AC 2011-1971: RECONFIGURABLE AND SCALABLE AUTOMATED SYSTEMS PROJECTS FOR MANUFACTURING AUTOMATION AND CONTROL EDUCATION

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Reconfigurable and Scalable Automated Systems Projects for Manufacturing Automation and Control Education

Abstract

Studies have suggested that individuals have different learning styles. Some students are more hands-on while others are more analytic. Automation and control courses often include laboratory exercises to provide hands-on experience. However, laboratory exercises often focus on one aspect of automation and control at a time, such as wiring or PLC programming. Needed are more comprehensive learning experiences that provide students the opportunity to integrate their knowledge and skills in building complete systems. To achieve this goal, the author recently implemented semester projects in which students build small-scale automated systems using Fischertechnik components along with industrial programmable logic controller, relays, and motors. Students' feedback suggests that this approach is viable and relevant to their learning experience and future careers. In addition, they are often proud of their finished projects and are willing to show them at university-sponsored outreach and dissemination events. This paper details the implementation, execution, and contents of these projects and how they relate to the course syllabus

Related Research

This section briefly reviews related work on learning styles, industrial automation and the economy, education on automation and control, and project-based learning.

Learning Styles. As described in Felder and Silverman[1], there are different student learning styles including (1) active/reflective, (2) sequential/global, (3) sensing/intuitive, and (4) visual/verbal. It has been suggested that different teaching styles can be adapted accordingly. Litzinger et al.[2] extend the application of learning styles not only to engineering but also to liberal arts and education. Their analysis revealed that the engineering students are significantly more sequential and more sensing than the liberal arts and education students and significantly more visual than the liberal arts students. Their data was also used to explore possible gender differences in learning style preferences between male and female engineering students. The female engineering students tended to be more sequential, more sensing, and less visual than the male engineering students.

Industrial Automation and the Economy. Automation has a profound effect on the way we do work. The U.S. Bureau of the Census estimated that nearly $40 billion was invested in U.S. industrial automation in 1990. In addition, across the five major industry groups that employ more than 40 percent of all manufacturing employees, nearly three out of every four plants use advanced manufacturing technology[3]. There has been heavy investment in the European Union and Asia-Pacific region as well[4]. In addition, a U.S. Census Bureau report notes that the yearly exports in the flexible manufacturing category (equivalent to industrial automation) were $19.44B in 2006, a 10% jump from $17.61B in 2005[5]. Moreover, monthly exports in the flexible manufacturing category were $4.06B in March 2008, a 0.5% jump from $4.04B in March 2007 [6]. This trend is likely to continue to increase as the manufacturing sector continues to transform to a high tech, less labor-intensive and value added industry using advanced automated systems.

Education in Automation and Control. Relatively few instructional technology development efforts have focused on the area of automated system design and education. However, there are two related projects related to control of automated systems using programmable logic controller (PLC) programming. For example, LogixPro 500 (http://www.thelearningpit.com/) employs animated educational simulations of processes, such as traffic control and batch mixing, to show how a ladder diagram relates to an automated process. Students can start and stop the animations, and study the corresponding ladder diagram for certain conditions or cases.

The author developed an Integrated Virtual Learning System for Programmable Logic Controller (Virtual PLC) under a previous NSF award. This system uses a combination of animations, simulations, intelligent tutoring system technology, and games to teach about programmable logic controllers (http://etidweb.tamu.edu/hsieh/Hsieh_VirtualPLC.html). As with LogixPro 500, students can view animations of processes and study the corresponding control programs. In addition, they can use a ladder logic toolkit to write and test their own control programs. In every evaluation so far, students have made statistically significant learning gains as a result of using the system, and rated the modules positively in terms of ease of use and understanding, clear objectives, amount of interaction, ability to motivate, relevance, and pace[7,8,9].

Both of these systems are good examples of how technology can be used effectively to teach PLC programming. However, a PLC is just one component of an automated system. Needed are technologies that enable students to learn how to integrate multiple components to form an automated manufacturing system, develop the associated control logic, and run the system. Also needed are more bridges between engineering education and industry practice, so that students have more opportunities to interact with engineers and learn about how they solve system integration problems. An online "community of practice" [10] would provide a forum for industry experts and students from diverse backgrounds and institutions to exchange ideas and share war stories.

Project-Based Learning. Project-based learning, a method grounded in constructivism, supports student engagement in problem-solving situations[11]. Yasemin and Tinmaz[12] report that students in a project-based learning environment deal with real-life problems, which may result in permanent knowledge.

Summary. In summary, students have different learning styles and development of a robust teaching strategy to accommodate all learners' needs is an interesting challenge. Automated systems play a significant role in our daily lives. These systems are the backbone of our national production systems and basic living infrastructure. More importantly, exports of automated systems make up a significant portion of our national economy. Therefore educating students with integrated knowledge about automated systems is a pressing need. A project-based curriculum seems to help students develop an integrated knowledge of a specific subject. In this paper, we share our experience in achieving these goals by adding a model-building project to the curriculum of an existing course.

Manufacturing Automation and Control Course Modification

The author teaches an undergraduate-level manufacturing automation and control course for Engineering Technology students at a U.S. university. The course covers the following topics: (1) programmable logic controllers and programming, (2) sensor technology, (3) industrial robots and programming, (4) vision system, and (5) industrial interfaces. These are major types of knowledge needed to understand and build automated systems. Methods for evaluating student performance include (1) homework and quiz, (2) monthly examination, (3) lab exercises, (4) lab final, and (5) final examination, as summarized in Table 1 below.

Table 1. Topics, evaluation methods, and instructional activities for undergraduate course on manufacturing automation and control.

Topic	Evaluation Methods
Programmable Logic Controllers and Programming	Homework and Quiz
Sensor Technology	Monthly Examination
Industry Robots and Programming	Lab Exercises
Vision System	Lab Final
Interface	Final Examination

Activity/Delivery Method	
Lectures	Lab Exercises/Hands-On experience
*power point presentation	*PLC programming
*real-life automated system video	*PLC interface with sensor
*animation of PLC instructions	*PLC interface with sensor and robot
*simulation of line balance	*Robot programming

** denotes use of Virtual PLC to teach this topic*

The topics and delivery methods are designed to be balanced among (1) active/reflective, (2) sequential/global, (3) sensing/intuitive, and (4) visual/verbal learning styles. One challenge is how to deliver integrated knowledge of an automated system. The labs include two exercises to teach students to interface PLC, sensor, and robot. However, for students who are more visual learners; these exercises may not be enough. To address this challenge, students were given the opportunity to complete an optional semester project. Students do not have to work on a semester projects, but if they choose to do so, the project can be used to substitute for taking the final examination.

The project requires students to apply techniques/methodologies discussed in classes and labs, such as use of sensors, relays, robot, PLC, and interfacing techniques. Students identify a product and a process to automate and submit progress reports periodically throughout the semester. Each team consists of two people.

Examples of student projects include:

1. Development of a pneumatic-driven robot system
2. Use of PLC for injection molding machine control
3. Multiple robot system collaboration for disk drive assembly
4. Robotic work cell design for egg packaging
5. Automated system for cutting seat belt retractor sleeves
6. Use of vision system for printed circuit board inspection

The goals of the project are to (1) increase interest about automation and (2) provide real-life problem solving experience.

Project System Platform

An automated system typically consists of controller, sensors, actuators, and system structure. Since this class enrolls about 40 students per semester, and teams consist of two members, the use of actual industrial-scale equipment would be tremendously costly. In addition, we wanted system components that could be reconfigured for different purposes and allow several systems to be integrated into a larger system (i.e., scalable). Table 2 lists the components of the platform used for the team projects.

Table 2. Project Platform and Contents

Project System Platform	
Items	Price
1. Allen Bradley Micrologix 1000 PLC	$200
2. Fischertechnik ROBO Starter Set	$110
3. 5/12 Volts DC Power Supply	$15
4. Industrial Relay	$10
5. PLC software	$0
Overall Cost	$335

Fischertechnik ROBO Starter Set*
1. push buttons
2. sensors
3. motors
4. module components
5. lights

**Each Starter Set can build 6 different automated modules*

As shown in Table 2, the project system platform included many common components needed to build an automated system. The cost of the platform is reasonable—approximately $335 each. More importantly, each constructed module can be reconfigured for many different applications and each constructed module can be scaled to form larger automated systems. Figures 1 and 2 show examples of possible configurations of a Fischertechnik ROBO Starter Set.

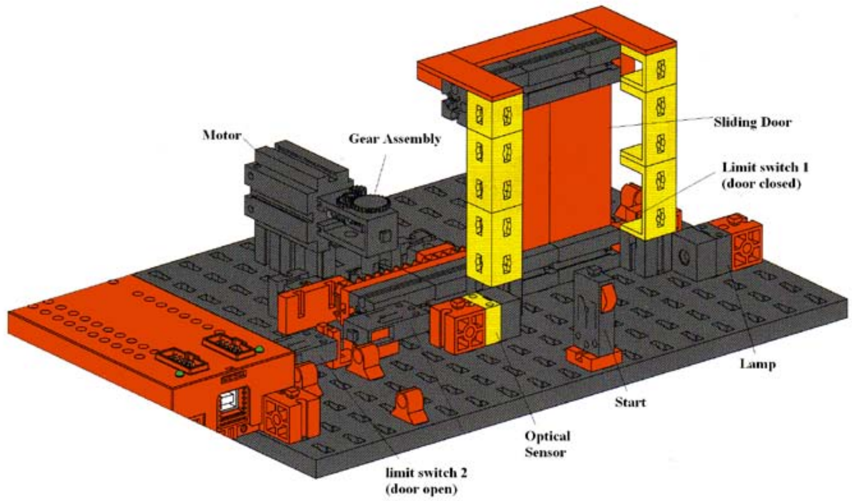

Figure 1. Physical Layout of Sliding Door Model

In Figure 1, the physical model consists of a sliding door which is operated using a 9V DC motor and gear assembly. A switch is used to start the operation. Two limit switches are used to monitor the state (open/closed) of the door. An optical sensor and lamp assembly is placed in front of the door to check for the presence of any object in that area. A relay is used to change the direction of the motor to open and close the door

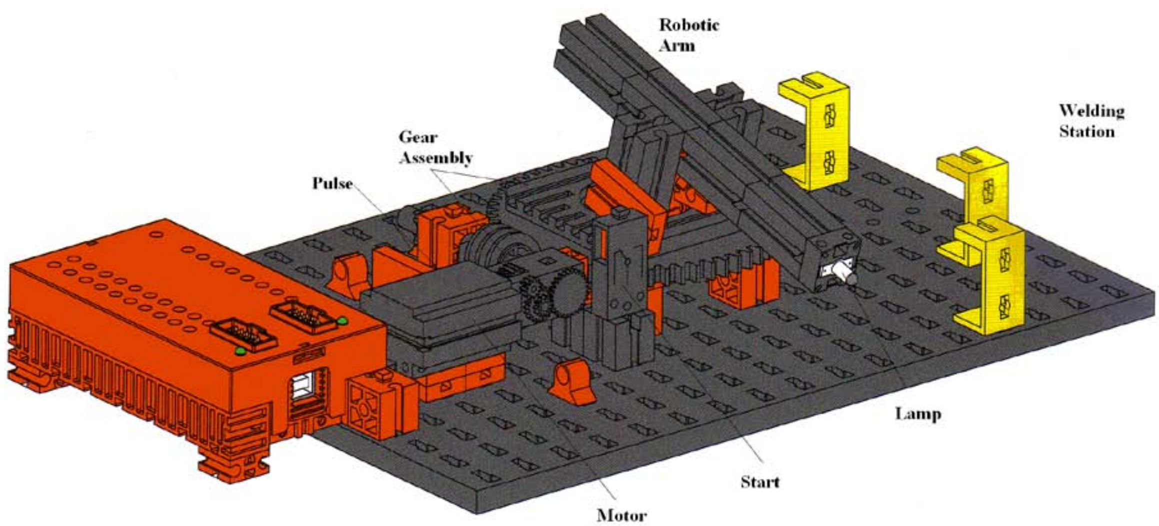

Figure 2. Physical Layout of Welding Robot Model

In Figure 2, the model consists of a robotic arm mounted with a welding torch. The motor and gear assembly is used to move the torch from one welding station to another. A start button is used to start the operation and a switch is used to count the number of pulses required to move the robot from one welding station to another.

Project Requirements and Evaluation

The students begin their projects half-way through the semester; which is when programmable logic controller (PLC) and sensor technology subjects are covered. At this point, the students know all the PLC instructions and principles of how different sensors work and they have practiced interfacing sensors, push buttons and motors with a PLC during the regular lab exercises. Therefore, they are equipped with knowledge needed to carry out the project. As shown in Table 3, the grading policy emphasizes having a working system and writing a report, then on system complexity and team presentation. This weighting is consistent with requirements for engineers in industry (about 90% of our graduates work in industry after graduation). Several project checkpoints are set up to guarantee the quality and completion of the project in time. This is also valued by the industry. Team member feedback is also used as a way of evaluating the success of the project. Everyone on a team is expected to contribute and the policy stipulates that team members will evaluate each other; if a team member's evaluation result is less than 60%, the instructor will hold a group meeting to figure out who has done what so that a fair grade can be assigned to each individual. Table 3 shows the requirements and grading policy for the semester project.

Table 3. Project Requirements, Grading Policy, and Project Checkpoints

Grading Distribution	
Items	%
1. System complexity*	10%
2. Working system	55%
3. Final report	25%
3. Presentation	10%
4. Team member evaluation	

* based on system functionality, I/Os, programming, and report

Project Checkpoints
3/29 - one-page system concept and required part list
4/12 - model construction complete
4/19 - I/O interface with PLC complete
4/26 - programming and schematic complete
4/28 - report complete

Samples of Project

Over the past three semesters, there have been several outstanding projects. The following sections briefly introduce four of these with brief descriptions and picture of the modules.

Elevator Model

Figure 3 shows a model of an elevator for a three-story building. Each floor has limit switch and light indicator to tell the controller when the platform arrives at each floor. The platform is driven by a motor and a relay circuit is used to reverse the rotation of the motor to enable the platform to move up and down.

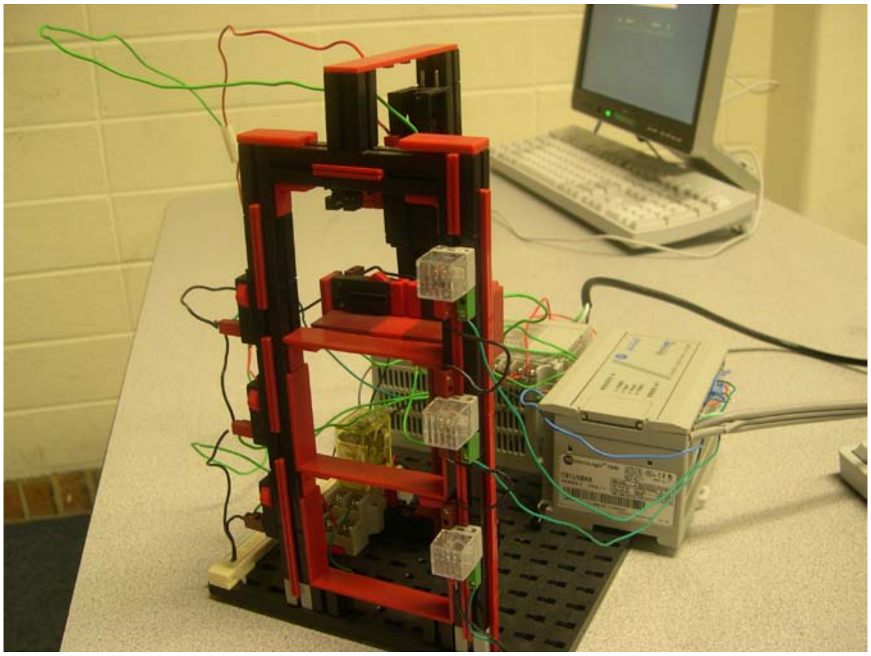

Figure 3. Elevator Model.

Whack-A-Mole Model

Figure 4 shows the design of a model for playing the game “Whack-A-Mole.” There are five lights in the model; each light represents a Mole. Next to each light is a push button representing a hammer. The program uses a random number generator to randomly turn on a light. A timer is triggered and the user has a few seconds to push the button next to the light. When the button is pushed, the light will turn off and the user will receive a point, which is displayed on a digital counter next to the model. For each game, there is a master timer that gives each user a time limit of 30 seconds. The highest score is stored in the memory and displayed on the digital counter. This model was very popular among the younger students attending a recent community outreach activity sponsored by the College of Engineering. Figure 5 shows one of the younger players.

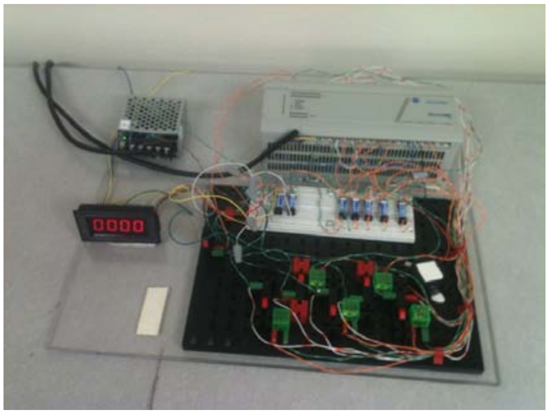

Figure 4. Whack A Mole Model.

Figure 5. Playing Whack-A-Mole Game.

Basketball Game Model

Figure 6 show a Basketball Game model. The model has several components, including a hoop, court, launcher, and point display. The hoop is mounted on a track driven by a motor. The motor can turn clockwise and counter-clockwise (via a relay), which makes the track move forward and backward. Users use a launcher to throw a ball toward the hoop. An optical sensor is installed inside the hoop. When the ball goes though the hoop, the sensor is triggered and a counter is used to keep track of the number of times that the sensor been triggered. This number is displayed in a digital counter. Users who score more than 10 points within the time limit can advance to the next level. At the next level, the hoop not only moves forward and backward, but also rotates.

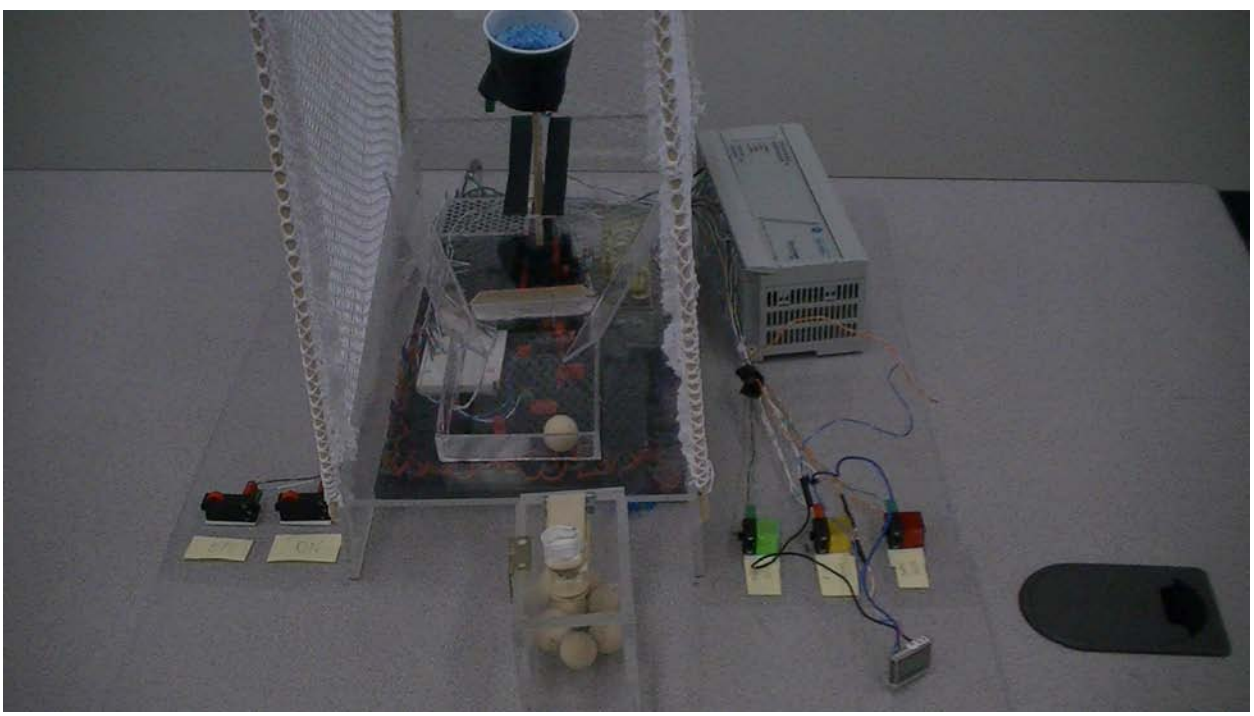

Figure 6. Basketball Model.

Evaluation Results

The evaluation has focused on two issues. 1) a comparison of individual students' pre-project grades and with their project grades; and 2) project team performance over three semesters.

A student's pre-project grade was determined by his or her performance on traditional written assignments such as monthly examinations, homework, and quizzes. The project grade was based on performance on activities such as building a working system, writing a report, and giving a presentation. For each student who participated in a project, the pre-project grade and the project grade were compared. Table 4 summarizes this information. Column 1 shows the number of students who worked on a project for Fall 2009, Spring 2010, and Fall 2010. The difference between each student's project grade and pre-project grade was computed. Column 2 shows the sum of the differences between these students' project grades and pre-project grades. Column 3 shows the average grade difference for each group of students (Column 2 / Column 1).

The results show a positive net gain of 5 to 9 points each semester. We also conducted a two-tailed paired t-test to determine if the net gains for each individual were statistically different. The hypothesis is "an individual student's project is significantly greater than his/her grade prior to the project." The statistical test results, which are shown on Table 5 confirm the hypothesis.

Table 4. Normalized Project Grade and Improvement over Each Semester

	Students	Sum of differences	Average difference
Fall 2009	14	71.13	5.08
Spring 2010	6	57.77	9.63
Fall 2010	8	52.95	6.62

Table 5. Statistical Testing of Grades.

	Pre-Project Grade	Project Grade
Sample Size	28	28
Mean	1.178	1.266
Variance	0.005	0.002
Note: t=-6.08 (critical value = 1.70), significant level = 0.05		

To answer the second question, the team project grades over three semesters were accumulated. There were seven teams in Fall 2009, three teams in Spring 2010, and four teams in Fall 2010. The team grades were normalized relative to the lowest team grade, which was normalized to 1.000. Table 6 shows the normalized team grades for all three semesters and the average team grade for each semester. As compared to the average team grade in Fall 2009, the average team grade improved by 1.36% in Spring 2010 and 3.11% in Fall 2010.

Table 6. Normalized Project Grade and Improvement over Each Semester

Project Grade*	Fall 2009	Spring 2010	Fall 2010
Team #1	1.073	1.067	1.017
Team #2	1.073	1.061	1.117
Team #3	1.006	1.000	1.106
Team #4	1.017		1.006
Team #5	1.017		
Team #6	1.011		
Team #7	1.007		
Average	1.029	1.043	1.061
STD	0.030	0.037	0.058
*Grades are normalized relative to the lowest grade.			

Students' Comments

Student comments can be summarized as follows. Several students in the final interview expressed that they understood the concept of a relay better after actually wiring a relay to a motor. In addition, after hours of trial and error, they learned to systematically wire I/O devices to a PLC and how to troubleshoot wiring problems. Some students commented that they would like to have examples of real-world timer applications during the lectures and labs (i.e., not just switches and lights). Overall, the students thought the project was helpful and supplemented the labs well. The instructor received two emails from recent graduates (Fall 2010) who have started new jobs expressing their appreciation of the project experience.

Conclusion and Future Directions

In this paper, we described the motive, plan, and results related to a project-based activity to enhance students' learning in an undergraduate automation and control course. The experience is challenging, but seems positive and has been well-received by students (some have even brought their parents to see their projects). Future plans include combining multiple models to form a large scale system and creating an on-line documentation system so that teams can blog about their learning experience throughout the project development stage. We also plan to conduct experiments using smart phones for remote control of systems to evaluate how this affects students' designs and learning.

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