

INTRODUCTION TO INDUSTRIAL AUTOMATION, A MULTI-DISCIPLINARY COURSE AT WESTERN KENTUCKY UNIVERSITY

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Abstract

The design of contemporary industrial systems and consumer products is increasingly blurring the boundaries between electrical (EE) and mechanical (ME) engineering. Many commercial systems are an appropriate blend of technologies from both disciplines. Traditional approaches to strengthening the educational experiences of engineering students have utilized traditional service courses in each of the disciplines. Although mechanics and thermal/fluid courses for the EE's and circuits/machinery courses for the ME's are important and necessary, they are not sufficient to give the students the skills to deal with these new systems.

Western Kentucky University has implemented a course, EE 285: Introduction to Industrial Automation, in an attempt to build a bridge between the EE and ME programs. The goal is give the students a common language in this area so that multidisciplinary capstone and professional projects are more easily accomplished. The results of two years of offering the course, including student feedback and course assessment are included. Examples of projects tackled by the students, lessons learned by the faculty, and lists of necessary equipment are provided.

Introduction

The Department of Engineering at Western Kentucky University (WKU) has been given the rare opportunity to develop an entirely new engineering program. Western's challenge has been to create unique undergraduate curricula in Civil, Electrical, and Mechanical Engineering focused on the needs of current and future industrial partners. The Mission of the WKU's Department of Engineering revolves around our vision of Project Based Learning. The central focus of this vision is that the faculty will engage students in activities to support development of a clear understanding of engineering practice. The roles of students - as learners, as observers, as assistants, and as practitioners - should be supported by both the external project activities of the faculty as well as the implementation of the curriculum such that the practice of engineering is clearly demonstrated.¹

The new engineering programs at WKU a tremendous potential for nationally-recognized excellence in undergraduate engineering education. The faculty is dedicated to the mission of project-based learning for undergraduate education.⁵ The engineering programs at WKU differ from the other programs within Kentucky and most engineering programs across the country in that there are no graduate programs. Instead of supporting graduate students and conducting traditional research, WKU faculty members are actively engaged in both the scholarship of application and the scholarship of teaching. Activities currently include involving students in industry to help solve local and regional problems, scholarship in the areas of recruitment and retention of students (including women and minorities), developing and applying state-of-the-art

teaching pedagogies throughout the curriculum, and other activities supporting a project-based, learner-driven engineering department.

Course Overview

Both the electrical and mechanical engineering programs have incorporated practice-oriented experiences into the curriculum by the addition of multiple laboratory experiences, design courses⁴, and project classes. Introduction to Industrial Automation is an important course in the fourth semester of both curriculums, intended to be a blend of these three types of practice-oriented courses. It serves as an important “building-block” in both programs, helping build a foundation for higher level integrated design courses.

To help support the project-oriented nature of the course, each individual student is assigned a hardware kit containing an Allen-Bradley Programmable Logic Controller (PLC) and an Atmel AVR microcontroller. The list of assigned sensors, switches, and other input/output (I/O) devices may vary depending upon the projects selected for the semester. A list of this equipment is given in Table 1. In addition, programming software for the PLC’s and compilers for the Atmel microcontrollers are in computer labs throughout the building. Students check out this equipment in a large plastic tote and use it for the entire semester. Considering a typical semester may have 32 students in the course, split into two sections, the College of Science and Engineering at WKU has made a substantial investment in the course.

Equipment	Description	Vendor	Cost
MicroLogix 1000	Programmable Logic Controllers	Allen Bradley	\$265
Cable	Programming Cable	Allen Bradley	\$50
OP-420	Operator Panel	Automation Direct	\$135
OP-ACBL-4	Cable (PLC - Panel)	Automation Direct	\$13
OP-ACBL-1	Cable (RS232 – Panel)	Automation Direct	\$15
TRD-S100-BD	Optical Encoder	Automation Direct	\$79
MSF-00-4A	Fiber Optic Photocell	Automation Direct	\$36
Power Supply	12 Power Regulated Supply	Any	\$45
DC Motor	DC Gear-Head motor	Any	\$23
STK 500	AVR Flash Microcontroller	Atmel	\$75
Accessories	Consumables and Supplies	Any	~\$14
		TOTAL COST	\$750

Table 1: Equipment Used in EE 285

The students work on a range of projects to build an understanding of not only the use and integration of these devices, but also to gain an appreciation of the strengths and difficulties of using the technologies of the other discipline. Both sets of students are required to have completed a course in structured computer language, currently designated as C and offered by the Computer Science department. The EE students are required to have courses their first courses in both digital circuits and circuits/networks. The ME students are required to have completed a course in the fundamentals of electrical engineering covering DC and AC circuits, digital logic, and some basic electronics.

This course is team-taught by faculty from both programs and is divided into three sections. The course begins with a three-week review of digital systems, followed by seven weeks on Programmable Logic Controllers and six weeks on Atmel microcontrollers. An overview of each of these three sections is given below.

Digital Review

Students are introduced to the modeling and design of digital circuits and their application to construct digital systems. Students learn to analyze a problem statement, formulate a mathematical model, and design logic networks having the required relationship between signals at the input and output terminals.

An example project introduces relays and requires the students to fabricate an H-Bridge circuit. The context of this project is to demonstrate a method for controlling the direction of rotation for a DC motor, a topic revisited during the PLC portion of the course. A schematic for an H-bridge is shown in Figure 1 below.

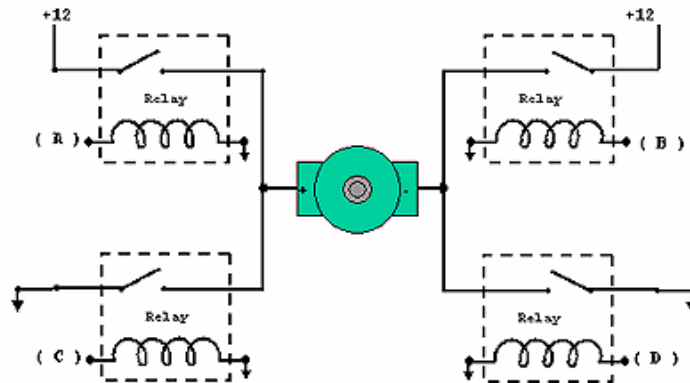


Figure 1: H-Bridge Circuit

The EE students have prior experience in circuit prototyping and testing, and are able to provide assistance to their ME peers. Although the students assist each other with projects such as this, each student is ultimately responsible for designing and building their own circuit.

Programmable Logic Controllers

Beginning with a comparison of the PLC to drum timers and relay networks, this section introduces the most common method of machine control used in regional companies. As with most PLC's, this model is programmed using a language called (relay) ladder logic. The Allen Bradley programming interface is Windows-based, a vast improvement over the traditional hand-held programmers or command-line interfaces. The student's work together to learn ladder logic, and quickly discover the PLC functions in a structured manner consistent with their previous experiences with C. Figure 2 below shows an Allen Bradley MicroLogix 1000 mounted on its mounting plate. These aluminum plates not only protect the PLC but also allow barrier terminal strips to be used so students are prevented from making circuit connections directly to the more delicate PLC terminals.

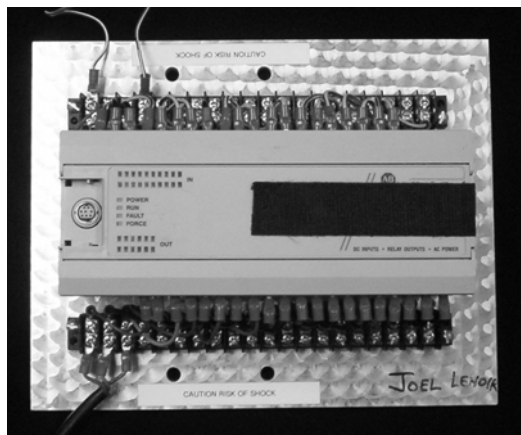


Figure 2: Allen Bradley MicroLogic 1000

Over a period of several weeks, students complete an increasingly difficult set of PLC assignments. Since each student has their own hardware, they can work on their own schedule and at their own pace. This section of the course does not meet every session, replacing class time with periods when the instructor is available for technical assistance.

An example of a final project for this section is shown below in Figures 3 and 4. This project required each student to fabricate a bracket for a dc motor coupled to an optical encoder and another bracket to mount a fiber optic photocell. The project the required the students to wire an H-bridge for the 12V motor using the relay outputs of the PLC, drawing upon the lessons learned in the first section of the course. The optical encoder functioned as a simple tachometer readable by the PLC, and the photocell was used to start and stop the process. Figure 3 is an example of a tachometer unit, while Figure 4 shows a typical student's work area in the floor of a departmental project room. Members of the Industrial Advisory Board found Figure 4 to be somewhat inspiring about the future of our students, reminding some of the advisors of long hours spent on their own school work years ago.

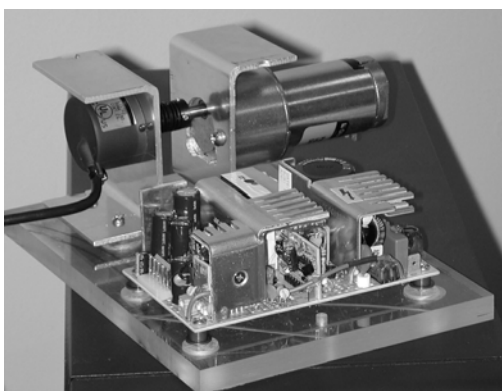


Figure 3: Student Tachometer Project

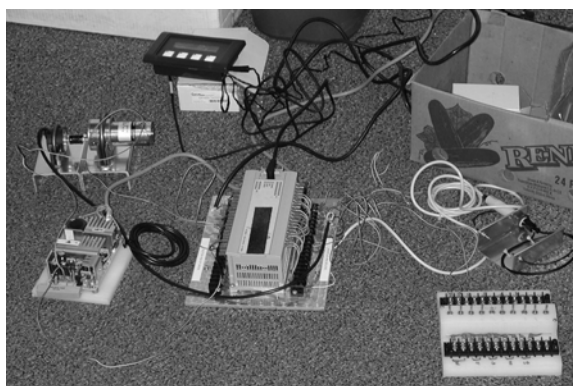


Figure 4: Student Work Area

The ME students were of technical assistance to the EE students on these larger projects. The ME students have been more extensively trained in the use of the machine shop, and were able to help the less experienced EE students design and fabricate the mounting brackets for their projects.

This course is the last time PLC's are presented in a formal manner to students in either program. However, students completing the course have made the PLC a tool they are comfortable with, both for capstone projects and projects with local industry. Students have reported that internships after this course have given them a chance to use their programming skills on several industrial systems.

ATMEL Microcontrollers

The final section of the course is used to introduce the students to Atmel AVR Flash Microcomputers, shown in a student project in Figure 5 below. Although each student's prior experience was with a higher level programming language, assembly language programming was used. This decision was initially made due to the lack of a C compiler, but it turned out to be a reasonable choice since students were more familiar with bit manipulation than expected. The use of the PLC provided an excellent introduction to memory mapping and bit control as tools in structured programming.

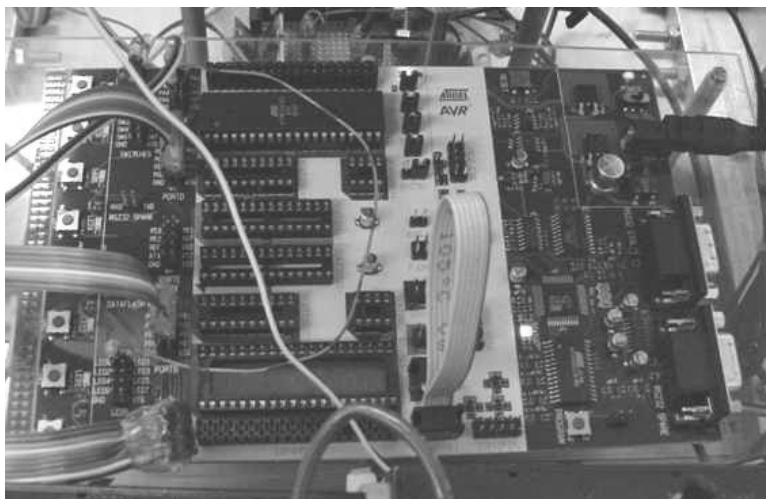


Figure 5: Atmel STK 500 Microcontroller

As with the PLC, students tackled an increasingly difficult set of projects to build an introductory working knowledge of microcomputers and the flow of data within a microcomputer system. In addition, students worked to understand the concepts of a state machine on several projects. The final microcomputer project involved interfacing the Atmel board to switches and two 7-segment displays to display a double-digit number. The switches were used to select the number to be displayed, and the microcontroller was required to display the number by multiplexing the data to be displayed.

This section of the course only served as a brief introduction to the tool of microcontrollers. Although this introduction was sufficient for the ME students, allowing them to understand the

power and limitations of the tool, the EE students need a greater level of understanding. In the next semester, the EE students take a more intensive course in microcontroller applications.

Summary of Course Assessment

Course outcomes were developed for each section of the course. These outcomes state the skill and knowledge students are expected to possess at the end of the course, and are shown below.

Digital Section Course Outcomes:

1. Ability to use Karnaugh maps to minimize the design of a logic circuit.
2. Design combinational logic circuits.
3. Design synchronous and asynchronous sequential circuits

Microprocessor Section Course Outcomes:

1. Demonstrate a working knowledge of the ATMEL AVR Flash microcomputers and the flow of data within a microcomputer system.
2. Demonstrate a working knowledge of the necessary steps and methods used to interface a microcomputer system to devices such as LCD displays, motors, sensors, etc.
3. Demonstrate the use of interrupts and other programming techniques related to microprocessors.

PLC Section Course Outcomes:

1. Create a structured PLC program to solve an automation problem.
2. Document a PLC program for archival purposes.
3. Document project results in an appropriate manner.
4. Wire sinking and sourcing sensors and power supplies to a PLC.
5. Build a proof-of-concept model for a sensor validation experiment.

Students used self-assessment to determine the success of the course in enabling them to achieve the course outcomes, with a 0 indicating no mastery and 10 very proficient. A typical course assessment for the PLC portion of the course is shown in Figure 6 below.

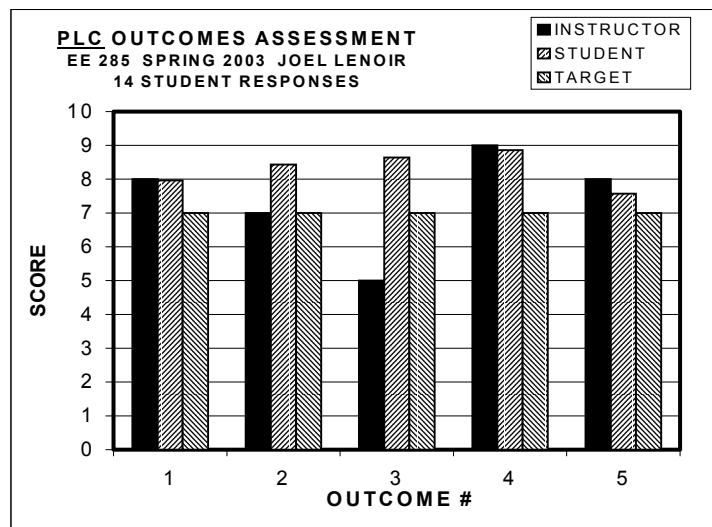


Figure 6: PLC Course Outcomes Assessment

In this example assessment, the greatest difference between faculty and student perceptions occurred on outcomes related to project and program documentation. Students felt they deserved more credit for the limited amount of documentation provided. The instructor recognized students needed a clearer understanding of the expectations for documentation. This type of course outcome assessment is used for every engineering course at WKU, and serves as a valuable tool for continuous course improvement.

Lessons Learned

This course is being offered for the third time in spring 2004. Based on the course outcomes assessment, specific student comments, and observations by course instructors, several major improvements have been made to the course. The most substantial change to the course occurred between the first and second offerings. The original plan was to pair ME and EE students together on a single set of hardware. Course assessment proved this to be relatively unsuccessful. Students were unable to divide the work of programming, with the ME's letting the EE's do the programming while they wired the systems and built any necessary hardware. Funds became available to fully equip the course with individual systems, and faculty felt the loss of teamwork was overshadowed by the need for each student to struggle with the programming. The faculty is working to increase the amount of interdisciplinary teamwork, with the expectation that some team assignments will be developed.

Another major change implemented in 2004 is the use of a C compiler. A new textbook for the Atmel section of the course provided a student copy of a compiler for use in the course. Although assembly language provides some benefits to the students, assessment revealed student comments and faculty perceptions showing students were not able to apply their C programming skills from the computer science course. Since both disciplines need students to be competent in C later in the curriculum, the decision to implement C on the Atmel was made this year. No data has yet been collected about this change.

The last major change involves the creation of student handouts with prewritten programs. Both faculty believed the development and implementation of programs developed during class time on the board was an appropriate method of presenting the material. Assessment revealed quite the opposite, with a majority of student requesting some simple initial programs already printed and documented. In retrospect, this seems appropriate for a class of sophomores and may actually improve the flow of the course. This change will be assessed at the close of the current course.

Conclusion

The course EE 285: Introduction to Industrial Automation, has become an important element of the second year in the EE and ME programs at Western Kentucky University. Students gain essential practice in structured problem solving and programming, and build a foundation for design and application courses to follow. Each student gains a better understanding of the tools available to both disciplines and adds a valuable tool for internships and capstone design projects. Course outcome assessment is an essential element of the course, already contributing valuable suggestions for substantial improvements to the course.

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Author Biographies

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