Design and Implementation of a Three Course Sequence in Control Systems

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Abstract

The Control Systems Engineering Technology program at Texas A&M University-Corpus Christi (A&M-CC) has a three-course sequence consisting of Principles of Measurements, Control Systems I, and Control Systems II. In fall of 2000, a committee of seven industry professionals was formed to help the faculty in the design and implementation of this sequence. This paper presents the final recommendations of the committee, discusses the development and implementation of the three courses, and describes the laboratory being developed with state-of-the-art instruments to support the sequence. The laboratory provides several capabilities, including internet-based experimentation, data acquisition, process variable measurements, control system modeling and design, sensor technology applications, and signal processing.

Introduction

At Texas A&M University-Corpus Christi, we are in the final phases of implementing a B.S. degree program in Control Systems Engineering Technology (CSET). The CSET curriculum has a three-course sequence consisting of Principles of Measurements, Control Systems I, and Control Systems II. The purpose of this sequence is to produce graduates that have a solid knowledge of control concepts, techniques, and applications. In fall of 2000, a committee of seven industry professionals, representing five companies, was formed to help the faculty in the design and implementation of the sequence. After several meetings, the Controls Sequence Committee (CSC) recommended that the three-course sequence should address a variety of instrumentation and control topics, including the following (not necessarily in this order): Measuring devices; various sensor types and characteristics (temperature, level, pressure, flow, force, displacement, etc.); selection of sensors; analog and digital signal conditioning, display of data; electronic devices; open and closed-loop control; controller design; process characteristics; digital controllers; modes of control; Laplace transform applications; control-loop characteristics; analog and digital controllers; controller design; controller mode selection; controller tuning procedures; distributed control systems; supervisory control; networks (local area networks, fieldbus, protocols, etc.); data transmission; gain and phase margins; stability; understanding of a complete control system; analyzers; media. The rest of this paper describes the implementation of the individual courses and presents the laboratory being developed to support them.

Course Development and Implementation

The CSC divided the topics among the three courses of the sequence in such a way that teaching and learning takes into consideration the proper prerequisite knowledge. The following paragraphs describe the contents of the courses as they were implemented. More details may be found at http://www.sci.tamucc.edu/~entc/BachnakPage.html.

Developing and teaching Principles of Measurements

This course was developed and offered for the first time in spring semester 2001. It is a four-credit hour course with a weekly laboratory of three hours. Topics covered include fundamental principles and methods of measurements and control; characteristics of sensors and transducers; electronic devices; signal conditioning; and flow, temperature, pressure, force, level, and motion measurements. Two textbooks were used according to the weekly schedule of Table 1 [1, 2]. The course outcomes, as stated in the syllabus, are as follows.

At successful completion of this course, students will be able to:

- Model a feedback control system
- Use common semiconductor components/devices such as transistors, diodes, voltage regulators, waveform generators, etc.
- State the principles of measuring devices and describe how they work
- Identify linear and nonlinear components and systems
- Design and analyze op-amp and signal conditioning circuits
- Design and analyze analog-to-digital converter circuits
- Design and analyze digital-to-analog converter circuits
- Describe various techniques/methods for measuring temperature, level, flow, pressure, force, displacement, and motion, and
- Design and analyze sensor-based circuits for measurement and control.

Table 1. Weekly schedule of Principles of Measurements

Week	Topics/ Activities
1	Course requirements/ Introduction to measurements and control
2	Diode circuits
3	Transistor fundamentals
4	JFETs, voltage regulators, comparators, waveform generators
5	Common elements of system components
6	Measuring instrument characteristics
7	Op-Amp circuits
8	Signal conditioning
9	Data sampling and conversion
10	Position, motion and force measurements
11	Temperature and flow measurement
12	Pressure and level measurement
13	Representation and display of data
14	Selecting sensors/ Sensor specifications
15	Project presentations and demos/ Project report due

The prerequisites for the course are two courses in DC and AC circuit analysis, a course in digital logic, and a course in C language programming. As shown in the weekly schedule, weeks 2 to 4 were used to cover semiconductor devices. The reason for this is that these devices are not currently covered anywhere else in the curriculum. In the laboratory, students performed a total of 10 experiments, ranging from simple circuits that illustrate the operation and characteristics of electronic devices (diode, transistor, op-amp, voltage regulator, etc.) to more complex circuits that address analog-to-digital and digital-to-analog conversion and ON/OFF control applications.

Developing and teaching Control Systems I

This course was developed and offered for the first time in fall semester 2001. It is a four-credit hour course with a weekly laboratory of three hours. Topics covered include control systems concepts; open and feedback control; Laplace transform; frequency response; control valves; electric motors; P, PI, and PID modes of control; analog and digital controllers; process characteristics; analysis of control systems; gain and phase margin; and stability. The prerequisites for this course are Principles of Measurements and Differential Equations. The course outcomes are stated as follows.

At successful completion of this course, students will be able to:

- Mathematically model a feedback control system
- Derive the transfer function of a control system
- Plot and interpret frequency responses
- Contrast quick-opening, linear, and equal percentage control valves
- Apply control valve sizing techniques to select the proper size for a given application
- Differentiate between induction, synchronous, and servo motors
- Differentiate between the various configurations of DC motors
- Analyze various stepping motor configurations
- Compare the characteristics and applications of the P, PI, PID modes of control
- Analyze and design analog controller circuits
- Analyze digital controllers
- Examine the characteristics of a number of processes, such as integral, first-order lag, and second-order lag and analyze operations of such systems, and
- Determine stability of control systems using Bode diagrams, Nyquist criterion, and the root locus method.

Two textbooks were used according to the weekly schedule of Table 2 [2, 3]. In the laboratory, students completed six exercises. One of these exercises illustrated the use of the Fluke wireless loggers for data acquisition. The other exercises demonstrated the analysis and design of control systems using MATLAB. This included plotting time domain responses, deriving transfer functions, graphing unit-step responses, computing rise-times, analyzing steady-state errors, plotting Bode diagrams for gain and phase margins calculations, using Nyquist plots for stability analysis, utilizing the root locus method for system design and parameter calculations.

Table 2. Weekly schedule of Control Systems I

Week	Topics/ Activities
1	Course requirements/ Basic Concepts and terminology
2	Types of control
3	System components
4	Laplace transform
5	Transfer function and frequency response
6	Control valve characteristics and sizing
7	AC and DC motors
8	Other types of motors
9	Modes of control
10	Analog and digital controllers/ Handout project
11	Process characteristics/ Project proposals due
12	Process characteristics/ Start project
13	Bode diagrams and stability
14	Nyquist stability criterion and root locus
15	Project presentations and demos/ Report due

Developing and teaching Control Systems II

This course is being offered for the first time in spring semester 2002. It is a continuation of Control Systems I and is a four-credit hour course with a weekly laboratory of three hours. Topics include control systems design; controller mode selection; control loop tuning; data acquisition systems; distributed control systems; supervisory control; data transmission; networks; analysis and specification of complete control systems. The course outcomes are stated as follows.

At successful completion of this course, students will be able to:

- Apply control loop tuning methods
- Apply control concepts to the operation of automatic control systems
- Describe the use and operation of distributed control systems (DCS) and supervisory control for the control of manufacturing and processing systems
- Design and develop data acquisition systems for process and industrial applications
- Apply the concepts of fuzzy logic to control applications
- Characterize the media used to communicate control loop signals and describe the use of fieldbus for process control, and
- Use LabVIEW for measurements, virtual instrumentation, and instrument control programming.

Several textbooks are used to teach this course, according to the weekly schedule of Table 3 [2-7]. The laboratory experiments will include the use of MATLAB and LabVIEW and several hardware components, including a Process Control Workshop by Feedback, Inc., data acquisition systems by National Instruments, and a level/flow process control system by Feedback, Inc. More details about the equipment are given in the following section.

Table 3. Weekly schedule of Control Systems II

Week	Topics/ Activities
1	Course requirements/ Cascaded systems
2	Ratio control/ Feedforward control
3	Multi-variable process control/ Override and selective control
4	Self-tuning adaptive controllers/ Tuning of feedback controllers
5	Controller design/ Design of multi-loop control systems
6	Fuzzy logic controllers/ Supervisory control
7	Networks/ Fieldbus for process control/ DCS
8	Data acquisition
9	Data acquisition systems
10	Data acquisition systems/ Work on project
11	Work on project
12	Pneumatic control/ Analytical devices: analyzers
13	First project presentations/ Work on project
14	Work on project
15	Final project presentations and demos/ Report due

The Laboratory

Identifying the equipment and software needed to support the controls sequence was a major task. The listservs of the Engineering Technology Division and the Instrumentation Division of ASEE were surveyed for this purpose. The feedback from these listservs showed that MATLAB/SIMULINK is the most widely used software package at U.S. institutions for simulating, analyzing, and designing control systems [8-15]. Another software, LabVIEW, is the most popular program for virtual instrumentation programming [16-19]. These two programs were selected as the main software for the laboratory.

The Data Acquisition and Control Laboratory[1]also consists of the following major equipment: desktop computer stations, data acquisition systems, level and flow measurement system, process control system, wireless data loggers, calibrators, and a variety of test equipment. Topic areas that the laboratory supports include sensors and their applications, signal conditioning, calibration, open- and closed-loop control, process characteristics, data acquisition, system modeling and analysis, system design, control mode selection, feedback control applications, controller design, system response, loop gain and stability, controller tuning, data analysis and representation, image and signal processing, algorithm development, automation, system programming, and internet-based experimentation. Our goal is to integrate theory, software simulation, and hands-on activities to prepare graduates to work as control technologists for a variety of industries, especially processing and manufacturing plants. Figure 1 shows one of the laboratory stations. The following paragraphs briefly describe the features and capabilities of the major components.

[1] This project is funded in part by the Air Force Research Office, award # F49620-01-1-0557

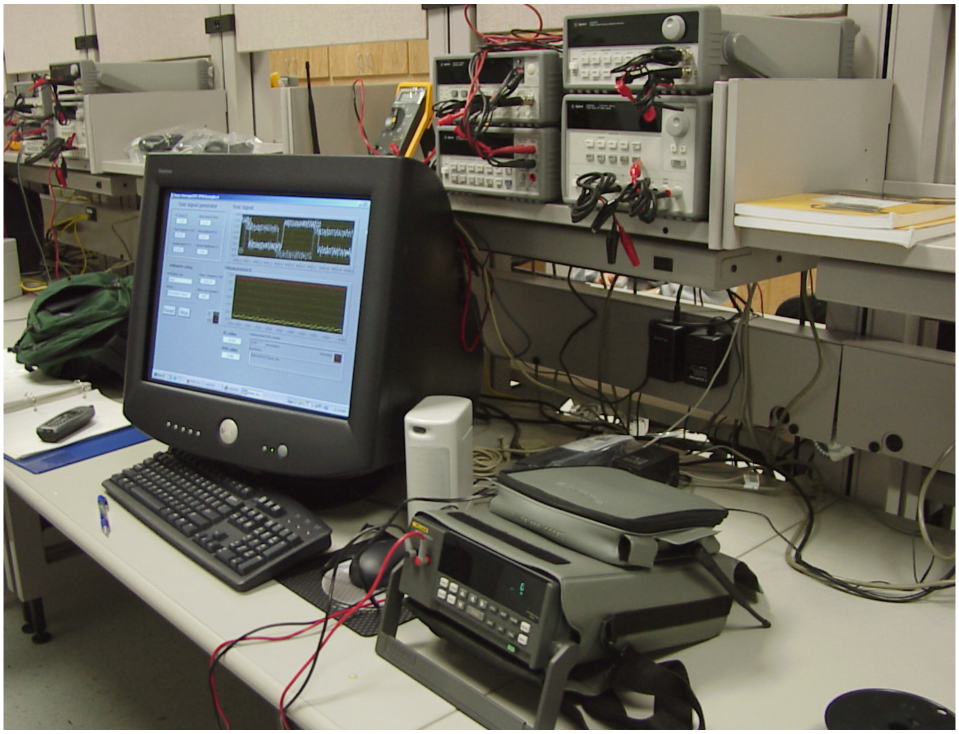

Fig. 1 One of the stations in the Data Acquisition and Control Laboratory

Data acquisition systems

Each system consists of several components, including a data acquisition board (NI PCI-MIO-16E-4), a 32-channel analog input module (NI SCXI-1102C), a 6-channel analog output module (NI SCXI-1124), mounting terminal block (NI SCXI-1325), isothermal terminal block (NI SCXI-1303), and a 4-slot chassis (NI SCXI-1000). These components will be integrated into real-time measurement units that interface to desktop computers and process control equipment. The National Instruments (NI) Software Solutions Department license, which consists of LabVIEW 6i (Laboratory Virtual Instrument Engineering Workbench), control and simulation toolkit, Internet, Gmath, and signal processing suites, is available for programming these units. LabVIEW 6i offers Internet ready capabilities and supports data acquisition tasks, virtual instrumentation functions, and process monitoring.

MATLAB/SIMULINK and associated toolboxes

MATLAB is one of the most popular programming languages used worldwide for a range of computing tasks in engineering and science. The package available in the laboratory consists of MATLAB 6, SIMULINK 4, Data Acquisition Toolbox, Signal Processing Toolbox, Control Systems Toolbox, Instrument Control Toolbox, Image Processing Toolbox, MATLAB C/C++ Graphics Library, MATLAB C/C++ Math Library, MATLAB Compiler, and Symbolic Math. These tools offer capabilities in data acquisition, data analysis and exploration, control system design, digital signal processing, image processing, data visualization, algorithm prototyping, modeling and simulation, and application development. Built-in interfaces allow quick access to instruments, files, and external databases. A serial port communication interface offers communication with external instruments and the GUI design tools allow developing interfaces and displays. SIMULINK is an interactive tool for modeling, simulating, and analyzing dynamic systems. It enables building graphical block diagrams, simulating dynamic systems, evaluating system performance, and refining control system designs. A MATLAB Student version that has most of the full version capabilities at a reasonable price (around $100.00) is available for students to buy online or from the University bookstore.

Level/flow process control system

This system, by Feedback, offers level and flow measurements and display (38-001 Level and Flow Process Control Trainer, including 38-100 Level/flow basic plant, 38-200 Process Interface, 38-300 Process Controller, 38-400 Level Sensor Pack, 38-420 Flow Sensor Pack, 38-490 Digital Display Module, 38-900 Discovery Data Acquisition Curriculum Software). Temperature, displacement, pressure, and pH sensors and transducers will be added to provide input data to both LabVIEW and MATLAB through the data acquisition systems.

Process control workshop

This system, by Feedback, offers real-time control via MATLAB and SIMULINK (37-001 Process Control Workshop using MATLAB). This allows using the system for advanced control concepts and research-oriented projects. The process is represented by a heating element controlled by a thyristor circuit that feeds heat into the airstream circulated by an axial fan along a polypropylene tube. A thyristor detector may be placed at one of three points along the tube, sensing the temperature at that point. The volume of airflow is controlled by varying the speed of the fan via a potentiometer. The system allows experimentation with distance and velocity lag, calibration, proportional control, disturbance and system response, and frequency response. MATLAB and its associated toolboxes can be used for real-time digital control, mathematical modeling, transfer function and state-space representation, PID control, and linear quadratic control.

Wireless logging system

The wireless logging system, by Fluke, consists of two wireless data loggers (Hydra 900 MHz wireless system 2625A/WL) communicating to a base station consisting of a wireless modem and windows application software (2625A/WL-700). The software allows a variety of functions, including instrument setup, data collection, creating real time trend graphs, and other data acquisition tasks. The wireless data loggers use spread spectrum radio transmission to reliably send data with a high degree of immunity to electrical noise and interference. Range of transmission may be up to 120 m inside buildings and to over 300 m line of sight. The base station can support up to 20 remote data loggers. The software allows exporting data in real time to Lotus 1, 2, 3, and Excel by using a Dynamic Data Exchange (DDE) link.

PC workstations

The PC workstations are interfaced to the process technology equipment through the data acquisition systems. A direct connection exists between one of the PCs and the process control workshop. Each workstation has a Pentium IV processor, 1.7 GHz, 256 MB RDRAM, 21" Display, two 40 GB hard drives, 1.44 MB 3.5" floppy drive, Ethernet 10/100, 8/4/32X CD-RW & 8X DVD-ROM, zip 250 drive. A networked laser printer is also available in the lab.

Test equipment

Test equipment that supports the laboratory includes thermocouple calibrators (Fluke 714 thermocouple calibrators), digital thermometers (Fluke 51-2 digital thermometer), temperature calibrators (Fluke 724 temperature calibrator), scopemeters (Fluke 123), hand-held meters (Fluke 73), multi-meters (Agilent 34401A), function generators (Agilent 33120A), power supplies (Agilent E3631A), and frequency counters (Agilent 53131A).

The integrated laboratory environment is capable of supporting a wide variety of experiments that can be performed during regular lab hours or through remote access using LabVIEW and MATLAB. Access through MATLAB is limited to computers connected to the department network, however, access through LabVIEW will be available from anywhere there is an Internet connection. Students will be able to acquire real-time data that can be analyzed and manipulated by using the Student Edition of MATLAB. Laboratory experiments that address several concepts and principles are being developed and implemented at the time of this submission. Our goal is to implement internet-based experimentation, which will eventually lead to offering technical courses online. This is expected to increase the productivity of both faculty and students. Students will be able to access virtual instruments from their Web browser and run experiments with built-in Internet tools. They will be able to receive and download live data to their own workstations where they can perform further analysis and processing.

Conclusion

The three-course sequence described in this paper offer students in the CSET program a solid knowledge in measurement principles and control systems analysis and design. The newly equipped laboratory provides teaching and research capabilities in several science and engineering areas, including sensor technology, data acquisition, control system design, system modeling, signal processing, image processing, and data visualization. Future plans include the implementation of Internet-based measurement and experimentation to facilitate offering technical courses online.

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Biography

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