A New Course in Programmable Logic Controllers:
A Project-Based Approach

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Abstract

Group projects provide a means to teach students many of the skills they need to succeed after graduation. In fall semester 2000, we developed and taught a course in Programmable Logic Controllers (PLCs) by employing a project-based approach using an "out-of-the-box" integrated PLC. A major goal of the project is to prepare students to apply effective problem solving techniques by addressing a reasonably complex real world problem. This paper describes the laboratory environment, discusses the project guidelines, and presents the projects implemented in fall 2000.   The paper also analyzes the project-based approach and concludes that the project is an essential component of a comprehensive learning experience when teaching PLCs.

I. Introduction

PLCs have been used extensively in a wide range of industries. As a result, many mechanical, electrical, and manufacturing engineering technology programs teach PLCs and their applications [1-8]. This paper describes the development and implementation of a new course that employs a project-based approach using an "out-of-the-box" integrated PLC. A major goal of the project is to prepare students to apply effective problem solving techniques through the implementation of a reasonably complex real world problem. This includes the ability to define problems, identify alternative solutions, design circuits, and test systems.   Project requirements included a written proposal, a progress report, a final written report, an oral presentation, and a demonstration. Students are given guidelines for the group project during the fourth week of the semester. Teams of two students propose, design, implement, document, and present a PLC-based project. To equip them with some basic skills and tools, students perform five simple laboratory exercises before starting the project. These exercises are designed to teach them how to set up and configure a PLC, create and compile ladder logic diagrams, and download and test programs. Students get involved with dealing with many tasks that improve their skills. Those include understanding design specifications, interpreting data sheets, software development, hardware-software integration, and system testing. The course is offered for a three-hour lecture and a three-hour laboratory per week. Table 1 shows a weekly schedule using the textbook used for the course [9]. As shown, a broad range of topics is covered, including programming, counters, timers, interrupts, industrial automation, and process control applications.

This paper describes the laboratory environment, discusses the project guidelines, and presents the projects implemented in fall 2000. The paper also analyzes the project-based approach and concludes that the project is an essential component of a comprehensive learning experience when teaching PLCs.

WK	Readings	Topics
1	Ch. 1	Intro to Programmable Logic Controllers (PLCs)
2	Ch. 2	PLC components
3	Ch. 10	PLC set-up and configuration
4	Ch. 3	Programming PLCs/ **Handout project guidelines**
5	Ch. 4	Counters and timers
6	Ch. 5	Memory organization
7	Ch. 5	Data manipulation
8	Ch. 8	Structured programming
9	Ch. 6	Simple data Elements/ **Group project proposals due**
10	Ch. 7	Data in files, blocks, and arrays/ **Start projects**
11	Ch. 11	Interrupts
12	Ch. 9	IEC 1131-3 programming
13	Ch. 9	IEC 1131-3 programming/ **Project progress report due**
14	Ch. 12	Process control applications
15	Ch. 14	Robotics, automation, and PLC Troubleshooting
	Ch. 15	**Project report and demo due**
16		Final

Table 1. Weekly Schedule

II. Project-Based Approach

Group projects have been used extensively to motivate students and help them achieve a deeper understanding of the subject being studied. A major challenge encountered with a project-based approach, however, is finding appropriate projects. One way to address this issue is to ask students to go through the following steps:

- ‣ Start by listing all the projects you can think of. Filter these projects by considering long term goals.
- ‣ Filter the new set of projects by considering short-term goals. This will result in a list of projects consistent with both long and short-term goals. Filter the new set of projects by considering the course requirements.
- ‣ Finally, filter the last set of projects by considering available resources, including time, money, and technical knowledge.
- ‣ Select a project from the last filtered set of projects.

Once a project is identified, students must go through a project management process that includes.

- ‣ Stating the objectives, including performance.

- ▸ Identifying available resources, including money, time, human, and material.
- ▸ Defining the objectives. This involves restating the original objectives after considering the available resources to ensure that the goals are achievable.
- ▸ Analyzing the problem. This involves an investigation of alternative approaches that achieve the desired goals. Since the object is to identify the best approach, the analysis should be thorough and complete. If the analysis does not generate at least one possible solution, redefining the objectives may be necessary.
- ▸ Selecting the best approach. This consists of a comparison of the alternative solutions based on some selection criteria that may include such factors as performance, cost, time, size, speed, etc.
- ▸ Developing a plan. This should consider all the phases that lead to the completion of the project. The plan should be comprehensive with a schedule of all activities and their relations.
- ▸ Implementing the plan. This includes the design, construction, and testing of the product.
- ▸ Evaluating the results. This entails evaluating the performance of the product in meeting the original goals. If the results are not satisfactory, a review of the previous steps is required.
- ▸ Completing the project and its proper documentation.

During week 9, students briefly describe their projects to their classmates and submit a one to two page written proposal. The proposal includes complete details as to the function of the system. The reason is that if students are not clear about what they want to build, it would be impossible to successfully proceed. The proposals are reviewed by the instructor and returned to students the following week. The instructor includes suggestions for improvements, alternative solutions, additional work required, etc.

At the end of the semester, students deliver 20 minute oral presentations describing their projects and explaining their plans. To help students prepare for this task, approaches and guidelines to technical presentations are discussed in class. All students participate in the evaluation process. Comments and Suggestions are given to the speaker so that he or she is aware of areas needing improvement.

III. Laboratory Environment and Exercises

The Siemens S7-214 is used in the laboratory. The S7-200 series is a line of integrated PLCs that can be used in various automation applications. The compact design, expandability, and powerful instruction set makes it a good solution for controlling small applications. The S7-214 package comes with a STEP 7-Micro/WIN programming software, a PC/PPI communications cable for interfacing with a PC, and an input simulator. Fig. 1. Shows the laboratory set-up. The STEP 7-Micro/WIN allows the user to create programs with either the Ladder Logic editor or the Statement List Editor. Students perform five laboratory exercises in preparation for the group project. The following paragraphs briefly describe these exercises.

Exercise 1: In this exercise, students get familiar with the PLC by performing the following tasks:

    (a) Set-up the PLC on a board they previously prepared.
    (b) Connect the PLC to the PC using the PC/PPI cable.
    (c) Configure the software so that the transmission rate is 9.6 kbps, COM port used is 0, timeout is 3 s, and local station address is 0.
    (d) Set the PLC type to CPU 214.
    (e) Create a ladder program consisting of one input (I0.0) and one output (Q0.0).
    (f) Download the program into the PLC.
    (g) Run the program and test it for proper operation.
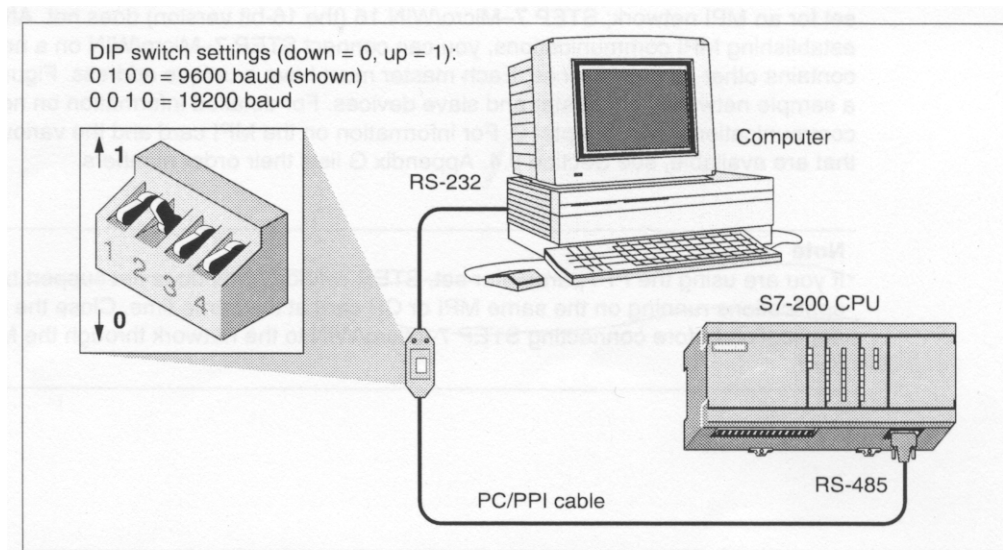

Fig. 1 PLC Set-up

Exercise 2: In this exercise, students learn about the steps involved in programming PLCs by creating a ladder logic program. This exercise and its solution are in the lab manual [10]. Students are asked to perform the following tasks:

    (a) Understand the operation of the Mixing Tank system shown in Fig. 2.
    (b) Create a new project called MixingTankExample.
    (c) Enter the ladder logic diagram, symbol table, and status chart for the system.
    (d) Turn in printouts of the Ladder Logic program, the STL program, the Symbol Table, and the Status Chart.

Exercise 3: In this exercise, students learn how to download, run, and test a program by performing the following tasks:

    (a) Place the PLC in Stop Mode then download the program created last week.
    (b) Place the PLC in Run Mode.
    (c) Under Debug, select Program Status. Also, examine also Chart Status.

(d) Use the Input Simulator Switches to manually verify the operation of the Ladder Logic program, one step at a time.
(e) Turn in the Ladder Logic program, a step by step procedure describing how someone can test the program to verify its proper operation, and suggestions for modifying the ladder logic diagram to improve its readability and/or the operation of the system.
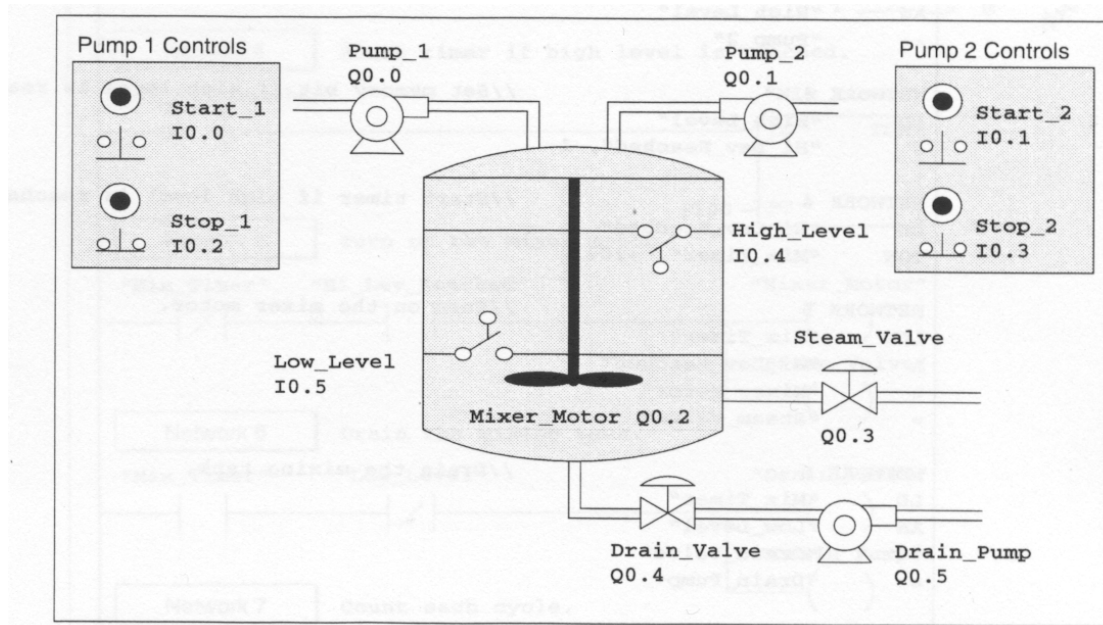

Fig. 2 Mixing Tank System

Exercise 4: In this exercise, students create their own program. Students are asked to create a ladder logic program for Fig. 3, including a symbol table and a status chart, that satisfies the following specifications.

(a) When the START button is pressed, Valve 1 (V1) is energized and fluid enters the tank.
(b) As the tank begins to fill, Level Switch 2 (LS2), which detects the lower limit of the fluid level, closes.
(c) When the tank is full, the normally open Level Switch 1 (LS1), which detects the upper limit of the fluid, shuts off V1 and starts the Agitator (AG).
(d) AG mixes the fluid for 45 s and shuts off. When AG turns off, Valve 2 (V2) is energized to drain the fluid.
(e) After the tank has been emptied, LS2 opens and V2 shuts off.

Exercise 5: In this exercise, students practice their skills of analyzing ladder logic programs. Students are given a program that uses data block definitions and asked to perform the following tasks:

(a) Enter the ladder logic program.
(b) Download, run, test, and understand the individual instructions and the overall function of the program.
(c) Turn in the Ladder Logic program, a short description of the function of each network, and suggestions for modifying the program to make it a better learning experience.
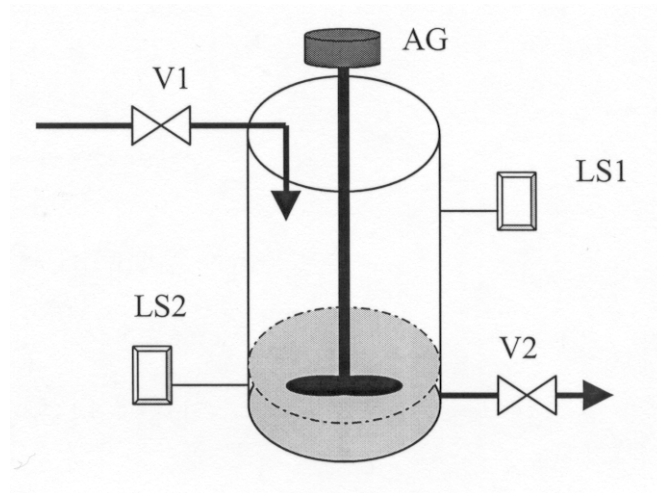

Fig. 3. Fluid Mixing System

VI. Group Projects

Three projects were implemented in Fall 2000. Short descriptions follow.

1. <u>PLC Controlled Electric Drive System:</u>

This project involved designing an electric drive system that has three basic modes of operation: automatic, manual, pre-determined. In the automatic mode the system responds to signals from six sensors located in the front, back, and sides of the board. In this mode, the possible actions are move forward, reverse, spin left/right, turn left/right, and accelerate. In the manual mode, the system is controlled by an operator, and in the pre-determined mode the system executes a set of instructions that moves the board in a square pattern. One component of the system is a controller box containing eight input switches and three LEDs. This allows all necessary inputs for the three available modes of operation. The electronic components used to implement the system include infrared LEDs, phototransistors, relays, DC motors, voltage regulators, transistors, decoder, and inverters. The team working on this project experienced major difficulties, many of which were attributed to the lack of time and prerequisite knowledge in electronic devices necessary to implement the system. A partial demonstration was performed at the end of the semester.   Figure 4 shows the system with the PLC in the middle of the board.

2. <u>Water Sump Simulator and Pump Control</u>:

This project involved two parts: a) designing a sump simulator, and b) developing the pump control scheme. The two parts of the ladder operate independently but are wired together so that one tests the other. Fig. 5 shows the system.

The simulator program provides a simulation of 100 gallon sump. The sump has two inlet valves which are each capable of adding 10 gpm. The sump is equipped with two discharge pumps. Each pump is capable of removing 15 gpm. The "sump" is fitted with four level switches. They are located on the sump at the following points: 20% , 30%, 70% and 80% . These switches close whenever the level is greater than or equal to the stated level. A reset input is provided to initialize the sump at a 50% level.
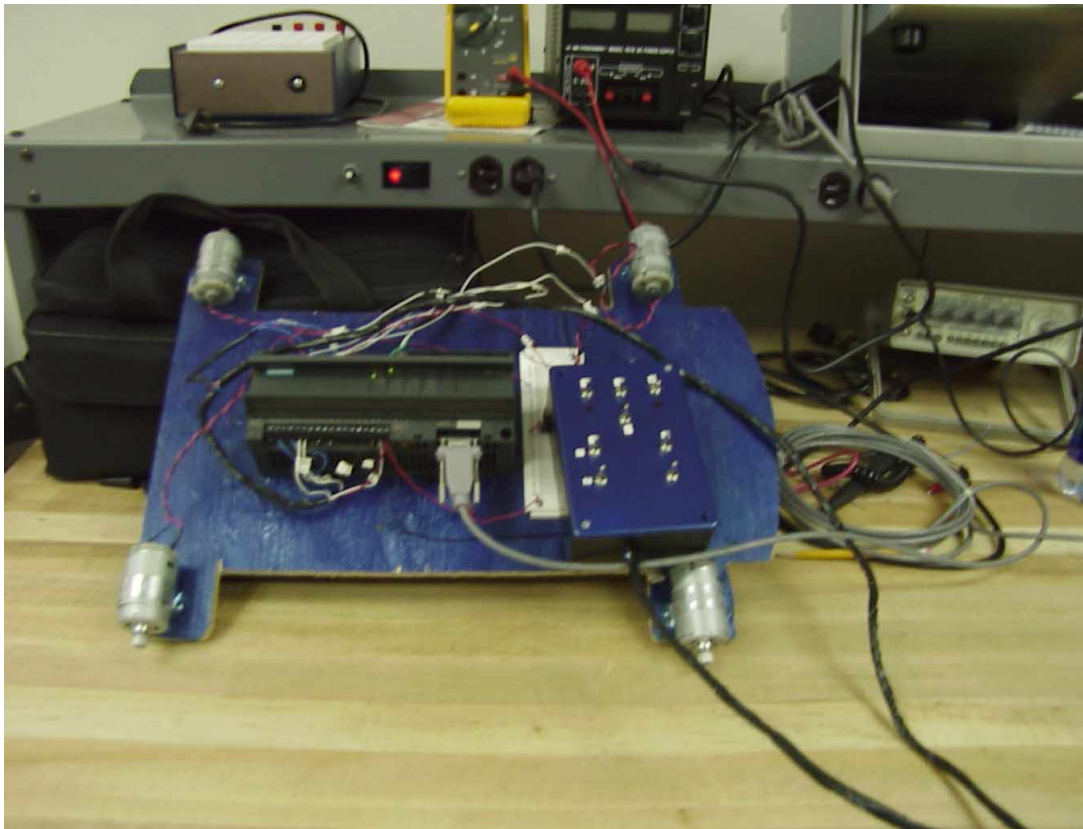

Fig. 4 Electric Drive System

The pump control consists of two pump control circuits. Each pump is equipped with a HAND-OFF-AUTO switch. There are four level control inputs (generated by the sump simulator and hard wired in). The design meets the following criteria:

   a) No pump can run in HAND or AUTO if the level is less than 20%.
   b) In HAND the pump runs continuously (if level greater than 20%).
   c) In AUTO the primary pump starts at 70% and stops at 30%.

d) In AUTO the secondary pump starts at 80% and stops at 30%.
e) Initially pump 1 is the primary pump. After 3 cycles (70% to 30%), Pump 2 will become the primary pump. After it has run 3 cycles, pump 1 will again become the primary and so on.
f) If the 80% level be reached and maintained for 30 seconds, an audible alarm and blinking red light will go on. There will be an acknowledge button which will silence the alarm and make the light shine steady. The alarm will be reset once the level is reduced to 70%.

Fig. 5 Sump Simulator and Pump Control

3. Security Housing Project:

This project involved building a small-scale house in order to demonstrate the functionality of a PLC based security system. The model's general layout consists of three neighbor's homes, the kiosk, the main house and the PLC, as shown in Fig. 6. The main house has four windows, a front door, and a garage door. The reset switch is located in the garage, which can be accessed by using the garage door opener. The opener consists of four switches, three of which are used to simulate a combination lock. Throughout the model, push button switches were used to simulate the opening and closing of windows and doors, but on the garage door opener the push button gives the owner the time that is needed to provide the system with the correct combination.

The operation is as follows. If the front door, garage door, or any of the windows is opened by anyone but the owner the buzzer and the alarm main light in the kiosk both turn on. Another feature included into this design was the roof indicator lights for each house. These lights flash if the houses have been broken into. The purpose of this is to stop the owner from entering his or her home while there may still be a burglar inside. The buzzer was included to call better attention to the guard on duty. Once the message has been relayed back to the guard, he or she can then inform the police about the situation. If the owner was to arrive and the green garage light comes on after the combination has been set then the coast is clear and he or she can enter. If the owner comes home and finds a red flashing light on his roof then he or she can avoid a confrontation with a burglar that may still be inside the home. A picture of the project is shown in Fig. 7.
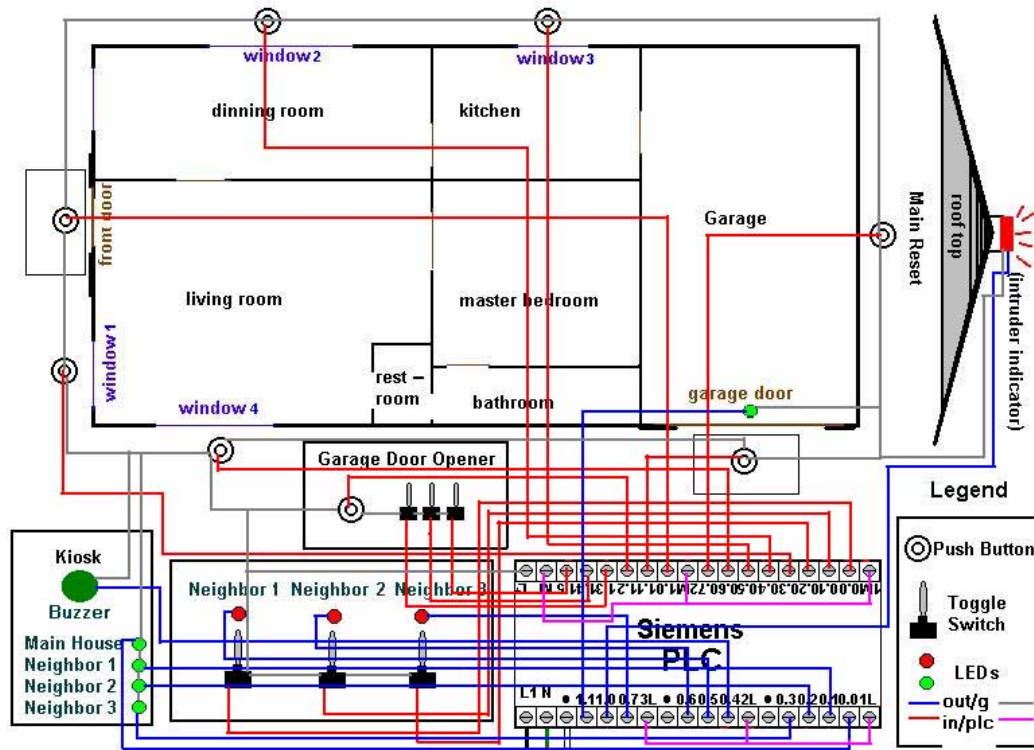

Fig. 6 House Layout and Wiring

V. Students' Feedback and Future Plans

Student feedback was positive and supports our belief that a project-based approach offers an effective learning experience. The number of hours students spent on the projects are shown in the following table.

Group #	Reported total man-hour
1	180
2	45
3	170

As mentioned earlier, group 1 did not completely finish their project. A major reason is that students did not have the proper prerequisites for designing an electro-mechanical system. To remedy this problem, prerequisites should be added to the course. At a minimum, the prerequisites should include Digital Logic and Principles of Measurements. This background will allow students to integrate both analog and digital designs.

Fig. 7. Security Project

VI. Conclusion

This paper describes a new course in Programmable Logic Controllers using a project-based approach. A major goal of the project is to prepare students to apply effective problem solving techniques through the implementation of a reasonably complex real world problem. Feedback from students validates our belief that the project is an essential component of a comprehensive learning experience when teaching PLCs. In addition to

allowing students improve their design and research abilities, we believe that students learn to work together more effectively as a result of the project experience.

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Biography

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