Interdisciplinary Automation and Control in a Programmable Logic Controller (PLC) Laboratory

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Abstract

The University of Bridgeport's School of Engineering created a new PLC Industrial Control Lab to accommodate lab-based, hands-on training using different types of Programmable Logic Controllers (PLCs). The Lab and associated courses were designed to meet ABET's EC2000 standards and prepare students for the workforce.

Keywords: engineering education, interdisciplinary lab courses, programmable logic controllers, robotics.

1. INTRODUCTION/BACKGROUND

At the beginning of the new millennium, engineering education programs were challenged to meet the latest set of standards established by ABET, known as *Engineering Criteria 2000* (EC2000). EC2000 emphasized outputs, as expressed in 11 learning outcomes [1]. In particular, upon program completion, graduates should have acquired the knowledge and skills to solve problems, using techniques and tools of engineering practice in a collaborative setting.

This approach to engineering education is not entirely new. Early engineering education focused on skill acquisition through apprenticeships, practical training, and the like, until the end of World War I [2]. The emphasis on engineering science and mathematics in engineering curricula was not introduced until the mid-1950s. This had the effect of producing engineers who could analyze a problem but were less prepared to design and apply solutions [2]. EC2000 was, in part, a response to the need for engineering graduates to be able to seamlessly transfer classroom and laboratory knowledge and practice to the workplace. Engineering graduates must be "job ready" and practiced in working as part of an interdisciplinary team [3] and [4].

2. PROBLEM STATEMENT

The University of Bridgeport's School of Engineering (UBSOE) identified the need for a Programmable Logic Controller (PLC) Industrial Control Lab to support laboratory-based courses in which students could be educated in technological processes that are part of the field of automation control. Course curricula should support student outcomes outlined in EC2000's Criterion 3. Program Outcomes and Assessment, specifically 3a-e, j, and k. Further, course curricula should be interdisciplinary such that electrical

engineering and mechanical engineering students could enroll in the same course. Finally, students should have the opportunity to learn on leading PLC models in order to be best prepared to work in the private sector. The lab should be equipped, then, with Allen-Bradley and Mitsubishi PLCs since the former is widely used in the U.S. and the latter is widely used throughout Asia.

3. METHODOLOGY
UBSOE's existing Interdisciplinary Robotics, Intelligent Sensing, and Control (RISC) Laboratory was expanded to incorporate the new PLC Industrial Control Lab. The new PLC Lab was equipped with electrical cabinets and control panels outfitted with five Allen-Bradley and four Mitsubishi PLCs [5]-[12].

Two courses were developed: EE 463: Industrial Controls, and EE 464: Programmable Logical Controls. In EE 463, students learn basic concepts in pneumatic controls and different types of sensors used widely in industry, robotics, and vision concepts. In EE 464, students learn basic and advanced concepts and applications for PLC programming. In addition, students learn to integrate various components with PLCs, such as sensors, switches, vision cameras, variable speed drives, etc. Instructional design for each course is more focused on inquiry and problem-based learning within the context of classroom community, and less focused on lecture-style instruction. All are supported in the literature [13] and [14].

3.1 Equipment Design and Integration
In the PLC Industrial Control Lab, all control cabinets share the same local network with different types of PLCs and Human Machine Interfaces (HMIs), so students are able to communicate to any of them from the class computer stations.

A team of PLC students designed an integration of different brands of control components into one application. The components were: SLC5/03 Allen-Bradley PLC, Network Card 1761-NET-ENI, Mitsubishi Variable Frequency Drive, and Cutler Hammer PM1700 Touch Screen. For this project, students were involved in wiring, communications cable design, equipment programming, and troubleshooting.

Students produced the layout design and wiring diagrams for the project to integrate the SLC5/03 PLC with the Mitsubishi Variable Frequency Drive (VFD) and Cutler Hammer Touch Screen, and to establish a network to the PLC. The design layouts and wiring diagrams were created using AutoCAD. Students were able to build a control cabinet with output to an AC motor, programming of the PLC, VFD, touch screen, etc. (See Figure 1.)
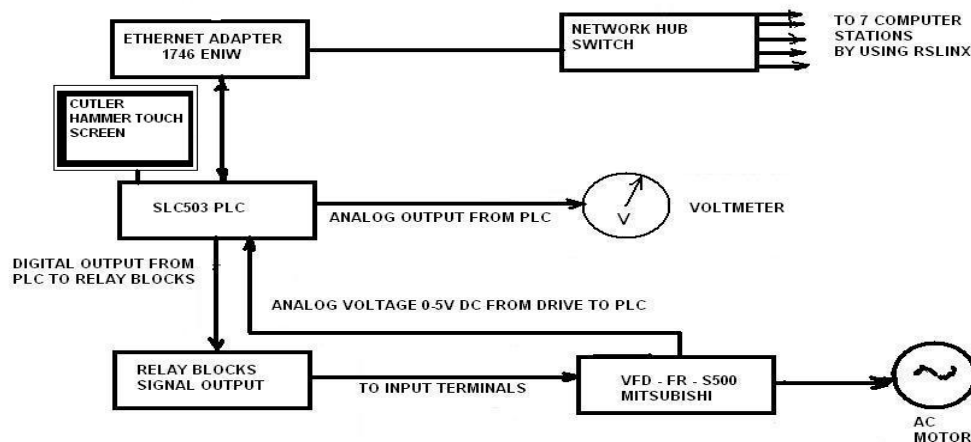

FIGURE 1: Any computer station can establish communication to the SLC5/03 PLC through the network hub switch and through the internet adapter (# 1746ENIW). At the same time, an AC motor (3-phase AC) runs commands from the PLC, transferring from the relay module to the Mitsubishi Variable Frequency Drive (VFD/FR/S500). The value of the frequency is converted to an analog voltage (0 to 5 volts) from the VFD; it is then read by an analog card. In this way, a closed-loop communication link is established between the PLC and the VFD.

During the project, students learned how to use the software FR Configurator to run the motor with different parameter sets and observe the effects. After the students decided which parameters were needed for the operation, they downloaded them into the VFD.

At the end of the project, different touch screen recipes for various applications had been created.

- **Recipe 1**
  Selector switch # 1 should be at the ON position. Press the start push button on the touch screen and select a value for the motor's speed. (The motor will run at one of three predetermined speeds.) The motor speed control parameter (expressed as voltage) is shown on the touch screen. Also shown is the motor's speed in RPM's.
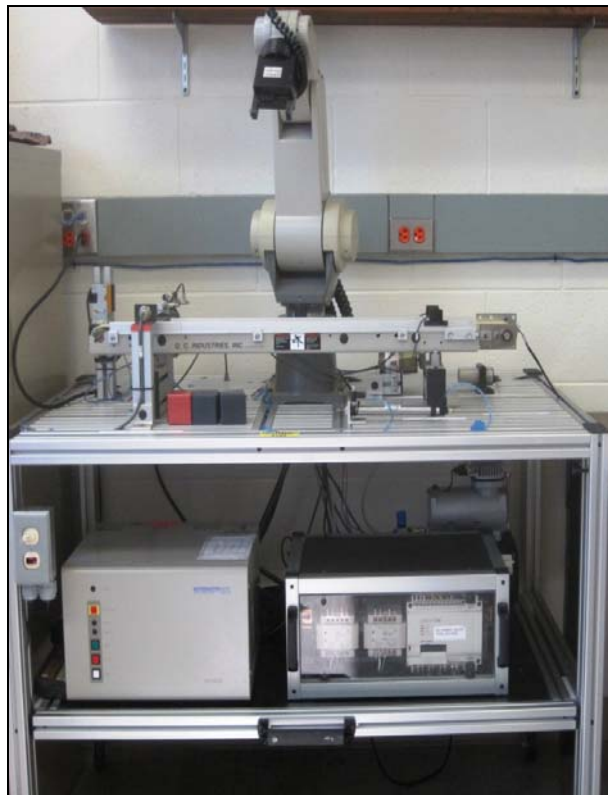

FIGURE 2: Robotic arm is shown, controlling a conveyor line, with optical, proximity, and capacitive sensors. A Mitsubishi PLC is located on a shelf below the arm and to the right, and a Mitsubishi RV-M1 robotic unit is on the same shelf, to the left.

- **Recipe 2**
  Selector switch # 1 should in the OFF position. In this mode, the motor will run continuously, first at a low speed (typically 50 to 100 RPMs), then at a medium speed (approximately 100 to 300 RPMs), then at a high speed (300 to 500 RPMs), then back to low speed, medium speed, etc. The analog voltage drive speed and RPM are displayed on the touch screen.

- **Recipe 3**
  This mode is designed to control the jogging operation by pressing the jog-forward or jog-reverse push button or touching the jog-forward/reverse icon on the touch screen. The motor will rotate forward or reverse, depending on which jog button is pressed. The analog voltage drive speed and RPM are displayed on the touch screen.

▪ **Recipe 4**
Establish motor control by reading the value potentiometer on the front panel. The speed can be increased from 0 RPM to a maximum of 500 RPM (as controlled by the PLC) by turning the potentiometer knob clockwise. To perform this test, the VFD parameter # 79 should have a value of 4.

3.2 PLC Programming and Robot Integration
The first author worked with a team of PLC students to design an automation conveyor line to implement closed-loop communications between the Mitsubishi robotic arm Roboware™ software and FX series Mitsubishi PLC. See Figure 2.

The major task of the project was to establish the communication and movements of the Robotics Arm using the Mitsubishi Movemaster RV-M1 series robotics kit. When the photo eye sensor detects the metal or plastic object on the loading area, the pneumatic cylinder then pushes the object to the part-detecting sensor (proximity sensor) (See Figure 3). If the object is plastic, the conveyor starts and stops at "position one," which is closer to the sensor. The robotic arm will move to pick up the plastic object and place it into "box one". If the object is metal, the conveyor stops when it is detected by the track sensor (see-through eye sensor) on the conveyor belt. The robotic arm moves to that position to pick up the object and place it into "box two".
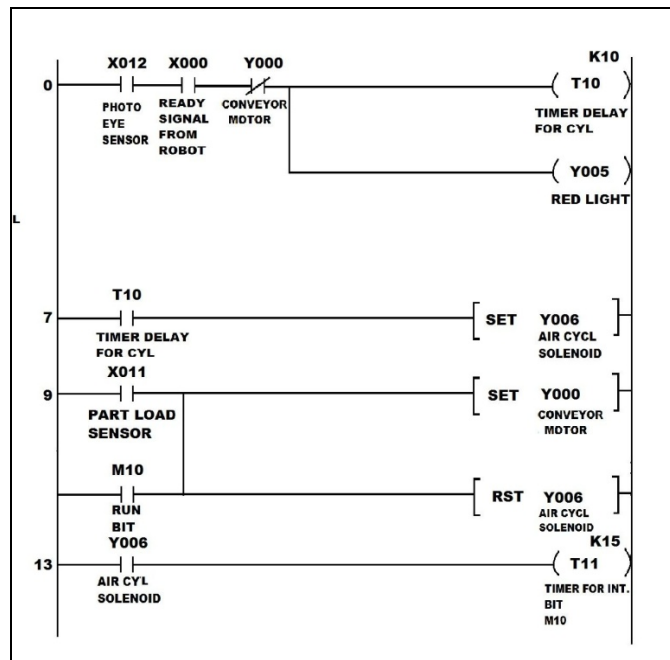

FIGURE 3: Controlling the belt movements (Y6), part present (X12), red light indicator (Y5) and ready signal from robot unit (X0), etc., presented in the ladder diagram. Constant communication between the robot controller and Mitsubishi PLC is provided through executing this program and running Roboware™ software.

The inputs and outputs are on the conveyor line, operated using the GX-Developer (Mitsubishi software). See Table 1.

Input	Address	Output	Address
Capacitive Proximity Sensor	X10	Conveyor Motor	Y00
Part Load Sensor (prox. sensor)	X11	Gear Motor	Y01
Photo Eye Sensor (loading area)	X12	Red Light	Y05
Track Sensor (end of the conveyor)	X13	Air Cylinder	Y06

TABLE 1: Programming of PLC and Robot

The command line to enter some commands such as MJ (Move Joint) is as follows:

Function: Turns each joint the specified angle from the current position. (Articulated interpolation)
(1)   The least input increment of the turning angle is 0.1, e.g. specify 15.2 for 15.2.
(2)   The open/close state of the hand does not change before and after the movement. Error mode II occurs before the axis motion if any turning angle entry exceeds the robot operational space.
(3)   The default turning angle is 0.

The position data table for pick and place scenario loaded into robotic amplifier can be found in Table 2.

Robotic Arm Position Data (PD)					
1	+254.6	+427.2	+174.6	-46.9	+32.2
4	-259.0	+185.1	+212.0	-87.0	+32.2
5	-256.6	+187.2	+236.0	-87.0	+32.2
6	-259.0	+185.1	+199.0	-87.0	+32.2
7	-259.0	+185.1	+235.0	-87.0	+32.2
8	-259.0	+188.1	+192.0	-87.0	+32.2
9	-259.0	+185.1	+263.0	-87.0	+32.2
10	-317.4	-24.5	+263.0	-86.9	+32.2
11	-324.5	-25.1	+43.1	-89.0	+32.2
12	-324.5	-25.1	+36.1	-89.0	+32.2
13	-324.5	-25.1	+44.1	-89.0	+32.2
14	+299.1	+182.9	+233.8	-81.0	+145.1
15	+297.9	+179.1	+196.4	-86.0	+145.1
16	+302.5	+184.8	+258.3	-76.9	+145.1
17	+22.2	+353.8	+258.3	-76.9	+174.7
18	+23.3	+371.4	+58.8	-92.0	+174.7
19	+28.8	+397.2	+44.9	-87.0	+174.7
20	-14.4	+281.1	+515.6	-49.0	+179.9

TABLE 2: Robotic Arm Position Data (PD)

3.3 Assessment
Assessment of student understanding and ability to implement a PLC's interaction with sensors, motors, and other objects were performed for both short-term and long-term assessment. (1) Short-term

assessment took place within the timeframe of an individual course. Each student was assessed by performance on eight homework assignments (20 percent of course grade), an in-class, mid-term exam (30 percent of course grade) and an individual, open-ended project, in which each student was expected to incorporate codes, commands, and design functions (50 percent of course grade). (2) Long-term assessment is conducted after course completion and post-graduation. Each student is surveyed periodically to determine how each component of the lab course has helped the graduate in his or her professional employment and career.

4. RESULTS
Students who successfully complete a laboratory course are able to: understand and implement different types of software packages for the purpose of robot control (such as GX-Developer or Roboware™ for Mitsubishi products or RS-500 and RS-5000 and Factory-Talk for Allen-Bradley products); and program Human Machine Interface (HMI) screens to integrate them into PLC control automation lines. After graduation, they can perform the tasks listed above and communicate intelligently with members of a team of designers working on automating any industrial process.

5. CONCLUSIONS AND FUTURE WORK
UBSOE's PLC Industrial Control Lab will continue to provide critical laboratory education for graduate engineering students. Further, the authors envision that the Lab will assist local companies in hardware design and manufacturing and provide the necessary software programming for different applications in process automation.

6. ACKNOWLEDGEMENT
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