

A QUICK AND EASY PLC LEARNING EXPERIENCE FOR MECHATRONICS

Clark T. Merkel, David Fisher, and Ron Hofmann
Mechanical Engineering
Rose-Hulman Institute of Technology

Abstract

This paper discusses how the topic of programmable logic controllers was added to an existing senior level course in the mechanical engineering program at Rose-Hulman Institute of Technology. A two week "PLC" experience was implemented based on the use of Allen-Bradley Pico PLCs and the PicoSoft application software. Additionally two different laboratory demonstration stations were built in-house to provide a "hands-on" control experience for students. This paper talks about how the "PLC" experience has been implemented and how well it has been received as part of the mechatronics course.

Introduction

Mechatronics at Rose-Hulman Institute of Technology has historically been a class focused on the use of microcontroller devices and the language skills needed to program them. In this course, students learn to program a Handy Board microcontroller and use it to monitor a variety of different sensors and control a number of different output devices such as DC motors or relays. This course is the first exposure for most students in the mechanical engineering program to digital systems and smart control. The class meets for a fifty minute lecture period three times a week and for a three hour laboratory once during the week over the ten week quarter. The laboratory primarily attempts to develop the students' ability and understanding of a Handy Board microcontroller. They work through a number of structured tutorials for five weeks and gain ability to use the Handy Board as a smart controller. In addition to working with this microcontroller, three weeks of the laboratory are devoted to digital breadboarding and

learning to program and build circuits for PIC microcontrollers. The quarter is capped by a project where the students design and build a system or device which uses the Handy Board microcontroller as the brains for their project. As a first exposure to smart control, the Handy Board is an easy-to-use and robust hobby controller. However, it is not a commonly used industrial device, nor is it suited to be an embedded controller for projects in other courses which the students take later on.

To address these perceived weaknesses, the course content has been expanded to include a module on programmable logic controllers (PLCs). A PLC is another name for industrial computer. It has been designed to have features which make it very useful in an industrial setting, such as being rugged and reliable, having easy-to-access ports for input and output to interact with other machines and sensors, modular design to allow for quick and easy interchangeability, and programmability that is both convenient and relatively easy to use. While some PLCs may be programmed using formal languages, many are programmed using a graphical program interface such as ladder logic.

Covering the use of PLCs in a mechatronics class provides both a platform to introduce and develop ladder logic representation of process control and the opportunity to work with actual devices that the students would be more apt to see in an industrial setting.

PLC Selection for Classroom Module

While searching for appropriate hardware to use for this content expansion, we found that many of the full size PLC systems were relatively expensive, had much more capacity

than we wanted, and required the purchase and use of proprietary software to program and simulate the control systems. Such systems seemed to be overkill for the short introductory module we wished to include in the course.

After looking at several smaller options, we found a relatively small, compact family of PLCs called Pico made by Allen-Bradley that was a much better fit to the scope of our course. In addition to small size, rugged construction, and relatively low cost, the Pico PLCs are programmable in two different yet accessible ways. They may be manually programmed using the pushbutton interface on the front of the device or they may be programmed by directly downloading a ladder logic program developed in PicoSoft application software by use of a separately purchased interface cable.

The low end PLC in the Pico family offers 8 digital input ports and 4 output relay ports. The units we have chosen for our implementation use a working voltage of 120/240 VAC although there are other models which work on 24 VDC power. Depending upon the PLC model, these units may include an internal clock, a LCD display, and a 4-way button switch on the front of the unit. A typical Pico PLC unit is shown in Figure 1.

In order to make this PLC a stand alone unit for use in our classroom, we mounted each unit on an electrical box and wired it through both a 1 amp fuse and a circuit interrupter outlet to a



Figure 1. Pico PLC.

standard three prong electrical connector. This could be connected to any 120 VAC power socket. This provided a safe and mobile PLC unit which could be powered easily and used in the lab, the classroom, or at a remote site. This mount is shown in Figure 2.



Figure 2: Mounted PLC Unit.

Ladder Logic Development and Simulation Software

One of the best features of using this PLC is the professional quality software package available called PicoSoft. Unlike the software for their other more powerful lines of PLC, Allen-Bradley makes a version of the PLC program software available free of cost. It may be downloaded from the Rockwell Automation website at <http://www.ab.com/plclogic/pico/picosoft.html>. Prior to purchasing these PLCs and utilizing them in this course, we had already been using other PLC vendor software in the class to provide students with a development system for creating and simulating ladder logic process control. PicoSoft was adopted for this development and quickly was found to be a superior product. It is very user friendly, easy-to-use, and offers great functionality. The Picosoft program software performs four main functions. First it allows the user to define which specific device from the Pico PLC family will be used and then allows the user to set some of the basic parameters on how the unit will operate. These parameters can include enabling

or disabling the pushbuttons and switch bounce control.

The second, and more important function is an easy-to-use and intuitive development environment in which the user can create their own ladder logic structure. It has a feel very similar to other Windows applications with the familiar pull-down menu bar items and convenient tool bar buttons. Most of the ladder construction can be completed with click and draw graphical selection of the different control items common to most ladder logic structures: process inputs, push buttons or switch inputs, outputs, relays, timers, counters, and clock functions. Each item can have additional specifications detailed using the Settings Window near the bottom of the workspace. Figure 3 shows a typical view of this development window in PicoSoft.

The third useful feature of PicoSoft is a Simulation mode. This mode allows you to simulate the behavior of the system in real time and allows the user to emulate the system inputs. It gives you additional access to view states of timers, counters, and other outputs. Different types of switches can be defined for

each input and the inputs can be easily accessed and activated using the pull down tabs in controls window along the left side of the screen. It provides all the tools you need to successfully test the control logic at the design point. The simulation window is shown in Figure 4.

The fourth and final feature is a communication window from which you can download the completed ladder logic structure directly to a PLC unit which is connected to the computer using the communication cable. While the PLC can be manually programmed using only the pushbuttons on the face of the unit, downloading the program is much more efficient. In addition to ease of downloading, the communication window allows some limited remote control of the PLC.

Demonstration Stations

Two in-house demonstration stations were built to provide systems that the students were expected to design control systems for and implement the control using a PLC unit. Students were presented with an ideal system description and assigned homework to develop

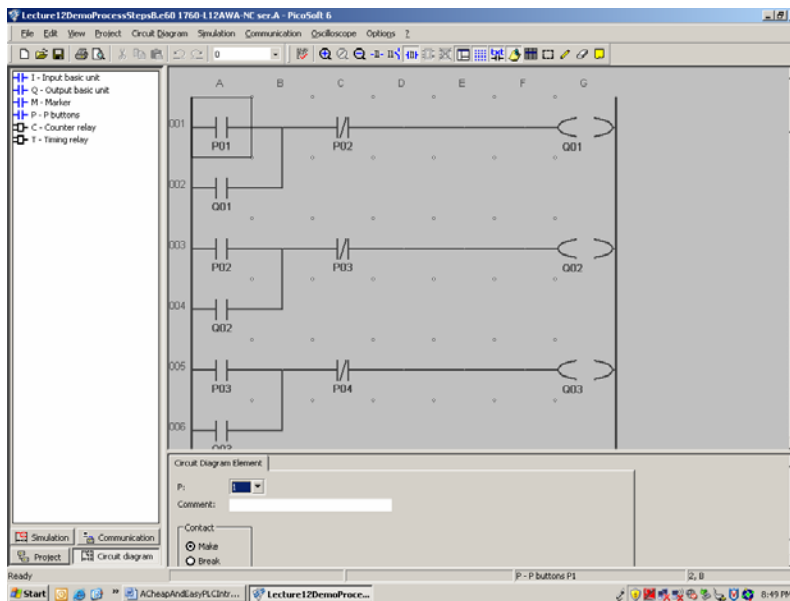


Figure 3: PicoSoft ladder logic (circuit diagram) development window.

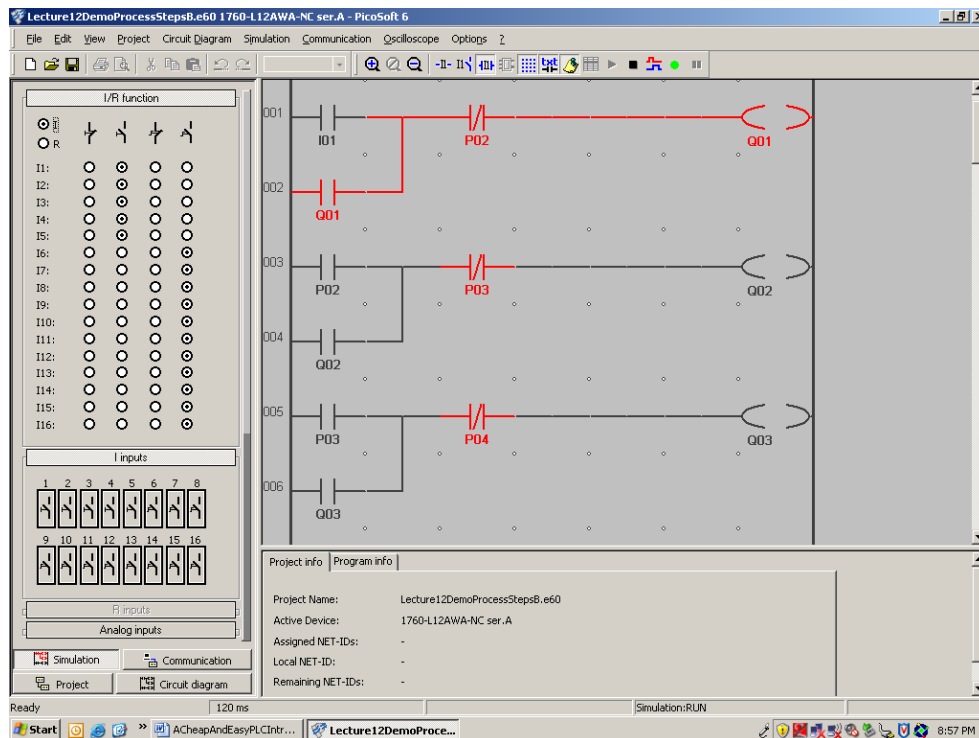


Figure 4. PicoSoft simulation window.

the control structure needed to implement the process. Later on, the students would be expected to implement these “homework” assignments on the demonstration stations. On the scheduled project days, students would be given modified specifications for the system and expected to adapt their “homework” solutions to match the new specifications needed to control the stations. After making the alterations in class and debugging their program through simulation, they were to download their programs on the PLC units of the demonstration stations and test to see if their control programs actually worked on the real systems.

The first demonstration station was a tank mixing problem. The station consisted of a water tank, which could be filled from a reservoir by turning on a pump. The program control was to start the pump and begin filling the tank. Float valves were used to monitor both empty and full tank levels. When the tank was filled, the pump would turn off and a motor would be turned on to operate an agitator to mix

the liquid. The agitator was to be run for a prescribed amount of time. Following mixing, a valve would be opened and allow the system to drain until the low level float was activated. The entire system also included access to an emergency stop switch that could be thrown and immediately halt all operations of the systems. Figure 5 shows the demonstration station.

The second demonstration station built was a pop-can conveyor system which was able to deliver, count, and sort pop cans of two different heights. A delivery mechanism could be indexed to deposit individual cans on the moving conveyor. As the can passed by two optical sensors they would be counted and identified as either tall or short. A relay activated swing arm was positioned at the end of the ramp to make the cans exit through one of two different exit chutes. There was also an emergency stop switch which could be used to control the power to all parts of the demonstration station and was to be monitored by the PLC. This system is shown in Figure 6.

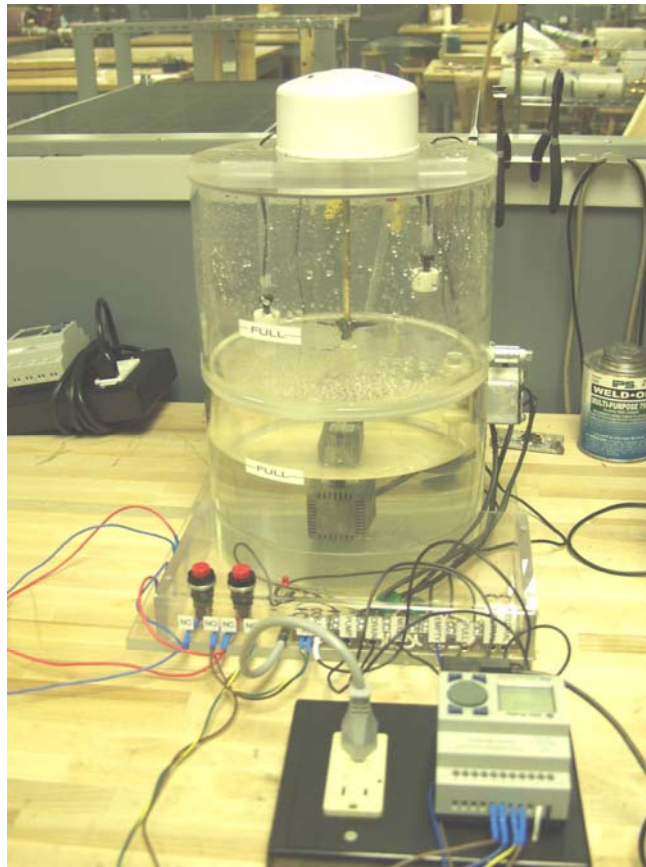


Figure 5: Mixing tank demonstration station.

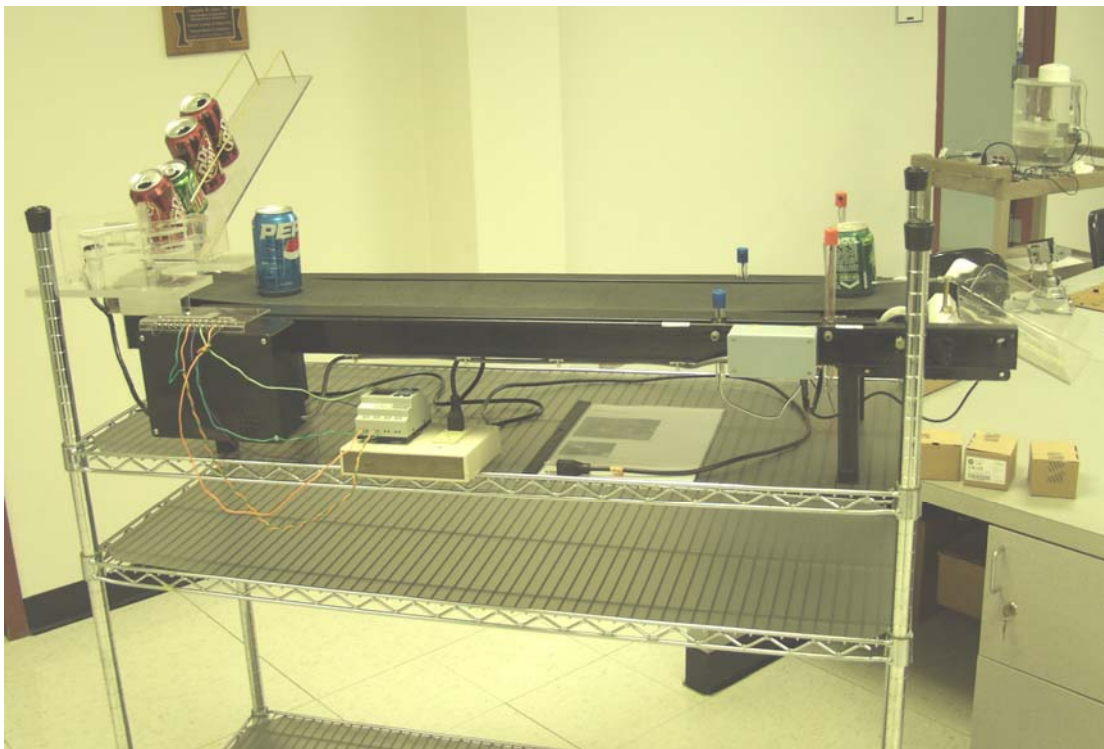


Figure 6: Pop can conveyor demonstration station.

Information Delivery

The module on PLCs was presented over seven classroom lectures/workdays spread over a three week period (These lectures were not given consecutively. Some other topics were interspersed and a test was also given during the three week period). The topics that were part of the PLC module included:

Lecture 1: Switches and Relays. An introduction to types and classification of common switches; explanation of relays and how they work; comparison of relays and transistors with advantages and disadvantages.

Lecture 2: Introduction to Ladder Logic. Basic ladder logic elements and structure; translation of Boolean and logic gate diagrams into ladder logic; start-stop systems; self latching ladder circuits; use of timing delays and counters.

Lecture 3: Using PicoSoft to Develop Ladder Logic Programs. Introduction to the four main functions of PicoSoft; creation of ladder logic structures in PicoSoft; simulation of logic structures in PicoSoft.

Lecture 4: Programmable Logic Controllers. Introduction to programmable logic controllers; comparison of different commercial systems; common features of PLCs; choosing a proper PLC unit for a given control task or process.

Lecture 5: PLC Project 1: Tank Mixing Problem. Modification of the system model to match new specifications; dealing with real components; communicating with the PLC unit; downloading and testing the control system on the hardware.

Lecture 6: PLC Project 2: Conveyor Count and Sort Problem. Modification of the system to match new specifications; simulation of the conveyor control system; downloading and testing of the control on the hardware.

Lecture 7: Rework and Completion of PLC Projects 1 and 2. Rework of control systems to fix problems encountered on previous attempts; download and retest control systems.

Student Feedback

This module was used for the first time during the fall quarter of 2005 and presented to 52 students in two sections of the mechatronics class. The module presented at that time did not include the second project as it was still under construction, but did include the mixing tank project. The module was repeated for 69 students in three sections during the winter quarter of 2005-2006. The second presentation of this module included both the mixing tank project and the conveyor project which had by then been completed.

Students were surveyed at the end of the winter quarter about the course content and the quality of the experience they perceived they had been given by the course. A portion of the survey pertaining to the PLCs is included at the end of this paper. The average response score on importance of the topics for introduction and use of ladder logic and the PLC demonstration stations were both perceived as important to very important by the students. They indicated that they felt less favorably about other topics also covered in the class. The average scores for the experience that the students received on the PLC modules indicated that the experience was perceived to be between an average and a positive experience.

Many students also added written comments to the survey. In general, the students indicated they liked the opportunity to work with the demonstration stations. Having the actual hardware and using real PLC units to control the stations provided the students with an experience they equated with more value. It also gave them additional confidence in their technical ability in that they now knew that they have made a real process work with this control device. It also seemed to make them more

aware of the benefits and limitations the units had. Many students found that their first attempt to control the physical units did not work correctly. While some had problems with communication between the computer and the PLC, more problems showed up due to incorrect assumptions that the students made about how the process switches actually worked. Some misinterpreted normally open or closed switch concepts while others had difficulty because real float switches bounce under turbulent system conditions, whereas ideal ones do not. Still others encountered less than ideal behavior when a pop can didn't deliver correctly or toppled on the conveyor belt. Additionally, timing delays had to be adjusted or tuned to make the indexing unit and the diverting arm function consistently. Few programs worked completely correctly on the first try, so most of the students were required to complete several iterations of ladder logic development, repeat the program download, and retest their modified control systems.

In previous quarters, students had been known to criticize the course when only ladder logic simulation had been used and it did not provide them any real experience with physical units or actual PLCs. These hands-on demonstration units seem to have provided a more satisfying and robust experience. While there remains room for improvement to the overall experience, the demonstration units have provided a way to help students gain confidence in their use of control devices that many will encounter during their future work assignments.

Conclusion

The qualitative comments of students indicate that the addition of the PLC project stations have been a good addition to the mechatronics course. It has made the ladder logic control content seem more relevant and has provided technical experience that students had previous not been given in our curriculum. It provides an experience with a controller type different than the other microcontrollers also covered in the

course, giving them a broader view of ways to add smart control to a system or design project.

Since the project systems described in this paper were implemented on a limited budget, the two demonstration stations experience some bottlenecks in access due to the need of many students to access the workstations to test their systems in the class. In the future we hope to address this limitation of resources by developing other additional work stations or may consider duplicating the existing ones. We will also be looking for resources to acquire additional Pico PLC units so that students may get more individual time and practice working with these devices.

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A section from the student survey:

II. PLC Topics:

Switches and relay: (Switch types and specification, concepts)

Topic importance:

Essential (5)	Very important (4)	Important (3)	Less than important (2)	Not important (1)
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_____ score

Your experience as presented in this class:

Very positive (5)	Positive (4)	Average (3)	Negative (2)	Very Negative (1)
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_____ score

Transistors: (basic concepts, simple transistor circuits and selection)

Topic importance:

Essential (5)	Very important (4)	Important (3)	Less than important (2)	Not important (1)
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_____ score

Your experience as presented in this class:

Very positive (5)	Positive (4)	Average (3)	Negative (2)	Very Negative (1)
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_____ score

Ladder logic: (elements of ladders, understanding and creating ladder structures)

Topic importance:

Essential (5)	Very important (4)	Important (3)	Less than important (2)	Not important (1)
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_____ score

Your experience as presented in this class:

Very positive (5)	Positive (4)	Average (3)	Negative (2)	Very Negative (1)
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_____ score

Working with PicoSoft: (learning use of ladder logic simulation package)

Topic importance:

Essential (5)	Very important (4)	Important (3)	Less than important (2)	Not important (1)
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_____ score

Your experience as presented in this class:

Very positive (5)	Positive (4)	Average (3)	Negative (2)	Very Negative (1)
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_____ score

Working with PLC demo stations. (gaining real experience with PLC)

Topic importance:

Essential (5)	Very important (4)	Important (3)	Less than important (2)	Not important (1)
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_____ score

Your experience as presented in this class:

Very positive (5)	Positive (4)	Average (3)	Negative (2)	Very Negative (1)
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_____ score

V. Recommendation on allocating time to future mechatronics topics:

For each of these general topics, from your experience, would you recommend we spend more, less, or the same amount of time and effort on each of the following topics.

Topic	More emphasis	Same emphasis	Less emphasis
Digital Background	more	same	less
Quarter Project	more	same	less
Breadboarding and circuit building	more	same	less
IC programming	more	same	less
Assembly programming	more	same	less
Working with PICs	more	same	less
Working with PLCs	more	same	less
Working with HandyBoard	more	same	less

Biographical Information

Clark Merkel is an Assistant Professor of Mechanical Engineering at Rose-Hulman Institute of Technology in Terre Haute, IN. He received his BS and MS in Mechanical Engineering and his PhD in Engineering from North Dakota State University. His areas of interest include mechatronics, robotics, mechanics, manufacturing, engineering modeling, and engineering education.

David Fisher is an Assistant Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his BS from Rose-Hulman and his MS and PhD in Mechanical Engineering from Stanford University. His areas of interest include microcontroller programming, CNC machining, biomechanics, and pen-based tablet computing.

Ron Hofmann is a technician for the Mechanical Engineering Department at Rose-Hulman Institute of Technology. He is the lab manager for the CNC machining shop, in charge of safety and usage of the CNC machines, machine shop computer lab, and laser engraving. He works with academic classes, faculty, students, and professional societies in the development of prototypes and new product designs.