PLC in Industrial Controls Course

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Abstract:

Electrical and computer engineering programs typically help students learn fundamental concepts and skills, but also desire to help the students become exposed to and learn some industrial applications. For example, many programs have courses in analog and digital circuits, microcontrollers, signals and systems and feedback control. This knowledge is the basis for industrial control applications, such as those that utilize programmable logic controllers (PLC). Many industrial processes utilize the PLC as a primary acquisition device for sensors and a controller for actuator. Many electrical and computer engineering students may not have used a PLC prior to working in industry. In an effort to bridge the gap, we recently developed an industrial controls course that covers the concepts, devices and common practices associated with control systems, with a primary focus on industrial applications. This course explores the hierarchical implementation of industrial control theory. Students acquire knowledge and develop skills related to PLC systems, which serve as the primary edge node for sensors, actuators and communication in many industrial applications. Electrical industrial engineering and safety standards are also presented throughout the course.

This industrial control course is offered for graduate students in Electrical, Computer, Mechanical, or Civil Engineering majors. Some upper level undergraduate students who meet a GPA requirement may also enroll in the course. The course structure is 2-hour lecture, 2-hour lab, for a 3-credit course. The following topics are introduced to students: feedback control, digital controllers, state diagrams, ladder logic diagrams, PLC implementation, manufacturing flow line analysis, hierarchical control, and network communications. Problem sets related to these topics were assigned. In order to improve motivation and learning, application-oriented and hands-on PLC design labs and projects were developed. Click Koyo Model C0-12DRE-2-D PLCs were used in the course.

Evaluations were based on student surveys and course evaluations. The course was first offered in Summer 2022 and again in Summer 2023. Overall 19 students have taken the course. All students finished the PLC labs and projects and took the survey. The results are that 95% of students “agree” or “strongly agree” that PLC labs and projects helped them to apply course material to improve thinking and problem solving, and 89% of students “agree” or “strongly agree” that PLC labs and projects related course material to real life applications.

Introduction

At our university, this Industrial Control course is offered to graduate students in the school of Engineering, as well as some upper-level undergraduates who meet a GPA requirement. This course covers the concepts, devices and common practices associated with control systems, with a primary focus on industrial applications. The course explores the hierarchical implementation of industrial control theory. Students will acquire knowledge and develop skills related to programmable logic controllers (PLCs), which serve in many industrial applications as the primary edge node for sensors, actuators and communication. Electrical industrial engineering and safety standards are presented throughout the course. The expected background for students includes knowledge of feedback and control systems.

The course has learning objectives and a flow of topics [1].

1. Demonstrate familiarity with the historical progression of control systems.
2. Analyze and use concepts of manufacturing hierarchical control and industrial control systems.
3. Apply discrete logic control to industrial control scenarios.
4. Analyze production models and flow lines in manufacturing.
5. Develop and use models of physical systems for analysis and design of control systems.

The topics of the course are listed.

- Introduction to process control
- Types of control: feedback, tracking, PID, digital, adaptive, state machine
- Types of logic: Boolean, ladder
- PLC implementation and applications
- Production types, concepts and models
- Manufacturing flow line analysis, line balancing, hierarchical control, network communications, production control
- Historical progression of control systems

PLCs are used to implement industrial controls that need to be reliable and robust, and may be complex and critical. PLCs take inputs from sources like sensors or switches and generate outputs like command signals for actuators [2]. PLCs can communicate, monitor, and control complex automated processes such as conveyors, temperature control, robot cells, and many other industrial machines [2]. PLCs are configurable, reliable, and over several decades have been the backbone of many industrial processes, such as Manufacturing Production Lines, Chemical & Petrochemical, Energy & Utilities, Pulp & Paper, Oil & Gas, Water and Wastewater Treatment, Pharmaceutical, Food, Tobacco, & Beverage, Automotive [2].

PLCs are a part of some engineering programs at universities [2-10]. The use of PLCs in an educational program allow students to apply concepts of control systems, and gives a more hands-on experience. This paper presents examples and effectiveness of PLC labs and projects that were developed for and used in the course, and assessment from student feedback (collected via a survey) and course evaluation.

Design of PLC Labs and Projects

This Industrial Controls course has a weekly structure of a 2-hour lecture, 2-hour lab, for a 3-credit course. For the laboratory activities, 5 PLC labs and 2 projects were designed. All labs and projects were done individually. Click Model C0-12DRE-2-D (Automation Direct, Cumming, GA, USA) PLCs were used in the course. Features of the Click Ethernet Analog PLC include 24 VDC power, ethernet and serial ports for communications, discrete Input (4-point, DC), analog input (4-channel, voltage), discrete output (4-point, relay), and analog output (2-channel, voltage). The utilized programming software was Click programming software v2.20 or later.

Table 1 shows the nine labs and the objective of each lab.

Table 1. List of Labs and Objectives

Labs	Lab Objectives
Lab #1 Introduction to Click PLCs	• To become familiar with the operation of the Click Model C0-12DRE-2-D PLCs
Lab #2 Quiz Game	• To become familiar with basic ladder logic
Lab #3 Automatic Box Filling System	• To become familiar with logic gates
Lab #4 Stepper Motor Control	• To become familiar with timers and counters
Lab #5 4-way Traffic Lights	• To become familiar with subroutines to perform actions that are frequently repeated

As an example of the developed PLC labs, the third PLC lab Automatic Box Filling System is shown in Figure 1.

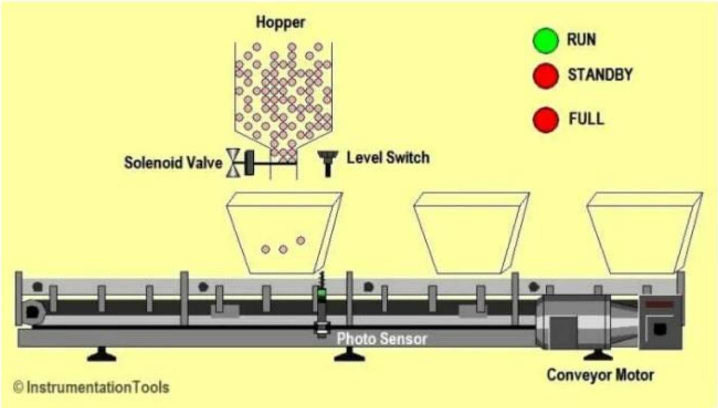


Figure 1. Automatic Box Filling System

Students were asked to develop a ladder logic program to simulate the system according to the given below.

1. Energize the RUN status light when the process is operating.
2. Energize the STANDBY status light when the process is stopped.
3. Stop the conveyor and energize the standby light when the right edge of the box is first sensed by the photo sensor.
4. With the box in position and the conveyor stopped, after 3 seconds open the solenoid valve and allow the box to fill.
5. The filling should stop when the level sensor goes true.
6. Energize the FULL light when the box is full. The FULL light should remain energized until the box is moved clear of the photo sensor.

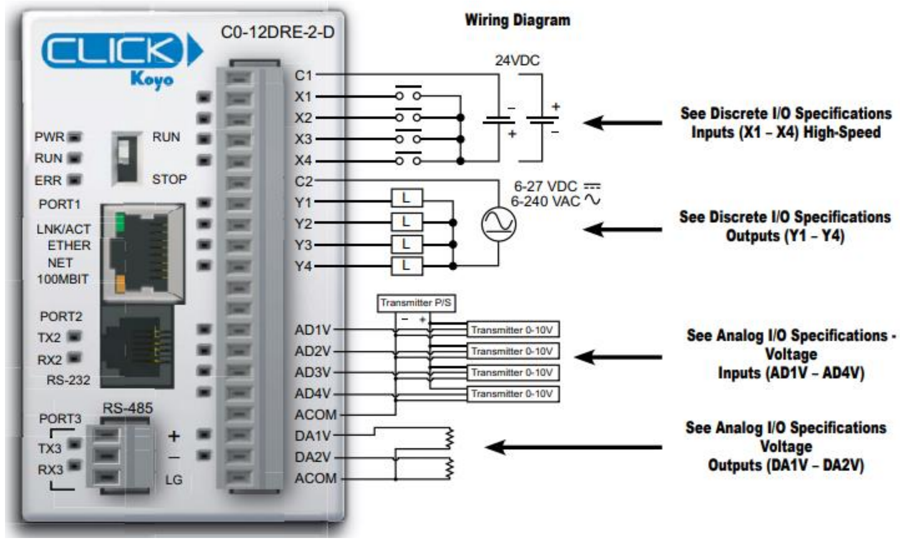


Figure 2. Wiring diagram for Click C0-12DRE-2-D

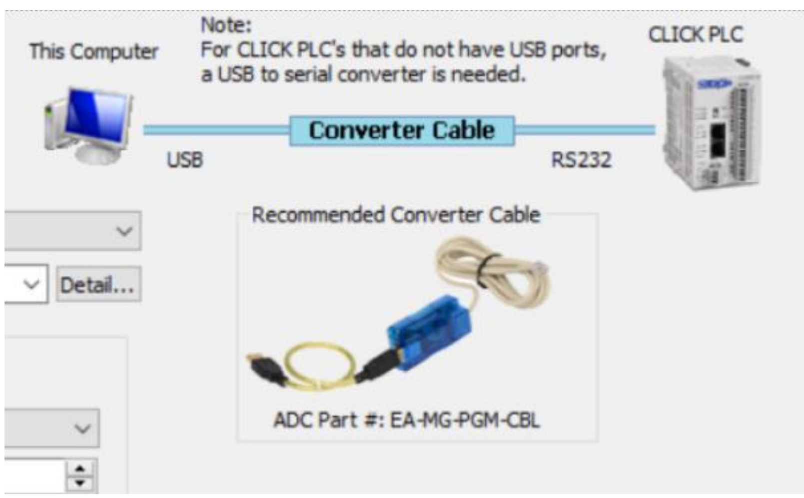
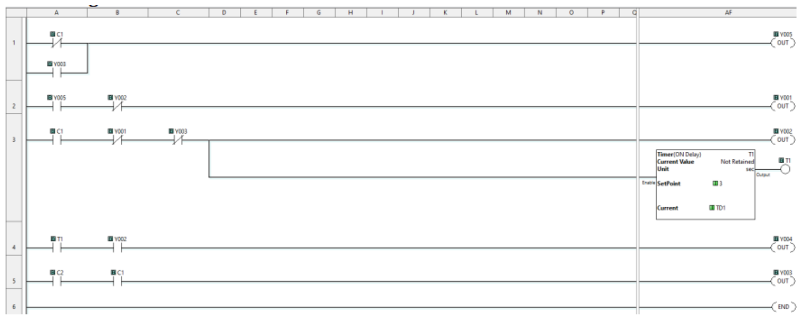


Figure 3. Connection from PLC to PC

The Click Koyo PLC included many discrete inputs and outputs which were needed for this lab. A 24 volt power supply module had to be connected to the PLC in order to provide extra power needed to turn every component on and made it work. The module was called the C0-01AC power supply and it would connect directly into a standard wall outlet. Figure 2 shows wiring diagram for Click C0-12DRE-2-D, and Figure 3 shows connection from PLC to PC. A student sample programming work is shown in Figure 4.



Inputs:
C1: Photo Sensor
C2: Level Sensor
T1: 3 second timer

Outputs:
Y001: Run Light
Y002: Standby Light
Y003: Full Light
Y004: Solenoid Valve
Y005: Motor

Figure 4. Student sample work for Lab 3 Automatic Box Filling System.

For the remainder of the lab periods, the students were to work on two individualized projects. Examples of projects by the students include Automatic Washing Machine system and Fluid Tank Control.

Controlling the level of fluid in a tank is required in many applications, including food or chemical industrial processes, fluids for engines and machines, and residential appliances. With this motivation, the student designed, fabricated, and tested a prototype system. A PLC was programmed as the controller.

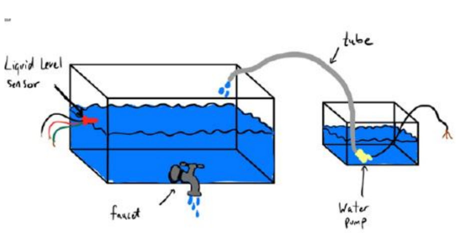


Figure 5. Project diagram

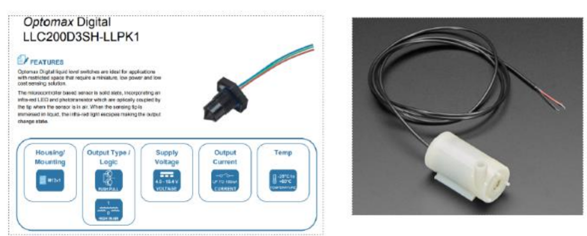


Figure 6. Water Level Sensor and Water Pump

Figure 5 shows a diagram of the system. There were two discrete inputs and one discrete output. In Figure 6, the inputs were the water level sensors, and the output was the water pump. In this project, the water level sensor and the water pump would both be either ON or OFF and no in-between. The logic of the controller used the valves from the water sensors to control the water running.

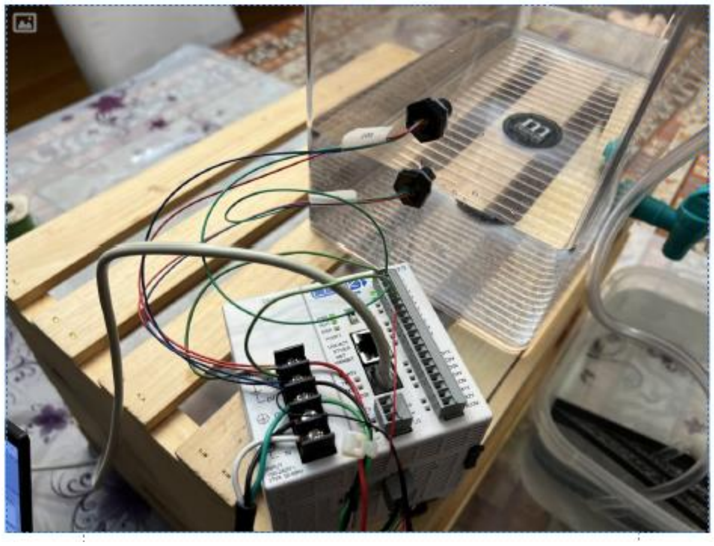


Figure 7. PLC connection

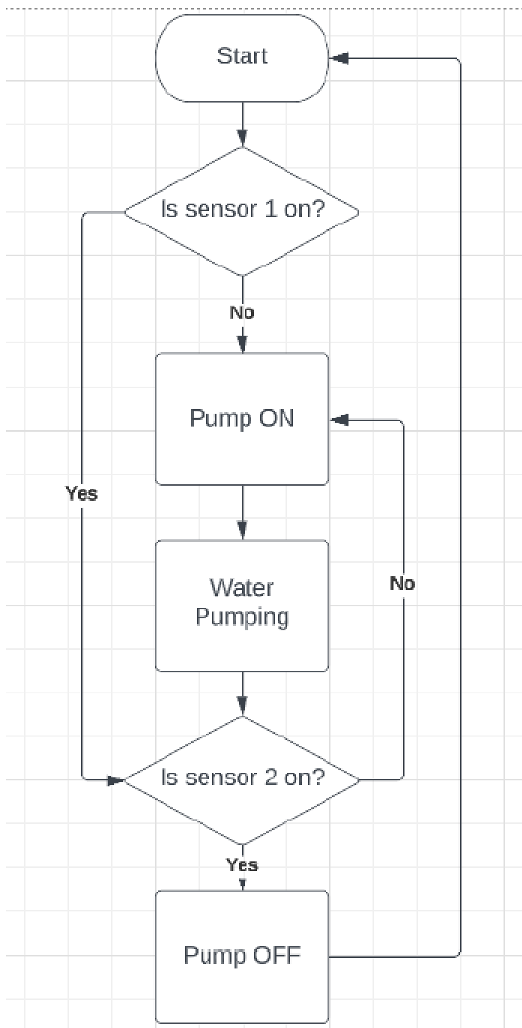


Figure 8. Programming flow chart made during a student project using PLC device

Figure 7 shows PLC connection. Figure 8 shows the programming flowchart of the controller logic. This was used to control the fluid levels in the tank.

Course Assessment of PLC Labs and Projects:

Course evaluation was conducted during the last two weeks of the semester to collect feedback to evaluate what the students thought about the course objectives. Of the 19 students who took the course over the two offerings in the Summer 2022 and 2023, 13 students completed the course evaluation. The results were 92% of students "agree" or "strongly agree" that they gained a basic understanding of the subject (Figure 9), and 92% of students "agree" or "strongly agree" that they developed specific skills, competencies, and points of view needed by professionals in the field most closely related to this course (Figure 10). 62% of students "agree" or "strongly agree" that they developed creative capacities (Figure 11). 77% of students "agree" or "strongly agree" that they learned to analyze and critically evaluate ideas, arguments, and points of view (Figure 12).

Another survey was conducted the last week of the semester to collect feedback to evaluate what the students thought about the PLC labs. All 19 students finished the PLC labs and projects, and took the survey. 95% of students "agree" or "strongly agree" that PLC labs and projects helped them to apply course material to improve thinking and problem solving (Figure 13). 89% of students "agree" or "strongly agree" that PLC labs and projects related course material to real life applications (Figure 14).

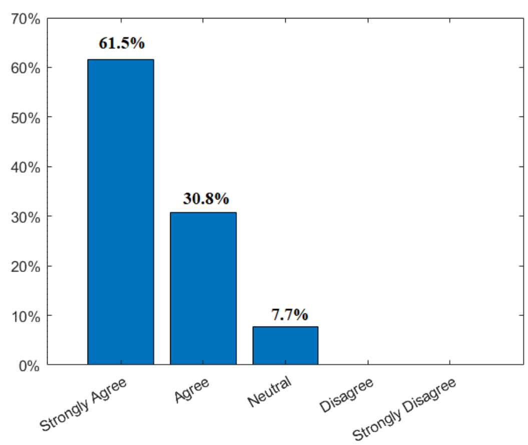


Figure 9. Gain a basic understanding of the subject

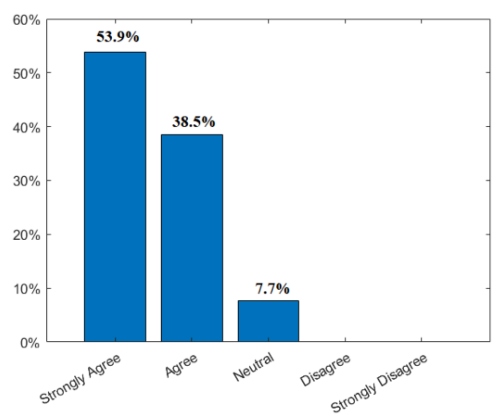


Figure 10. Develop specific skills, and points of view needed by professionals in the field most closely related to this course

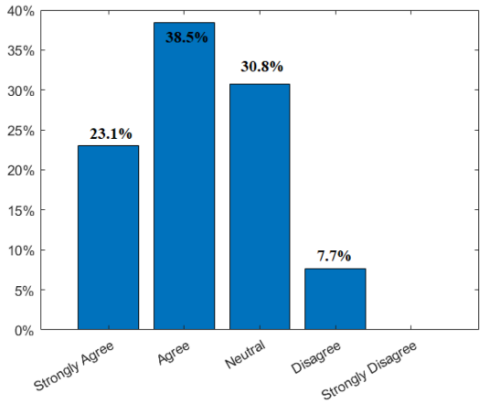


Figure 11. Develop creative capacities

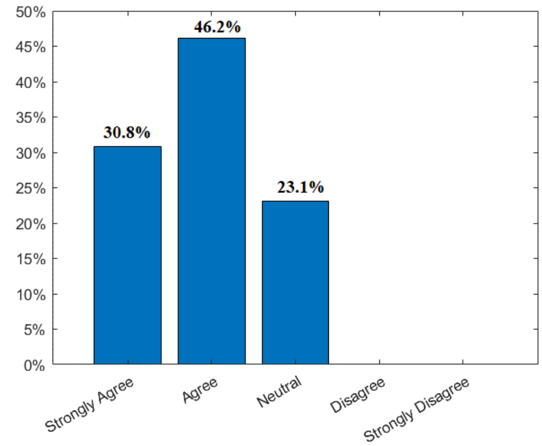


Figure 12. Learn to analyze and critically evaluate ideas, arguments, and points of view

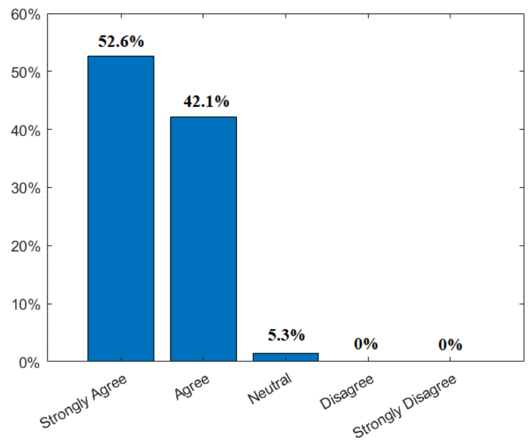


Figure 13. PLC labs and projects helped improve thinking and problem solving

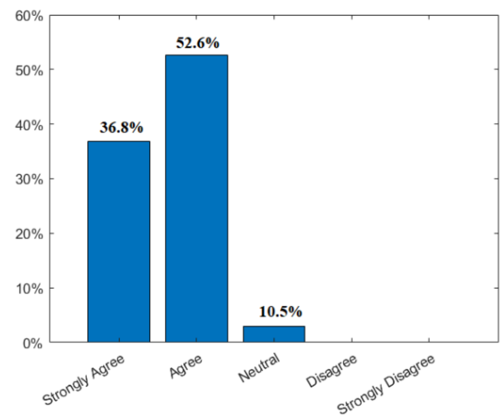


Figure 14. PLC labs and projects related course material to real life applications

Discussion and Future Directions

University engineering programs primarily teach fundamental concepts and skills, but also strive to expose and develop skills for more recent developments and industrial applications. This study described a recently developed course intended to review certain fundamentals, apply to industrial control, and develop skills using PLC devices. The course topics and lab activities appears to be exposing students to industrial controls and developing skills related to PLCs. Based on the survey, students felt that they gained basic understanding, developed competencies and skills, and critically analyzed ideas. Regarding the PLC based labs and projects, the students felt that the PLC related activities helped them better understand industrial controls.

The course could be improved more in the future to better expose and prepare students. More physical apparatus could be set up to mimic various industrial control modules and have the students develop PLC programming and connections to control and test. Some of these setups could be based on prior student projects. Such as the described Fluid Tank Control system. Other new labs could have the students develop communication for the PLC using serial protocols used in industrial applications, and also communicate over ethernet to internet web services. These labs would help expose and develop relevant skills even more.

Such efforts such as described for this course contribute to the efforts of many engineering programs to expand ways to expose and develop relevant skills in students to prepare them for industrial and commercial careers and applications.

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