducers, interface electronics, data acquisition and instrument control hardware/software are covered. The final four weeks are reserved for student-initiated laboratory design projects. The course also requires an individual research report on a specific industrial instrumentation system of each student's choice. The distinction between lecture and laboratory hours is blurred in this course since the course is exploration and project driven. The lab/lecture hours are used interchangeably based on students' need.

For the first part of the lab, students mostly work individually to become sufficiently proficient with LabVIEW programming. Once the hardware and software integration starts, students work in a group of two; and they develop the necessary software together as well. It is observed that the students easily pick up the programming part; but then things slow down a little when hardware development starts even though they have had electronics before this course.

Typical course content:

- **Fundamentals of programming logic:** Virtual instruments; indicators and controls; front panel and block diagram; data types and data flow programming; case and sequence structures; arrays, loops, and clusters; graphs and charts; subVIs; and file I/O.
- **Sensors and transducers:** Resistive, capacitive, and inductive sensors; temperature sensors; position, displacement, and speed sensors; force and pressure sensors; vibration and acceleration sensors; proximity and presence sensors; electro-optical sensors; flow and flow-rate sensors; and liquid-level and humidity sensors.
- **Signal conditioning and data acquisition:** Analog-to-digital and digital-to-analog converters; sampling rate, multiplexing, resolution, range, and code width; grounding, isolation and noise; single-ended and differential measurements; attenuation, amplification, and filtering; excitation and linearization; impedance mismatch and loading; digital signal conditioning; signal transmission (voltage vs. current loop); and hardware architecture of a modern multi-function data acquisition card.
- **Instrument control:** Components of an instrument control system (GPIB and RS-232); detecting and configuring instruments; and instrument drivers.
- **Instrumentation system design:** Design specifications; functional block representation; design, debugging, and testing; interpretation and presentation of data; user interface; temperature control system design; motor speed control system design; and instrumentation project incorporating multiple sensors, signal interfacing electronics, data-acquisition hardware, instrument control, and LabVIEW programming.

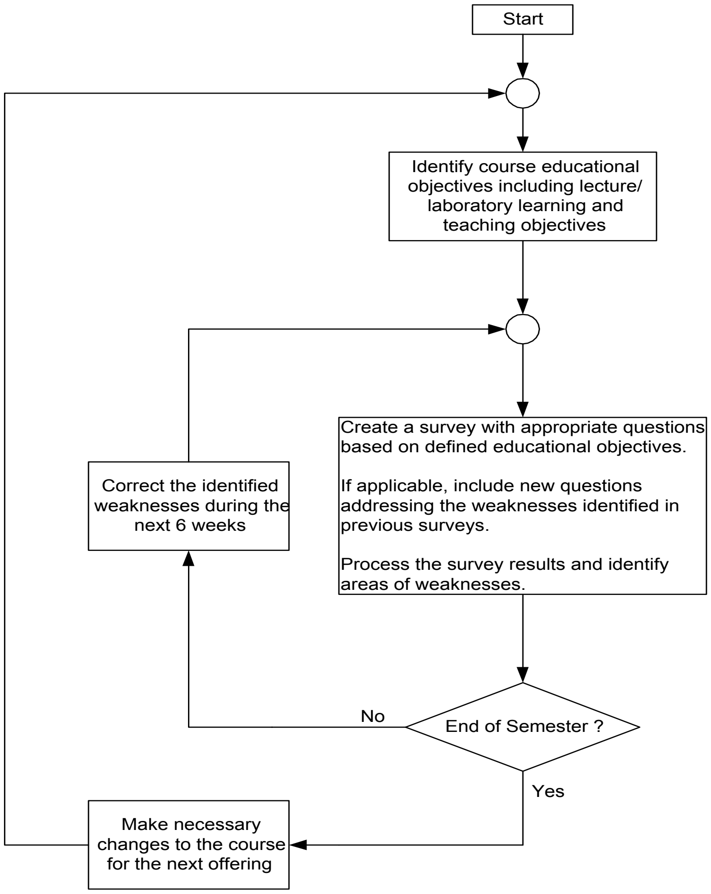


Figure 1 Assessment-improvement-verification feedback process flow chart.

Course Learning Objectives:

- Understand the principles of operation of commonly used sensors, transducers, and instruments
- Understand fundamental programming logic transferable to other programming languages
- Write programs based on an industry-standard graphical programming language
- Gain experience in interpreting technical specifications and selecting sensors and transducers for a given application
- Understand terminologies associated with instrumentation systems (e.g., range, sensitivity, dynamic response, calibration, hysteresis, error, accuracy, precision, data uncertainty, mean and standard deviation)
- Use data acquisition software and hardware to collect and analyze data from a physical system
- Gain experience in developing computerized instrumentation systems for industrial processes using multiple sensors, interface electronics, data acquisition card, and GPIB and serial instruments

Course Teaching Objectives:

- Foster discovery, self-teaching, and encourage desire and ability for life-long learning
- Provide students with access to industry standard hardware and software required for data acquisition, instrumentation, and control
- Provide an experience in designing an instrumentation system based on specifications
- Develop soft skills including teamwork, open-ended problem solving, formal report writing and presentation
- Provide an enthusiastic environment for learning
- Assign homework to reinforce the understanding of material covered in class
- Encourage students to use the office hours for discussing academic and related non-academic issues

Typical laboratory experiments:

- Two-way traffic light simulation
- Data acquisition using thermocouple & CJC, and IC temperature sensor
- Humidity and temperature monitoring with data logging
- Liquid level control using ultrasonic sensor and on/off control of pump
- Measuring V-I characteristics of electronic components incorporating instrument control
- Two-channel virtual oscilloscope
- Measuring frequency response of an electrical system
- Speed control of dc motor using pulse-width modulation and encoder feedback
- Part placement application incorporating conveyor belt, proximity sensors, and pneumatic part dispenser
- Power quality analysis by measuring ac voltage and current via isolated sensors
- Temperature control system implementation using on/off controller
- Speed control system for a dc motor using GPIB and RS-232 controlled instruments

Laboratory Setup

The laboratory has twelve stations to accommodate 24 students. Each station is equipped with a PC, and GPIB/RS-232 interfaced instruments such as digital multimeter, triple output laboratory power supply, arbitrary function generator, and color two-channel digital oscilloscope. A typical lab station is shown in Figure 2 below. The laboratory is also equipped with GPIB/RS-232 capable high power (150 V/8 A) dc power supplies for motor control applications including electrically controlled motor loading system.

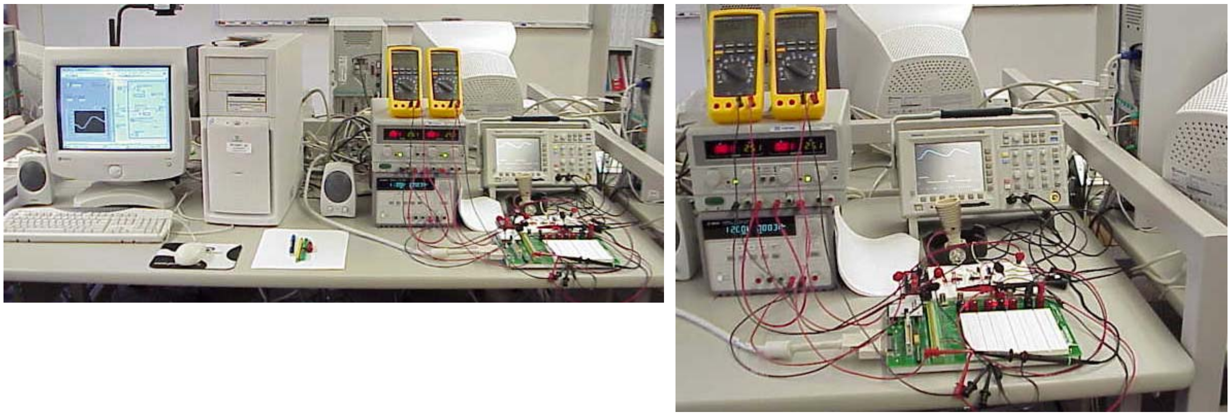


Figure 2 Typical laboratory station.

The instrumentation and data acquisition specific software and hardware are briefly described below.

Software:
LabVIEW 6.0 from National Instruments[12]

Data acquisition (DAQ) board:

- Model 6024E from National Instruments
- High performance multifunction board
    - 16 single-ended or 8 differential analog input channels, 12 bit resolution, 200 kS/s
    - 2 analog voltage output channels, 12 bit resolution, 10 kHz update rate
    - 8 digital I/O channels with TTL/CMOS compatibility

  - Timing I/O (2 up/down counters and 1 frequency scaler, 24-bit resolution, 20 MHz and 100 kHz base clocks)
  - Digital trigger

<u>GPIB controller board:</u>

- IEEE 488.2 compatible architecture
- Eight-bit parallel, byte-serial, asynchronous data transfer
- Maximum data transfer rate of 1 MB/sec within the worst-case transmission line specifications

<u>Signal conditioning accessory:</u>

- Model SC-2075 from National Instruments
- Desktop signal breakout board
  - Connects directly to 6024E DAQ board
  - Attached breadboard with built-in power supplies (+15 V/-15V, +5 V, and 0-5 V)
  - Binding posts for analog input
  - BNC connectors for analog I/O and triggering
  - Spring terminals for analog and digital I/Os and counter controls

Typical Laboratory experiences:

Laboratory experiences are grouped in four basic categories: software development only; basic analog/digital I/O integrating sensors/transducers; ON/OFF control application; and instrument control application. As mentioned earlier, the final four weeks of the course is dedicated to student-initiated laboratory projects. A sampling of the laboratory experiences is briefly described next.

<u>Basic analog I/O experiments:</u>

The first DAQ experience with analog I/O is executed through the design of an experiment to estimate the value of an unknown resistor. Since students already received enough experience with LabVIEW programming and well versed with fundamentals of electricity and electronics, they are provided with minimal instruction. With some guidance, most students come up with a setup similar to the one shown in Figure 3.

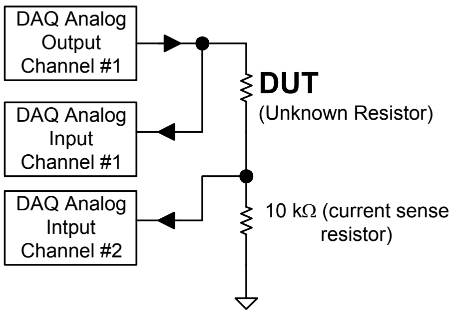
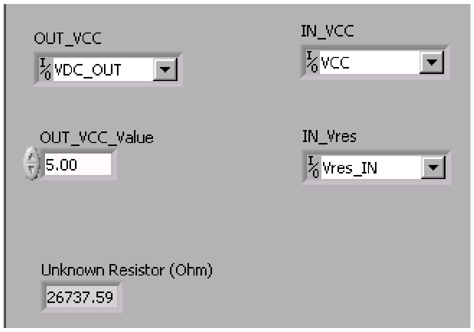


Figure 3 DAQ setup for measuring unknown resistor.



OUT_VCC: VDC_OUT

IN_VCC: VCC

OUT_VCC_Value: 5.00

IN_Vres: Vres_IN

Unknown Resistor (Ohm): 26737.59

Figure 4 Front panel for measuring unknown resistor.

The corresponding front panel and block diagram are shown in Figures 4 and 5, respectively. This simple exercise uses one analog output and two analog input channels; and the concept of timing of sampling among the inputs and output channels are introduced through the use of a sequence structure.

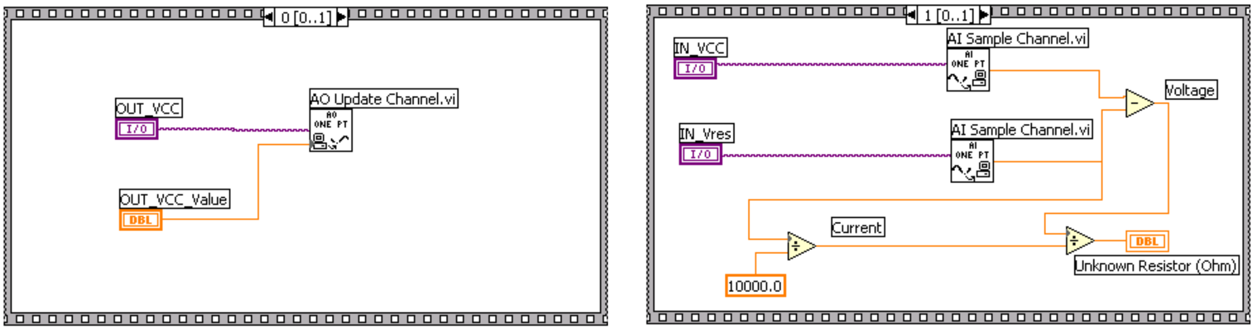


Figure 5 Block diagram for measuring unknown resistor.

Typically, a second experiment dealing with basic analog I/O is carried out before delving into continuous analog I/O. One-half of the class design an experimental setup to obtain the current-voltage characteristics of two-terminal semiconductors devices, whereas the other half design a setup for measuring frequency response of simple passive filters. The most common setup for the semiconductor characterization developed by students is similar to the one shown in Figure 6. The front panel and block diagrams for both experiments are shown in Figures 7 and 8, respectively. In most cases, a good bit of time is spent in updating the software to be able to measure I-V characteristics of multiple devices (e.g., LED, switching diode, power diode, and zener diode) or to measure frequency response of filters with various network topologies.

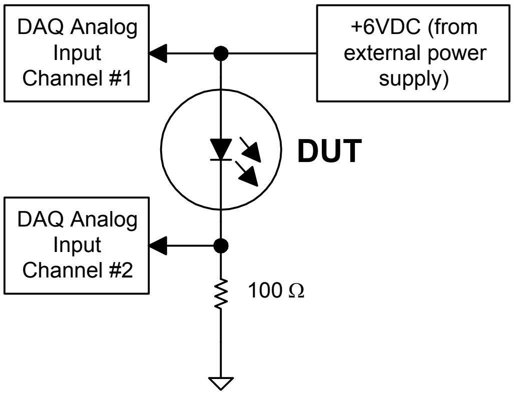


Figure 6 DAQ-setup for measuring current-voltage characteristics of two-terminal semiconductor devices.

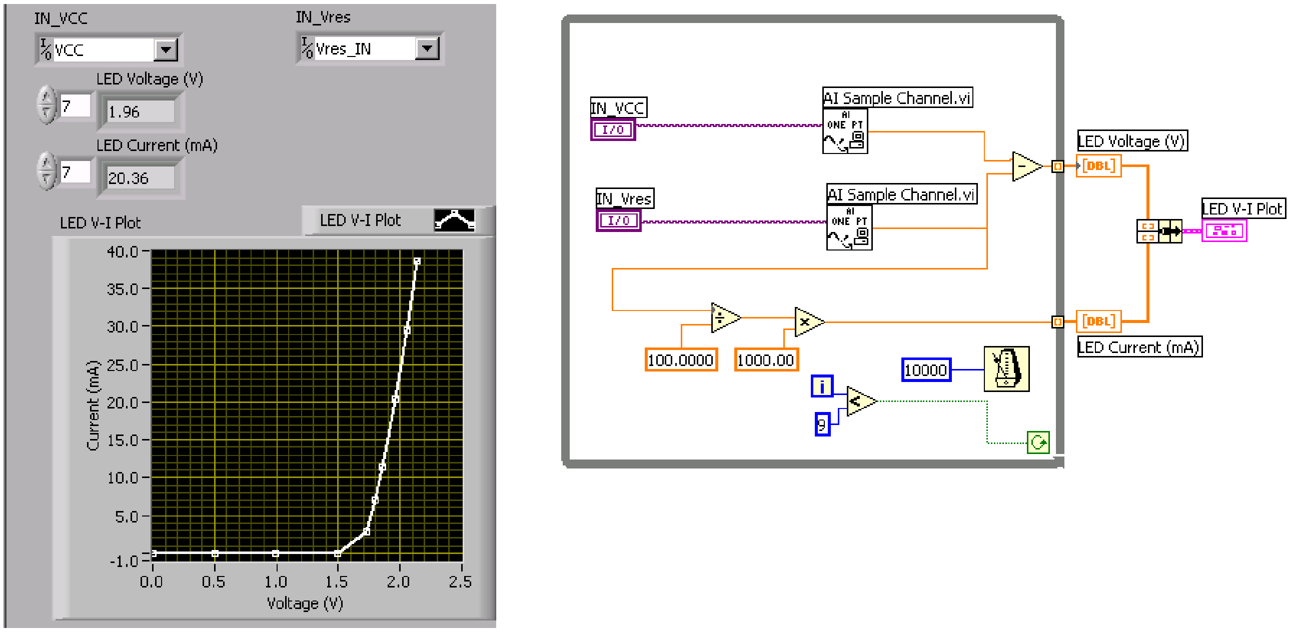


Figure 7 Front panel and block diagram for measuring current-voltage characteristics of two-terminal semiconductor devices.

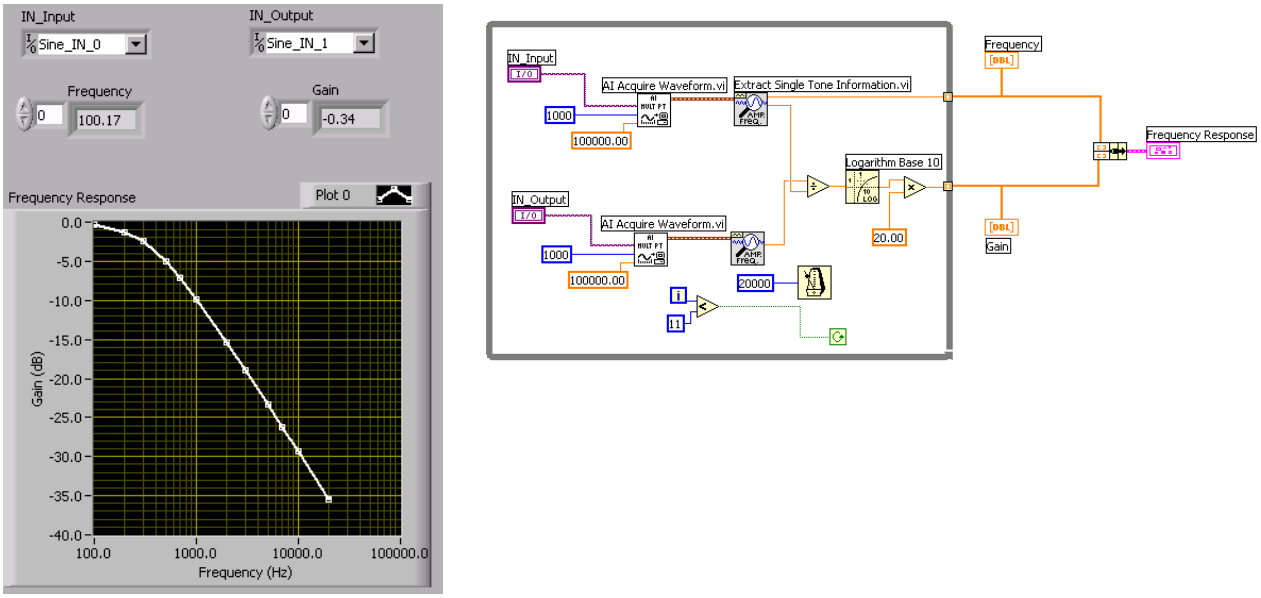


Figure 8 Front panel and block diagram for measuring frequency response of passive filters.

<u>ON/OFF control experiment:</u>

One of the experiments used to introduce the concept of ON/OFF control is the design of a temperature control system[15,16]. Students first design a temperature control system for a reference temperature of 55°C using an IC temperature sensor (LM35CAZ) and other discrete components as shown in Figure 9. On the first try, most student groups do not incorporate any hysteresis into the design; and they learn the need for hysteresis to be included in the control mechanism the hard way (by experimentally observing erratic switching of the MOSFET). Once a hysteresis of about 5^{o}C is added, the design is thoroughly tested against ambient as well changing load conditions. The concept of system time-constant is introduced at this stage. Figure 10(a) shows the amplified temperature signal (1 V /div with 10^{o}C/V scale) and the gate-to-source voltage of the MOSFET (5 V/div). The circuit ran into switching noise problem every time the MOSFET was turned off. With some guidance, students were able to solve this problem by placing an ultrafast diode across the heating element to provide a path for the inductive turn-off energy to dissipate (the heating element was after all not purely resistive!).

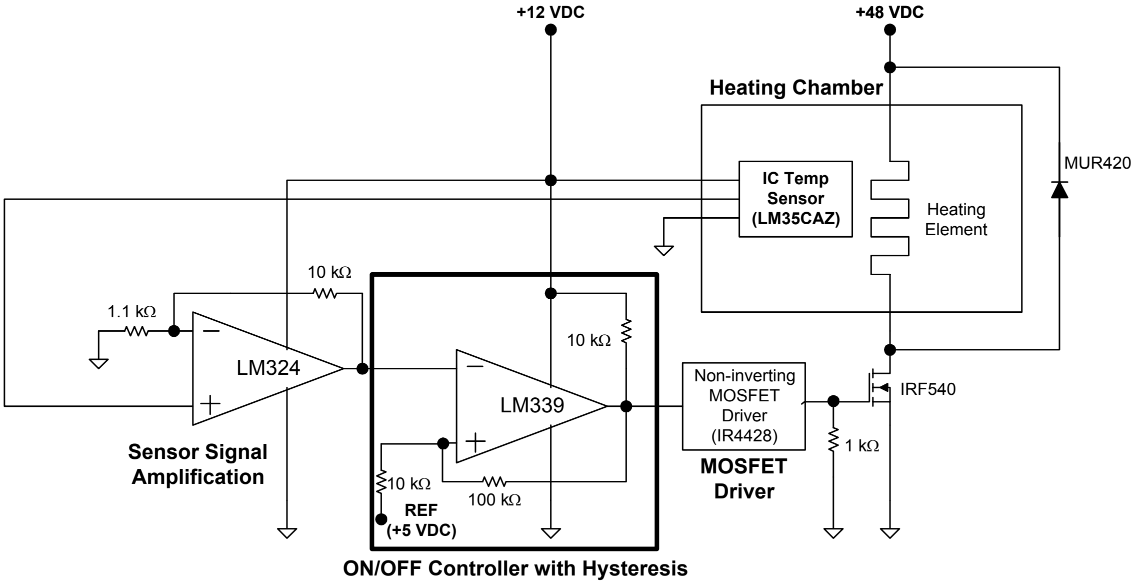
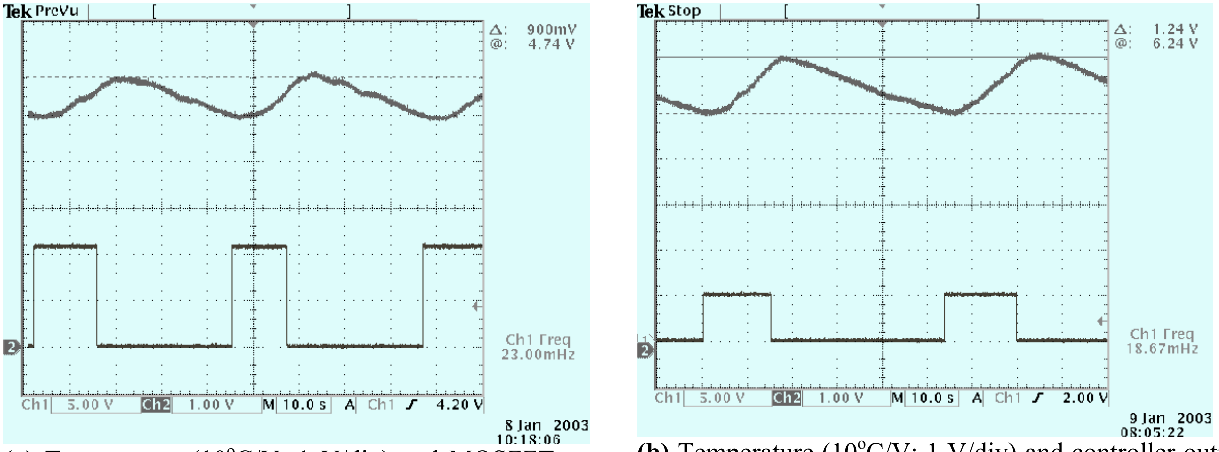


Figure 9 Discrete ON/OFF controller implementation for a heating chamber.



(a) Temperature (10^{o}C/V; 1 V/div) and MOSFET gate-to-source voltage (5 V/div) for discrete implementation.

(b) Temperature (10^{o}C/V; 1 V/div) and controller output via digital output channel (5 V/div) for LabVIEW implementation.

Figure 10 Recorded oscilloscope waveforms for temperature control system.

Next, the ON/OFF controller with hysteresis was implemented in LabVIEW and the DAQ board was used to input the amplified temperature signal and output the control signal to the MOSFET driver, as shown in Figure 11. Typical student-developed front panel and block diagram for implementing the controller is shown in Figure 12. The block diagram includes while-loop, case structures, analog input, digital output, array indexing, and the use of a local variable. Figure 10(b) shows amplified temperature signal in and control signal out of the DAQ board for the software controller as measured by an oscilloscope.

Students undertook a qualitative performance comparison analysis for the temperature control system. The measured temperature hysteresis in the software-controlled system was slightly higher than that of the discrete controller. The effects of sampling and I/O delays were related to physical measurement at this stage.

Instrument control application:

One of the experiments used to introduce the concepts of instrument control is the development of an automated test setup for measuring the speed versus armature voltage characteristics of a permanent magnet dc motor. The general setup is shown in Figure 13. In this specific example, all instruments are controlled via GPIB bus; however, the course addresses instrument control via RS-232 interfaces as well.

The 24 V dc motor with a 12.5:1 gearhead is fed by a GPIB controlled power supply, and the applied voltage is measured via a GPIB controlled digital multimeter. The speed of the motor is sensed through a shaft-mounted incremental encoder with 100 pulses/revolution. The digital speed information is fed into one of two counters available on the DAQ card. An appropriate interfacing and filtering circuit was added in order to feed the encoder output to the counter input. A LabVIEW program was written for generating the speed versus armature voltage characteristics. Figure 14 shows a typical student-generated front panel and the corresponding block diagram. For this specific example, LabVIEW-supplied instrument drivers were used to write to and read from the instruments. However, design of custom instrument drivers[17] based on manufacturer's listing of GPIB and RS-232 commands is also covered in this course.

Student-initiated laboratory projects:

The last four weeks of the class are dedicated to the final projects carried out by students in a group of two. This is when the fun starts. Early in the semester, students develop project topics with appropriate feedback/guidance from the instructor. A feasibility report is required of each group by the eighth week of the fifteen-week semester. The feasibility study is quite detailed as it requires preliminary ideas supported by circuit schematics, parts list, LabVIEW program flow chart, and project completion schedule. Students are in charge of selecting the necessary sensors, transducers, and actuators. If a part needs to be purchased, students are responsible for selecting a vendor and obtaining the price quote. A minimum of four sensors/actuators and two computer-controlled instruments are required to be part of any project. Students also use the reasonably well-equipped departmental shop for fabrication and metal/wood work to support their projects. A formal presentation and a final report are due at the last lab meeting. Some of the projects successfully completed by students are: liquid flow and temperature control system, motor speed control system, 3-phase power consumption and power quality monitoring system, pressure control system, simulated manufacturing system, and wireless data logging system.

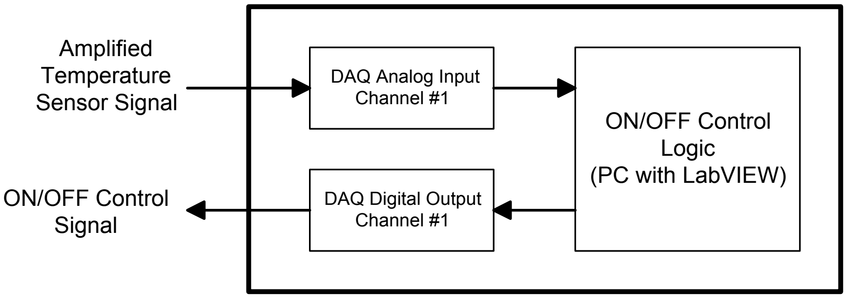
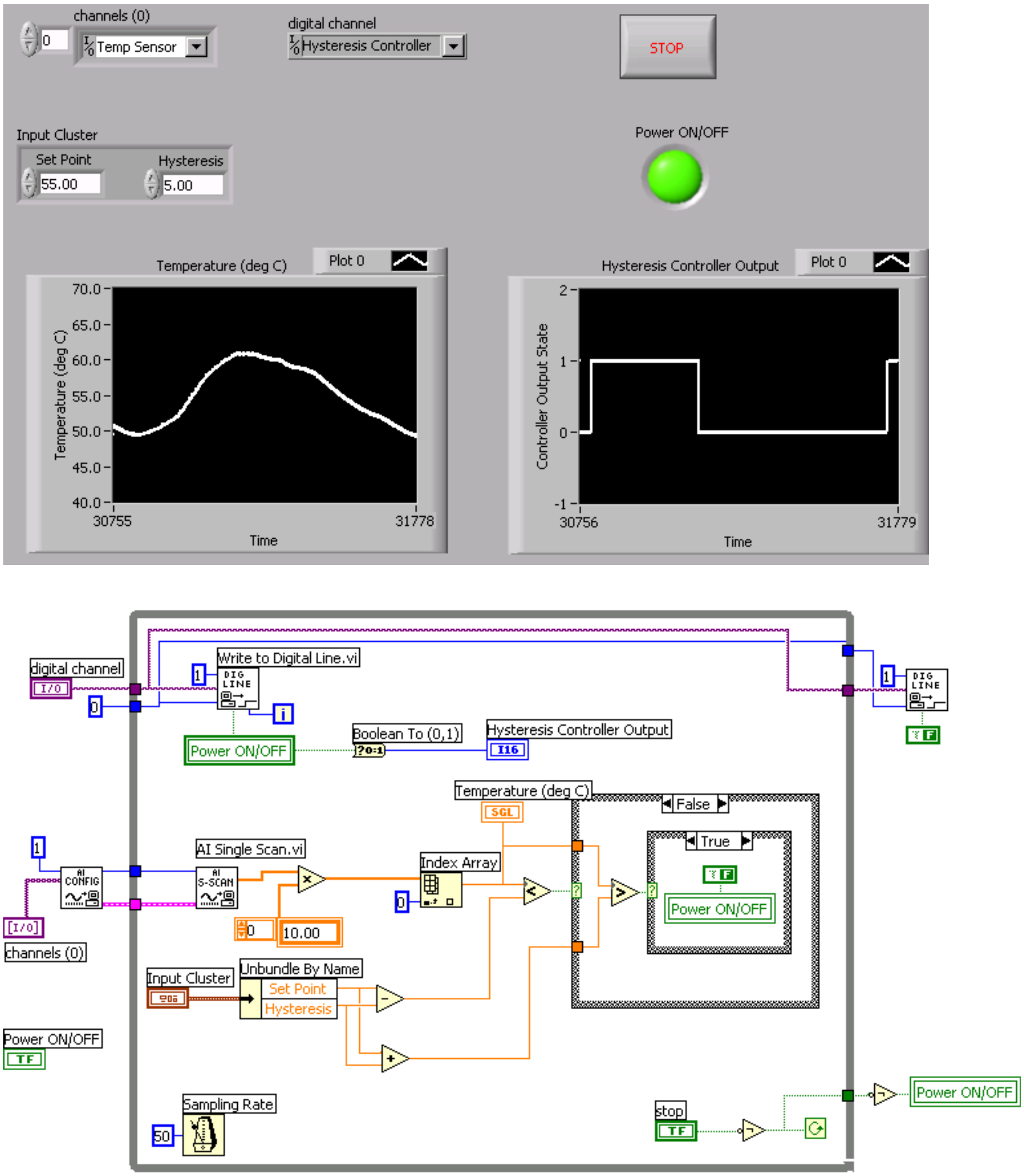


Figure 11 DAQ-based ON/OFF controller implementation for a heating chamber.


channels (0): 0, Temp Sensor

digital channel: Hysteresis Controller

Input Cluster
Set Point: 55.00
Hysteresis: 5.00

Figure 12 Front panel and block diagram for ON/OFF controller with hysteresis.

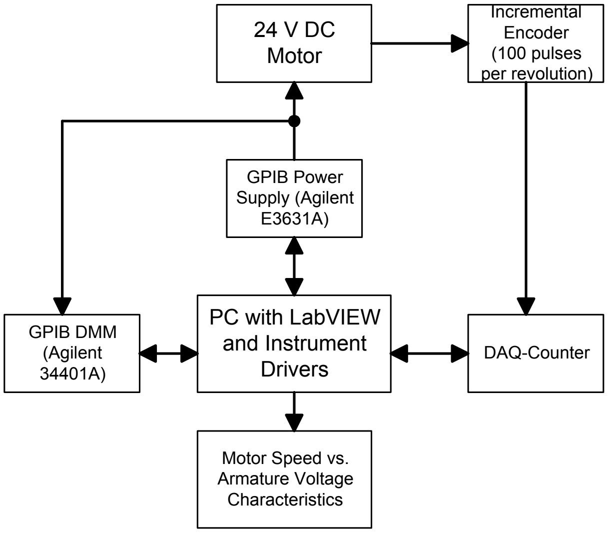
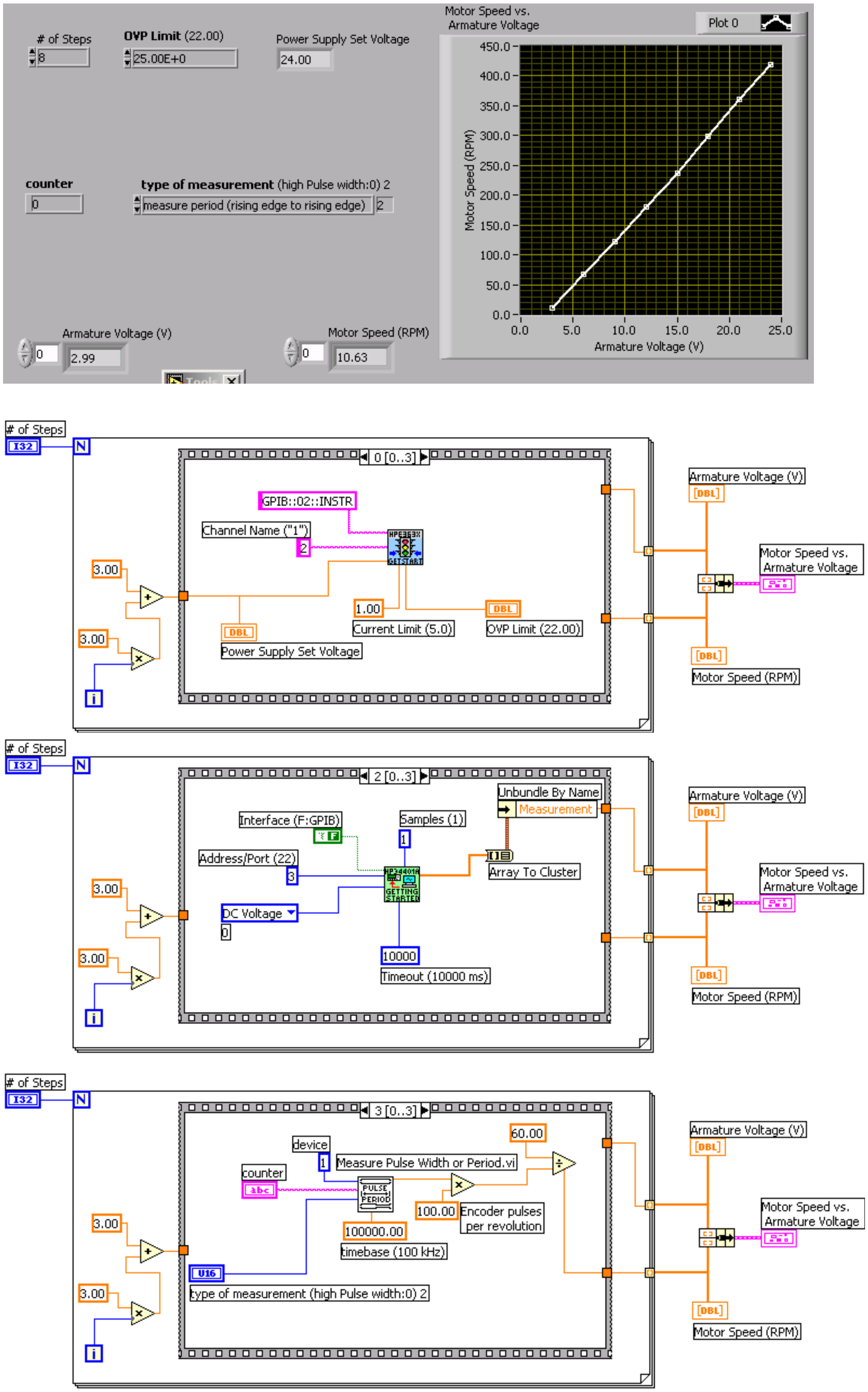


Figure 13 Automated motor speed vs. voltage characteristics measurement using GPIB instrument control.

Student Feedback

Quantitative analysis of student feedback is not reportable at this stage. However, majority of students were pleased with the course structure. Qualitative feedback from students is presented below through their comments.

- ✓ *Liked working with software and hardware integration*
- ✓ *Enjoyed working with partner*
- ✓ *Applying classroom knowledge to real-world examples was interesting*
- ✓ *Great to have specification-based project development experience*
- ✓ *Very thorough, easy to follow LabVIEW programming exercises at the beginning of the semester got me a great start*
- ✓ *Just getting to do a self-developed lab project was fun*
- ✓ *Very interesting course……making me lean towards computer-based automation career*
- ✓ *I found the course challenging and interesting*
- ➢ *Reliance on partner was a problem*
- ➢ *Writing lab reports was time consuming*
- ➢ *Include a little more structured learning environment*
- ➢ *Lab instructions are sometimes hard to understand*
- ➢ *Got a little bored when the class got slow……when people were struggling with what I understood*
- ➢ *A little more time dedicated to interface electronics design would be helpful*
- ➢ *Include some biomedical measurements application*



\# of Steps 8

OVP Limit (22.00) 25.00E+0

Power Supply Set Voltage 24.00

counter 0

type of measurement (high Pulse width:0) 2 measure period (rising edge to rising edge) 2

Armature Voltage (V) 0 2.99

Motor Speed (RPM) 0 10.63

Figure 14 Front panel and block diagram for automated motor characterization using instrument control.

Summary

Experience with the development of an instrumentation and data acquisition course embedding problem-based learning is presented. A few students struggled at the beginning of the semester, as this was their first experience with problem-based learning. It was also observed that many students had not had to design, debug and test a system that had multiple functional blocks in previous courses. The majority of students had difficulty breaking the design into functional modules and designing and testing them separately before putting them together. Improving student competence in this area will be incorporated at the next offering of this course. On the positive note, project-oriented nature of the course was much appreciated by the students. Overall, the experience has been very rewarding and challenging. More assessment data need to be gathered to ensure that the stated learning and teaching objectives are met

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BISWAJIT RAY
Biswajit Ray is currently with the Electrical & Electronics Engineering Technology program at the Bloomsburg University of Pennsylvania. Previously, he was with the Department of Electrical & Computer Engineering at the University of Puerto Rico – Mayaguez Campus, and EMS Technologies, Nocross, GA.