2006-37: AUTOMATION LABORATORY DEVELOPMENT ENHANCES STUDENT LEARNING

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Automation Laboratory Development Provides Enhanced Student Learning

Abstract

This paper describes experiments and course content associated with an upgraded course in Automated Production Systems. The objective of the Automation Laboratory is to provide experiential learning opportunities, while at the same time providing exposure to real world industrial automation equipment and tools. Included in the paper is a description of the content and objectives of each laboratory session and a description of the hardware platforms used to accomplish the laboratory exercises.

Introduction

The University of Tennessee at Martin offers an ABET-accredited Bachelor of Science in Engineering degree with concentrations in civil, electrical, industrial, and mechanical disciplines. A three course sequence involving various aspects of control technology is offered (Table 1). Some of the courses are required of all engineering students, regardless of discipline, while others are available on an elective basis.

Table 1. Courses in Controls Sequence versus Degree Requirements

Courses	Disciplines			
	Civil	Electrical	Industrial	Mechanical
ENGR 317: Instrumentation and Experimental Methods	Required	Required	Required	Required
ENGR 462: Linear Control Systems Design	Not taken	Required	Required	Required
ENGR 475: Automated Production Systems	Not taken	Elective	Required	Elective taken by most students

The first course, ENGR 317: Instrumentation and Experimental Methods, emphasizes sensors and measurement techniques used in experiments and controls applications. It is the only course of the three required of all engineering majors and helps address ABET outcomes associated with experiment design. The second course, ENGR 462: Linear Control Systems Design, emphasizes the concepts and methods used in the design and analysis of systems that use continuous feedback control. This course is mathematically intensive and is similar to that found in most undergraduate degree programs. The course does not include a lab, but incorporates assignments that require students to implant control algorithms into motor control experiments designed by Quanser[1]. The third course, ENGR 475: Automated Production Systems, focuses on production and manufacturing applications that involve discrete or batch processes. This course is not mathematically intensive and is more hands-on than the course in Linear Control System Design.

Much of the content contained in the Automated Production Systems course is traditionally referred to as Industrial Controls. An Industrial Controls course is not as common in

undergraduate engineering degree programs as is a course on continuous feedback control. Industrial control courses are, however, found in virtually all engineering technology curriculums[2]. The lack of an industrial controls course in an engineering curriculum is somewhat surprising, since many processes and products use the methods taught in such a course. As pointed out by Clough[3], discrete and batch process control is often a missing link in an undergraduate engineering student's controls education. In fact, the first technical skill listed in the Society of Manufacturing Engineer's list of educational competency gaps is Manufacturing Process Control[4]. Members of the UT Martin Industrial Advisory Committee, who come principally from manufacturing backgrounds, have consistently emphasized the importance of this course. Although industrial controls courses are not common in engineering curriculum, they do exist, and Bachnak[5] describes a similar three course sequence.

The focus of this paper is on the laboratory used with the Automated Production Processes course. This three semester hour course consists of two one-hour lectures and a three-hour lab each week. All industrial discipline students and most mechanical engineering students take this course, while electrical engineering students may take the course as an elective. The objectives of the course are to: 1) provide students with exposure to the methods used to automate discrete or batch manufacturing or industrial processes, and 2) expose students to industrial hardware and software used in automated processes. Meeting these objectives requires that students study a variety of logic implementation and programming techniques and learn to develop automation systems using standard industrial control components. The laboratory component of this course provides an important experiential learning environment that permits students to gain hands-on experience using concepts and methods presented in the lectures. The Automation Lab is structured to handle eight to ten students per laboratory section. This allows adequate interaction between the instructor and students. A larger lab section size would decrease student access to the instructor and require more space and lab equipment.

In 2000, an effort was initiated to modernize and add a wider variety of experiments to the Automation Laboratory. This development activity was completed in 2005 when the laboratory was moved to a larger room. The approach used to modernize the laboratory was to have students redesign and upgrade existing equipment as part of their senior capstone projects. This approach kept the cost low and provided enhanced learning opportunities for the students developing the experiments. The students developing the projects gained valuable real world experience in the design and integration of automated equipment. Additionally, requiring that the students integrate the components and wiring into neat and professional looking enclosures provided the students insight into the skills and time required by industrial electricians who maintain equipment in manufacturing plants. Funding for the modernization was provided by the university and industrial supporters.

Content

The development of an automated process involves the integration of sensors, actuators, and controllers to change or maintain the state of a plant or process. The Automation Laboratory contains activities designed to teach students the basic principles associated with some of the most common actuators and controllers. Although sensors are used in the lab exercises and some instruction is provided, detailed instruction on common electrical and mechanical sensors is

provided in the required course on Instrumentation and Experimental Methods. Actuation methods covered in the course include pneumatic and hydraulic actuators and motors. Controllers covered in the course include programmable logic controllers (PLCs), servomotor controllers, and robotic arm controllers.

Lab Experiences

Table 2 provides a list of laboratory experiences along with the number of three-hour lab sessions devoted to each during a 15-week semester. One session is dedicated to the midterm exam for the course. One session is frequently lost due to Thanksgiving or Fall or Spring Breaks, and one session is frequently lost at the end of the semester due to senior project presentations. Thus, Table 2 shows the typical number of three-hour lab sessions devoted to each topic for a 15-week semester.

Table 2. Automation Laboratory Experiences and Sessions

Exercise Topic	Number of Sessions
Safety Lecture	1
Component Show and Tell	1
Discrete PLC Machine Schematics	2
Discrete PLC Machine Programming	3
Process Control PLC Machine	1
Industrial Robot	3
Servomotor Controller	1

Safety Lecture Experience

In this first session students are given an overview of the automation lab along with a safety lecture that addresses general and specific safety issues related to the automation laboratory space and equipment. Acceptable practices and procedures are reviewed, and the students are provided with a handout that sums up the safety topics of interest. It is emphasized that the safety rules discussed are meant to complement university safety guidelines, not to replace them. A short quiz on the safety lecture is given.

Component Show and Tell Experience

In this session, the instructor and students pass around and discuss a variety of control system components as a preview of what they will encounter in the course lecture and the lab experiences. Air cylinders, line conditioning devices, flow regulators, and fittings are some of the pneumatic devices presented. Solenoid valves, spool valves, limit switches, proximity switches, control switches, mechanical and solid-state relays, contactors, and motor starters are some of the electrical components presented. Servomotors and stepper motors are also presented and described to the group. The importance of being able to identify components typically encountered on automation equipment is emphasized with respect to the upcoming lab experiences and to future encounters in industry.

Discrete PLC Machine Experiences

Students reverse engineer PLC-controlled machines and produce pneumatic and electrical schematics during the first two sessions. The instructor gives a demonstration and pointers on how to trace pneumatic and electrical circuits. The machine functions are recorded and state tables, showing all the machine input and output states, are constructed. Ladder logic is then designed and programmed into the PLCs via RS-Logix software, and the programs are debugged and demonstrated for inspection and credit. These discrete PLC activities typically span five weeks. Each student submits a report documenting his or her activities from initial notes to final successful program execution. The report contents must include, as a minimum, the pneumatic and electrical schematics, a complete state table, a hardcopy of the finalized ladder logic, an electronic copy of the finalized ladder logic, and a short narrative describing the machine, the reverse engineering process, machine and process documentation, and programming and debugging.

Process Control PLC Machine Demo Experience

Students are given a handout describing the process control PLC machine. The hardware and software are described and demonstrated by the instructor, and students operate the machine, thus exploring its operation. The analog interfacing of PLCs is emphasized and related to the course lecture.

Industrial Robot Lab Experiences

Students initially program the robot arm to move through four to six taught points of their choice. Using the teach pendant and the knowledge gained from the lecture sessions, a combination of linear- and joint-type moves are programmed. In two subsequent lab sessions, looping, branching, digital input/output, macros, and program pause and abort commands are added to the initial programs. In each of the sessions, students demonstrate their programs for credit. In the last of these sessions, a hardcopy of the students' final robot program is also turned in for credit.

Servomotor Controller Experience

Students are given a handout describing the servomotor control demonstrator. The hardware and software are described by the instructor, and students operate and make small modifications to the demonstration program, such as motor speed, distance traveled, and number of motion repetitions. The hardware and software limits are explained and demonstrated. The idea that the single axis of motion comprised by the bench represents an axis of a CNC machine tool or a linear robot joint is emphasized.

Relation of Automation Course Lecture Topics to Automation Lab Activities

Table 3 is a dateless version of a typical course schedule given to students at the start of a Fall semester. The lecture topics generally lead the lab activities in sequence and the sequence of topics is: general concepts, general hardware components, ladder logic, PLCs and their

interfacing, general robotics, robot programming, general CNC concepts, CNC machine hardware, and CNC programming. The course culminates in a comprehensive final exam.

Table 3. Automation Course and Automation Laboratory Schedule

Week	Lecture Topics	Lab Activities
1	Syllabus Introduction to Automation *(outside flexible manufacturing video)*	Overview of Lab and Lab Safety Lecture
2	Automation and Control Technologies Intro. to Hydraulic and Pneumatic Systems	Observe Components and PLC Assignments
3	Hydraulic and Pneumatic Control Valves Hydraulic and Pneumatic Schematics	PLC Machine Schematics
4	Electrical System Elements *(short motors video)* Introduction to PLCs	PLC Machine Schematics
5	Ladder Rung Logic PLC I/O Addresses, RSLogix Software	PLC Programming
6	PLC Timer Instructions PLC Timer Applications	PLC Programming
7	PLC Counter Instructions Analog to Digital Conversion	Midterm EXAM
8	PLC Logic and Math Instructions Intro. to Robotics *(outside robot video)*	PLC Programming
9	Jogging the Robot Programming the Robot: Motion Program Instructions	PLC Process Control Demo Lab and Robot Jogging
10	Robot Register and I/O Instructions Robot Branch Instructions	Robot Programming
11	Robot Timer and Program Control Instructions Robot Macro Instructions *(short robot video)*	Robot Programming
12	Intro. to CNC *(short CNC Video)* CNC Machine Feedback Devices	Robot Programming
13	*None – Thanksgiving*	*None – Thanksgiving*
14	CNC Programming *(outside CNC video)* CNC Drill and Mill Commands	Servomotor Demo Lab
15	Cutter Compensation Course Wrap-up and Review for Final Exam	Servomotor Programming

Tables 2 and 3 show that the number of lab sessions per experiential activity ranges from one to five, depending on the nature of the material being covered. Several videos are employed in the course to supplement the PowerPoint-based lectures. Lab handouts are provided to the students as needed. It is readily evident that very much material is covered in this course and there is essentially no slack in the scheduling of lectures, labs, and exams.

The nature, scope, and scheduling of the lab experiential activities has been described. A description of the lab equipment follows.

Lab Equipment

The Automation Lab contains six primary experiment platforms. Two of the experiments are used to reinforce principles associated with discrete (on/off) controls and use Programmable Logic Controllers (PLCs) with relay type inputs and outputs. These platforms (Figures 1 and 2) use pneumatic cylinders to pick and place objects using grippers. Both of these platforms were

Figure 1. Pneumatically operated gripper platform having four degrees of freedom.

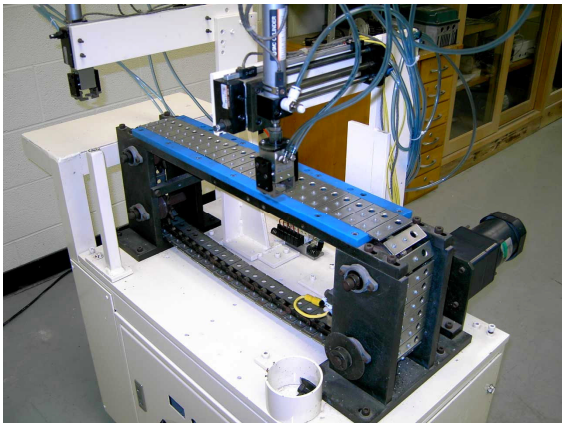

Figure 2. Pneumatically operated gripper and conveyor platform.

donated by Parker-Hannifin of Greenfield, TN. Each has been modified and equipped with a new Allen-Bradley PLC, solenoid valves, pneumatic tubing, etc. Figure 3 shows the interior of one of the control panels designed and fabricated by students.

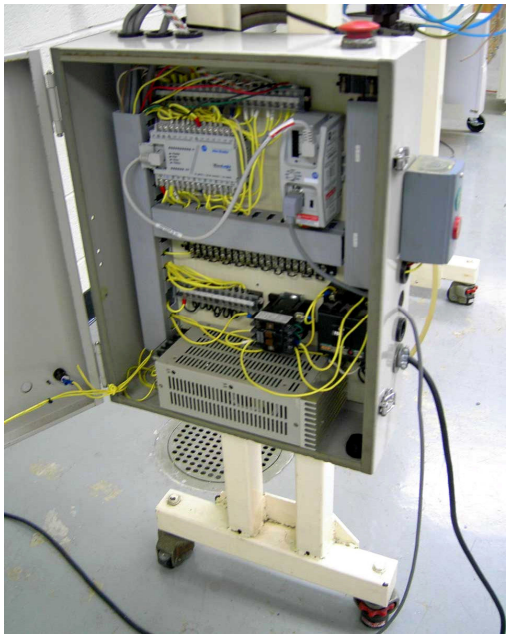

Figure 3. Interior of new control panel designed and fabricated by students.

Two additional experiment platforms (Figure 4) are used to reinforce principles associated with using PLCs with analog type inputs and outputs. These experiments simulate process control involving continuous control of flow rate, liquid levels, and temperatures. Both of these experiments had their origin in a National Science Foundation funded project that used personal computers as controllers. Student teams were used to modernize the platforms to include Allen-Bradley PLCs and PanelView 300s.

Figure 4. One of the platforms used to teach process control techniques.

Figure 5 shows the inside of one of the control panels and Figure 6 shows the panel display used to change temperature and liquid level control set points. All of the PLCs are programmed with Allen-Bradley RS-Logix software and the PanelVIEWs are programmed with Allen-Bradley PanelBuilder software.

Figure 5. Interior of Process Control Panel designed and fabricated by students.

Figure 6. Panel view screen used to change process parameters.

The fifth experiment platform (Figure 7) uses an Allen-Bradley servomotor and controller to position a table using a recirculating ball screw. The servomotor and controller were donated to the university by Goodyear Tire and Rubber Company of Union City, TN. The controller is programmed with Allen-Bradley GML Commander software, which was purchased with University grant funds.

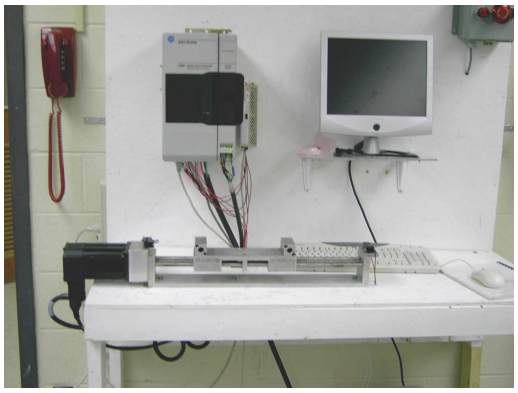

Figure 7. Servomotor control station designed and developed by students.

The sixth and final experiment platform is a Fanuc robotic arm (Figure 8) that can be used separately or integrated with one of the discrete PLC experiments. The digital inputs and outputs of the robot controller are brought out into a small plastic enclosure containing red LEDs and

Figure 8. Fanuc robotic arm and controller.

toggle switches. The red LEDs simulate outputs from the robot controller and the toggle switches are used to simulate external inputs to the robot controller.

Students in the Automation Lab

The students appreciate literally getting their hands on equipment that is representative of what they may encounter in industry. They also appreciate the differences between this lab and a typical engineering experimental lab. Some students are uncomfortable crawling around the machines at first, and others are not as adept at using a digital voltmeter as their peers. They do assist each other, as limited group work is permitted in the lab, and much confidence is gained in little time. Students are also typically enthused when seeing a machine do exactly what they program it to do, and for many students it sinks in quickly that the machine software will not fix their faulty logic for them. Some students will go above and beyond what is required and program the machines to perform more and more complex tasks than are requested.

Student Feedback

A recent (2004) graduate of the UT Martin program indicated, by telephone, that the automation course and laboratory were beneficial to him in his position at a local manufacturing firm, where he works directly with robots and PLCs. This graduate indicated that he had had experience with PLCs prior to taking the course and further indicated that the robotics material of the course yielded the most benefit for him in his career. However, the graduate did relate that the PLC material of the course would have benefited students who had no PLC experience prior to taking the course, in his opinion.

Another recent (2005) graduate indicated, by email, that her position at a manufacturing firm has required her to read electrical diagrams and schematics in ladder diagram form, troubleshoot electrical systems with a voltmeter, and perform end-of-line troubleshooting. She has recently been placed in charge of a newly-launched assembly line. This graduate has been selected to receive training to become a back-up engineer for in-house control panel testers, in part because of her experiences in the UT Martin automation course and lab. Working with such testers requires logic and programming skills, and there is also much Allen-Bradley equipment at the firm. This graduate is drawing on knowledge and experiences from the automation course and lab.

Although these are comments from only two students who are successful in their careers and are benefiting from the automation course and lab, the authors look forward to soliciting more feedback from former students. The authors are encouraged by this admittedly limited feedback, but also understand that a broad survey of graduates would be necessary to draw any statistically meaningful conclusions about how this course benefits former students in their careers.

Future Improvements to the Automation Lab

Currently each of the experiments used in the laboratory is standalone. As pointed out by Rehg[2] and Adam et al[6], the next generation of PLC laboratories should allow for the communication with system level controllers via networks. Networking the experiments in the lab to allow interaction between the different experiments is possible and would provide students with exposure to realistic problems that are similar to ones which they will likely experience in industry. However, instruction on networking concepts, protocols, and techniques would be

difficult to incorporate within the existing course and would require the offering of a more advanced elective.

Integrating the robot and one or both of the discrete PLC-based machines has been discussed as another way to bring more reality into the automation lab. Interfacing PLC machine and robot inputs and outputs and programming them to work in a coordinated manner would expose students to a layer of system complexity not currently available. This could be accomplished with a minimum of hardware and cost.

Having a second robot of the same (or similar) size as the current one would also enhance the lab activities in that students could gain experience in safely coordinating two robotic arms. Combining some grant proposal writing and contacting used robot vendors could be a way to pursue this, barring another generous donation from industry.

Having students design and implement a workcell for the existing industrial robot that performs a specific task(s) would be yet another way to expand the automation lab capabilities on a limited budget, just as past expansions based on student projects have been.

All of these potential improvements to the automation lab have the common theme of systems integration, which is a very important part of automated production systems, and are being given consideration at the current time.

Future of the Automation Course and Laboratory

The automation course and laboratory serve a very important role in the UT Martin controls curriculum, and the laboratory, especially, has evolved and been enhanced much since its inception. Future enhancements may need to be along the lines of offloading topics to new elective courses to be developed that perhaps share the laboratory space and equipment, at least initially. As an elective course, the future of the automated production systems course and laboratory are fundamentally tied to the evolution of other elective courses. Splitting the automation course into multiple courses to increase time on topics is a possibility that has been discussed. Offering a robotics elective, a PLC elective, a CNC elective, and perhaps a control systems components elective would clearly be something that would have to evolve over time, owing to staffing and facility size issues. Those familiar with the nature of automation will recognize, though, that each of the major topics involved could easily be the topic of one upper-division elective. As the UT Martin program continues to grow, this is something that can be investigated.

Regardless of the future number of electives and their content, it will be desirable to retain small section sizes. Historically, having a maximum of twenty students in a lecture and up to ten students in each lab section has yielded good results at UT Martin in terms of student access to the equipment and to the instructor.

Conclusions

An automation laboratory providing experiential learning opportunities and providing exposure

to real world industrial automation equipment and tools has been described. Descriptions of the lab experiences' content, objectives, scheduling, and hardware platforms used to accomplish them were presented. The relationship of the automation laboratory to the UT Martin controls curriculum sequence and the automation lecture course it accompanies was discussed. Future improvements to the laboratory and course were enumerated, and the common theme of systems integration as a lab learning experience was noted.

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