



An Arduino-based Programmable Logic Control (PLC) Lab Activity for Undergraduate Engineering and Technology (ETM) Students

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Abstract

A PLC lab activity is developed for use in an Undergraduate Engineering and Technology (ETM) electronics survey class. The existing class uses the Arduino to teach real-time programming and basic electronics. One of the department goals is to include Based Programmable Logic Control (PLC) training in a number of the existing courses including the electronics survey class. To incorporate a PLC programming experience using the Arduino, the freeware software package SoapBox Snap is used. The lab is developed and tested in the classroom. The success of lab activity is evaluated using pre and post surveys, assessments, and classroom observations.

The lab activity objectives are to a) introduce the student to PLC control and ladder logic, b) provide a hands on activity using the PLC, c) prepare the student for future classes in the ETM program, and ultimately employment in industry. PLCs are common in industry and used in other technology classes such as mechatronics, and robotics. Teaching the basics in the electronics course provides familiarity with the concept that potentially improves performance of the students in advanced courses.

The survey course already includes a lab activity using a magnetic starter, and a variable speed motor drive. The magnetic starter lab has two pushbuttons for start and stop, and a dual in-line package (DIP) relay. The relay is used to seal in the starter circuit. An Arduino Pulse Width Modulation (PWM) pin is connected to a transistor amplifier that drives the motor. The motor drive lab is completed first and the PLC lab is completed during the following week. By completing the motor drive lab first wiring is correct before starting the PLC lab. This allows the students to concentrate on the PLC lab.

SoapBox Snap is used to implement the PLC in the Arduino. SoapBox Snap consists of two components, an Arduino sketch, and a PLC programming environment that runs on a windows personal computer (PC). The sketch is uploaded to the Arduino with no changes. The sketch does not contain the PLC program. The program is developed on the PC, including both the ladder logic, and Input / Output (I/O) mapping, then uploaded to the Arduino. The PLC program is stored in the Arduino Electrically Erasable Programmable Read Only Memory (EEPROM).

The lab activity consists of a PLC lecture followed by a pre-quiz/survey. At this point students know what a PLC is, but the question is do they have any understanding. The lab activity consists of two parts. First a magnetic motor starter is implemented. This is followed by a variable speed motor drive. At the conclusion of the lab the quiz/survey is repeated. The post-quiz/survey includes the muddiest question and a few additional questions regarding interest level.

Results based on classroom observation, and the quiz/survey results are analyzed. The results are used to determine if the lab should remain as a permanent part of the electronics survey course.

The lab provides the students with a hands on PLC experience. The experience gained is useful in the balance of the ETM curriculum. After graduation students can take the experience into their developing careers.

Introduction

A Programmable Logic Controller (PLC) programming activity is desired in an engineering technology and management program (ETM). The ETM program is a four-year Bachelor of Science degree training students in applied engineering, manufacturing, operations, and business. The students learn plastics machining, casting, welding, quality, computer programming, electronics, and receive a minor in business. The students have two programming courses and an electronics survey course. In addition they have a senior-level course in Robotics and Computer Integrated Manufacturing (CIM). In an effort to bridge the gap between the electronics course and CIM, a PLC lab assignment is added to the electronics course.

The electronics course is a survey course that includes topics such as Ohm's law, power, electronic and electrical components, and real-time programming. The real-time programming portion of the class uses the Arduino as the hardware platform. Students program various projects and wire them to the Arduino using a small breadboard. Using the Arduino for a PLC project creates a zero cost adder for this course.

The learning objectives are the skills that we want the students to master or at least be introduced to. This is an introductory course so mastery at this level may not be achievable, but we can lay the groundwork for future courses. The goals represent the restrictions imposed by time and money. The learning objectives and goals are as follows.

Learning objective:

1. PLC basics
2. PLC configuration
3. Input / Output (I/O)
4. Programming using ladder logic
5. Common PLC circuits
6. Analog I/O

The goals for lab the activity:

1. Add a PLC lab to the existing course
2. Allow all students to work individually as opposed to groups
3. Use existing hardware
4. Provide a meaningful PLC experience for the students

In the existing course the students create a variable speed motor drive with a pushbutton stop / start circuit and a relay, also known as a magnetic starter, see Figure 1. The new PLC lab follows the variable speed motor lab with no wiring changes. In this manner the circuit wiring is completed and tested before the students begin the PLC activity. This allows the student to concentrate on the PLC activity.

A freeware PLC software package available from SoapBox Automation, known as SoapBox Snap, runs on the Arduino. This package allows the student to meet the learning pre- and post-assessments are used to evaluate student competency, and any increase therein.

This is similar in scope to the lab activity described in by Eslami in [1]. In this case an electric motor training unit and a PLC trainer are connected to form the learning system. This fails to meet the goals above for the electronics survey course because the department does not have the resources. Even if the equipment were available a single trainer, or even several trainers would not allow the students to work individually.

A summer research case study is given by Hsieh in [2]. The case studies include controls using the Arduino, and a PLC. The type of PLC is not mentioned but it is assumed to be a commercial PLC.

A mechatronics laboratory for green energy technologies is developed in [3]. The activities include "C language programming on PCs and Arduino, Basic Stamp, and PIC microcontrollers". Other labs at the junior level include "real-time control - programming in C/C++ for analog/digital control, microcontroller- and PLC-based control systems". The brand of PLC is not mentioned.

Embedded system designs using the Arduino, and PLCs are discussed in He [4]. A variety of tools are used to evaluate model based designs. This is done using Simulink©, Bounded Model Checker for C (CBMC), and other tools.

The lab activity described below meets the goals and learning objectives listed above.

Lab Activity

The lab activity consists of downloading and installing the software, configuring the I/O, entering the ladder logic and testing. The hardware is wired and tested in the preceding lab. This allows the student to concentrate on the PLC aspect of the lab exercise

A pre-lab lecture covers the basics of PLC control with special emphasis on common PLC circuits. The most common of these is the magnetic starter circuit shown in Figure 1. After the pre-lab lecture a blackboard quiz is given as a baseline.

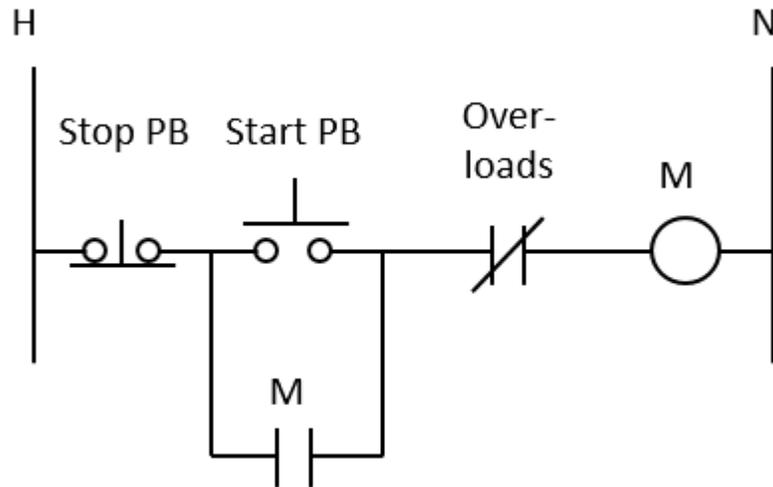


Figure 1 A magnetic Starter.

Students install SoapBox Snap from the web [5], or from a shared drive. A tutorial is provided in SoapBox [6] for the Arduino [7]. Additional information is provided in the lab instructions and as demonstrated by the instructor. The student must initialize the Arduino Electrically Erasable Programmable Read Only Memory (EEPROM) and then download the Arduino sketch. The Arduino sketch contains the firmware for the PLC solver. The students' PLC program is stored in the EEPROM. At this point the Arduino is a PLC.

The next step is to configure the SoapBox runtime application. This includes configuration of outputs, and the communications port. This is shown in Figure 2. In this case the communications port is port 89, but this will depend on the port assigned to the students Arduino. Soapbox Snap assumes all of the Arduino I/O are inputs unless configured otherwise. The configuration section must be completed exactly as shown in Figure 2. Digital outputs 4, 11, and 12 are configured as outputs. Digital output 3 is configured as pulse modulation (PWM), and is used as the drive for the variable speed motor.

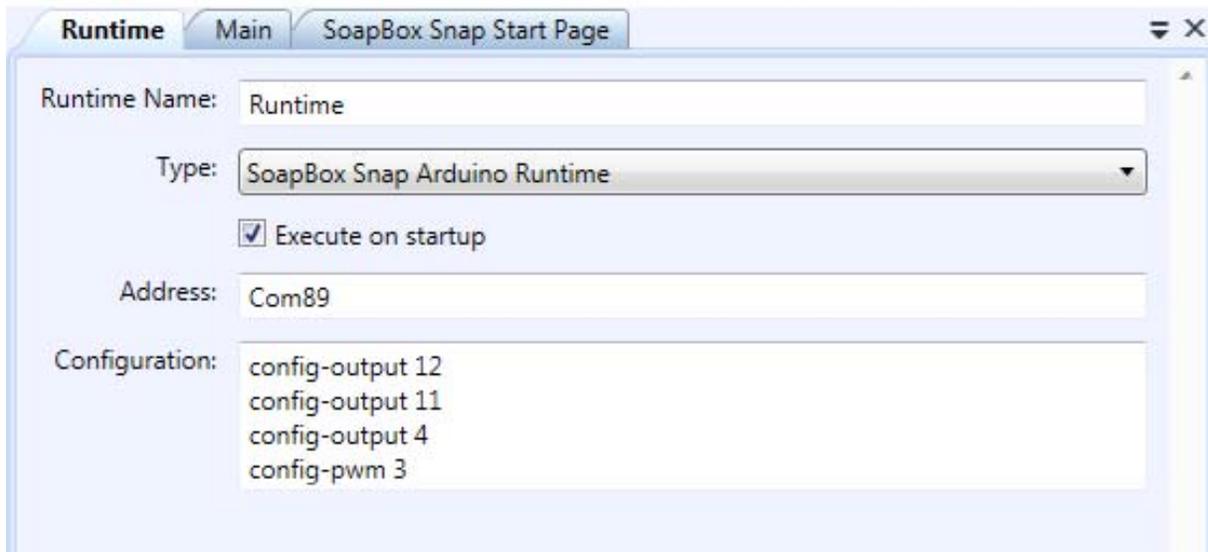


Figure 2 The soapbox snap runtime configuration page showing the Arduino comport, and the configuration of any outputs.

The completed I/O configuration is shown in Figure 2. The discrete inputs and the analog inputs are referenced in the program using the pin numbers, for example pin2, or A0. The discrete outputs and the analog outputs are configured using drop-down menus in the device configuration window, Figure 3. In addition, outputs may be forced on or off using the drop-down menus.

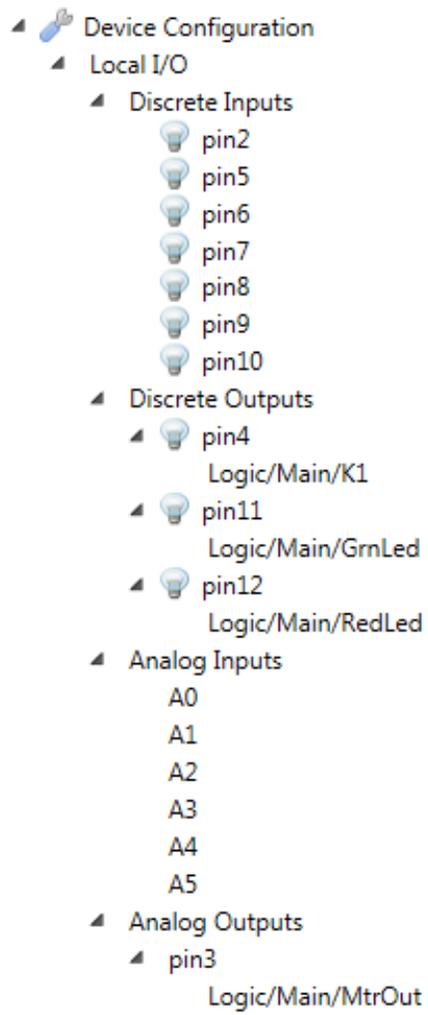


Figure 3 SoapBox Snap device configuration.

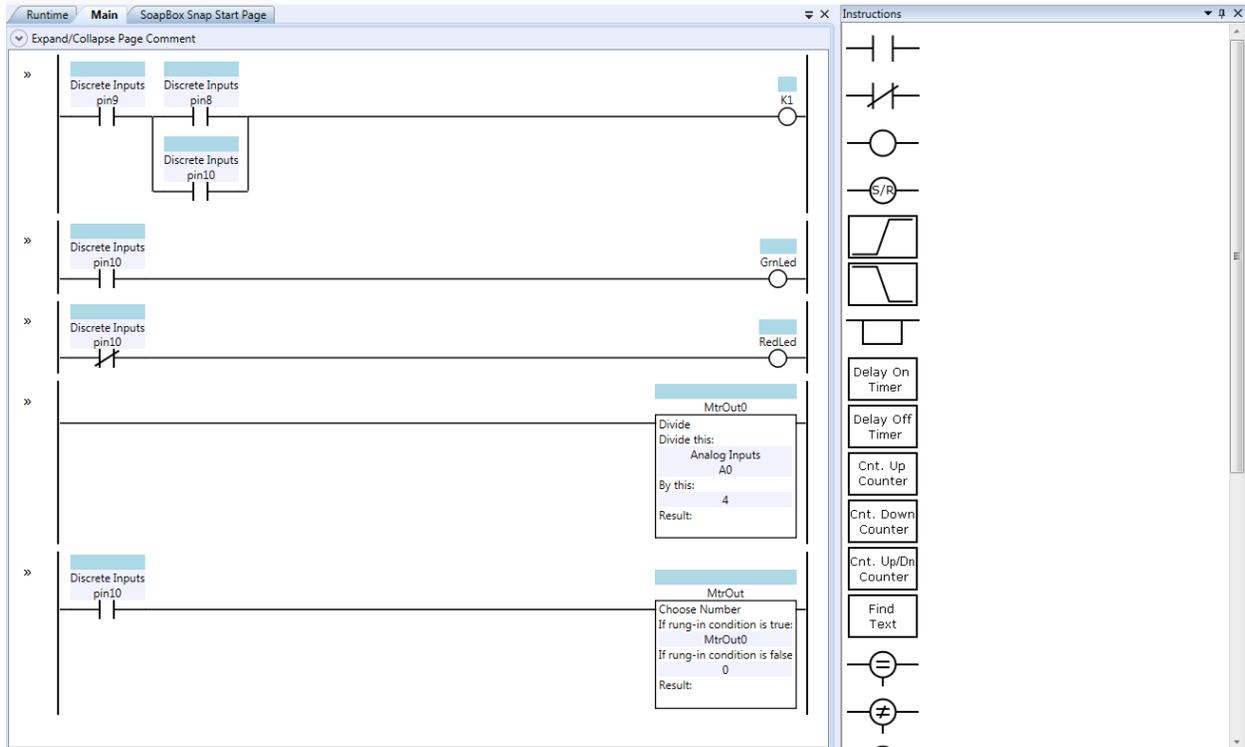


Figure 4 Soapbox Snap Ladder Logic editor.

Ladder logic programming is performed in the main screen, Figure 4. The available instructions are shown in the right pane and are placed in the ladder logic by dragging and dropping. Names, nicknames, and references are inserted as needed into the individual instruction dialog boxes. The ladder logic is written to the Arduino PLC using the "download" command. SoapBox Snap has both the download and upload command but the upload command is not implemented, so the student should always select the download command. This can be confusing to students because when using the Arduino Integrated Development Environment (IDE) the write command is upload. In SoapBox Snap writing to the Arduino is done using the download command.

After the ladder logic program is downloaded to the Arduino, the student can go online with the controller and see an animated view of the ladder logic program. Coils and contacts that are energized are highlighted in green, similar to most ladder logic programming environments, including, Allen Bradley, Modicon, and Click.

Exercise One

The first programming exercise is a magnetic starter. The start and stop buttons and the relay make up the magnetic starter. The start button is connected active high to simulate a normally open push button (PB). The stop button is connected active low to simulate a normally closed PB. The relay contact is active high and simulates a normally open auxiliary contact from a motor starter. The PWM pin, D3 is set to 100% duty cycle when the auxiliary contact is closed, and 0% duty cycle when the auxiliary contact is open. The result is that the motor operates as if it were a magnetic starter.

The most common PLC circuit is the magnetic starter which is programmed in exercise one. Students typically have a difficult time understanding the operation of the normally closed stop button. The stop button input is energized unless actuated. The normally open stop contact passes power unless the stop button is actuated. Students are encouraged to operate the start and stop buttons and watch the screen until they thoroughly understand the operation of the circuit. It is difficult to make the students understand this using power point or other lecture devices. With a live circuit operating students are able to grasp this concept. This is verified with the pre-and post quizzes.

Exercise Two

Exercise two allows student to work with analog I/O. In this exercise the magnetic starter is retained, and a variable speed drive is implemented. The potentiometer is connected to A0 and used to drive the PWM output D3. The potentiometer has a range of 0 to 1023, and must be converted to the range of 0 to 255. This is another common PLC circuit used in industry. If the auxiliary contact is not energized the PWM output is set to zero 0% duty cycle.

Assessment

Pre-and post quizzes are used to determine achievement of the learning objectives. The quizzes are the same and include 20 questions randomized from a block of 40 questions. The results are summarized in Table 1. The content is grouped by learning objective. The number of questions for each learning objective is listed in the second column. In the author's experience the magnetic starter is the most problematic concept for students so there are five questions on this topic, and three for the other topics. The results per learning objective are given as well as the total. Each learning objective is equally weighted in the total. The pre- and post-assessments and the change are given.

Table 1 Pre and Post Quiz Results

Learning Objective	Number of Questions	Pre-Quiz Average	Post-Quiz Average	Change
PLC Basics	3	47%	68%	21%
Configuration	3	90%	90%	0%
I/O	3	49%	47%	-2%
Ladder logic	3	8%	40%	32%
Magnetic starter	5	32%	74%	42%
Analog	3	0%	30%	30%
Combined	20	38%	58%	23%

At the beginning of the lab most students have never heard of a PLC, and a baseline at this point would be of no value. The goal of the lab is to give students hands-on experience with a PLC. We want to assess an increase in the student's skills with the lab experience as opposed to a PowerPoint lecture only. Thus the pre-assessment is given after the PowerPoint lecture. The

students then perform the lab activity. The post-assessment is given after the lab, and the results are analyzed.

Scores on the pre-assessment show that students understand the configuration process but retain (from the lecture) no information about ladder logic or analog. This is interesting because the PowerPoint contains much more information about ladder logic and analog and almost no information on configuration. It is possible that configuration as represented by the quiz questions is intuitively more obvious to the students than some of the other topics. Other scores on the pre-assessment, including PLC basics and I/O are at 50% which seems appropriate for the level of exposure. As predicted the magnetic starter scores are slightly lower.

The combined score improves from 38% to 58% after the lab activity. The greatest improvement revolves around the magnetic starter. This should be expected because the lab is a magnetic starter. Students learn by doing. The configuration and I/O scores remain essentially unchanged. Ladder logic scores improved by 32%, again, a “learn by doing” experience.

The improvement in Analog scores, 30%, likely comes from the poor scores on the pre-quiz. The students perform an analog lab activity, but this seems unlikely to be the driving factor in improvement based on the content of the survey instrument.

There is a 21% improvement in PLC basics. This improvement is most likely due to conversations between students, and with the instructor during the lab activity.

The Scores improve from 38% to 58% after the lab activity. The absolute values are not important because the assessment instrument may be too difficult for students at this level of experience. What is important is the shift. The lecture and lab combination is much more effective than the lecture alone.

Conclusions

The goal of this work is to provide a PLC lab experience in an existing course, involve all of the students as primary learners, use existing hardware for reasons of cost, and provide the students with an activity that results in measurable improvement skills as defined in the learning objectives.

To this end SoapBox Snap is used to create a lab experience that meets the objectives. The existing Arduino, breadboard, and components are used. Every student has the hardware, so all students perform the activity, as opposed to some working and some watching.

The improvement in achievement of the learning objectives is measured, and the results summarized in Table 1. The lab is primarily designed to ensure that students have a complete understanding of the magnetic starter. This item in particular improves by 42% based on the five questions given to the students. In addition there is an improvement of 23% in overall PLC knowledge as defined by the combined results. Based on these results the PLC Lab will be added to the existing course.

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