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Training Engineers and Technologists via Model Trains

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Training Engineers and Technologists via Model Trains

Abstract

This paper looks at a novel way to teach Programmable Logic Controls via N-Scale Model trains. Many electric machinery courses have a component that covers Programmable Logic Controllers (PLCs), since they are widely used in industry to control motors and provide supervisory control for variable speed drives. A problem with teaching PLCs is that they are used to control large and usually very expensive equipment. This makes developing a realistic laboratory experience very difficult. Most labs consist of toggle switches and pushbuttons for inputs and lamps for output. More elaborate process control systems are available from several lab equipment manufacturers, but these systems are expensive and the students sometimes have difficulty understanding the process they are trying to control. Several years ago the author began using N-Scale model trains as the system being controlled. This provides a small and low cost system with the added benefit that the students immediately understand the proper operation. Optical sensors are placed around the track for position and speed control. The speed and direction of the train is set via an analog output from the PLC. Two track switches are also used to change the train from inner and outer loops. When combined with the existing toggle switches, pushbuttons, and lamps; this makes a realistic system for developing controls. If you add an operator interface panel, the students can develop full scale systems similar to those found in industry.

This paper covers the materials used for the basic N-Scale layout and the additional hardware necessary to interface with the PLC. The inputs to the PLC are 120 V optical sensors, so no additional interfacing is needed. The outputs are one analog signal (a variable voltage) and four 120 V digital signals. All of these need to be modified. The PLC analog output does not provide enough current to drive the train, so a power op-amp circuit is used. The track switches require 18 V ac, so the 120 V outputs are used to control an 18 V supply via relays.

The student response to using this system has been extremely positive. The system has been used by electrical, industrial, and mechanical engineering students, as well as by electrical and mechanical technology students. As a senior design project, the base system was expanded into an elaborate system with four optical sensors, two inductive proximity sensors, and a limit switch that could allow two trains to operate simultaneously. The system was also used for special project classes at the undergraduate and graduate level. The student feedback and learning assessments for all these cases is included in the paper.

Background

This paper discussed a novel way to approach the teaching of Programmable Logic Controllers (PLCs) via N-Scale Model trains. A problem with teaching PLCs is that they are generally used to control large and usually very expensive equipment. This makes developing a realistic laboratory experience very difficult. Most labs consist of toggle switches and pushbuttons for inputs and lamps for output. An example of this type of interface is shown in Figure 1. While more elaborate process control systems are available from several lab equipment manufacturers, these systems are very expensive. An additional problem is that the students sometimes have difficult time understanding the process they are trying to control. In 2008 the author began using N-Scale model trains as the system being controlled. This provided a small and low cost system with the added benefit that the students immediately understood the proper operation.

The features of the system were (the first three items are shown in Figure 2):

- Optical sensors are placed around the track for position and speed control.
- The speed and direction of the train is set via an analog output from the PLC.
- Two track switches are also used to change the train from inner and outer loops.
- An operator interface panel, so that the students can develop HMI systems similar to those found in industry.

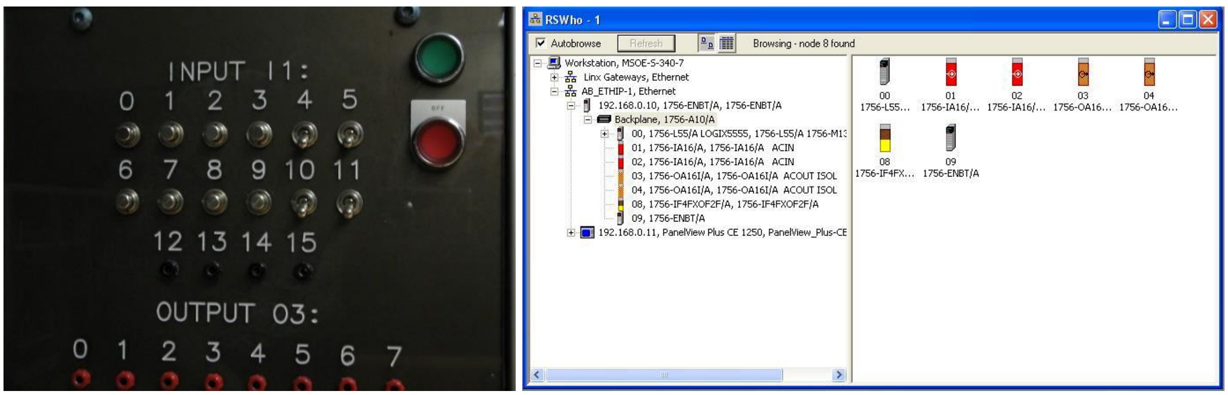

Figure 1. Basic Input / Output System for PLC Showing the External Connections and Internal Hardware of the PLC

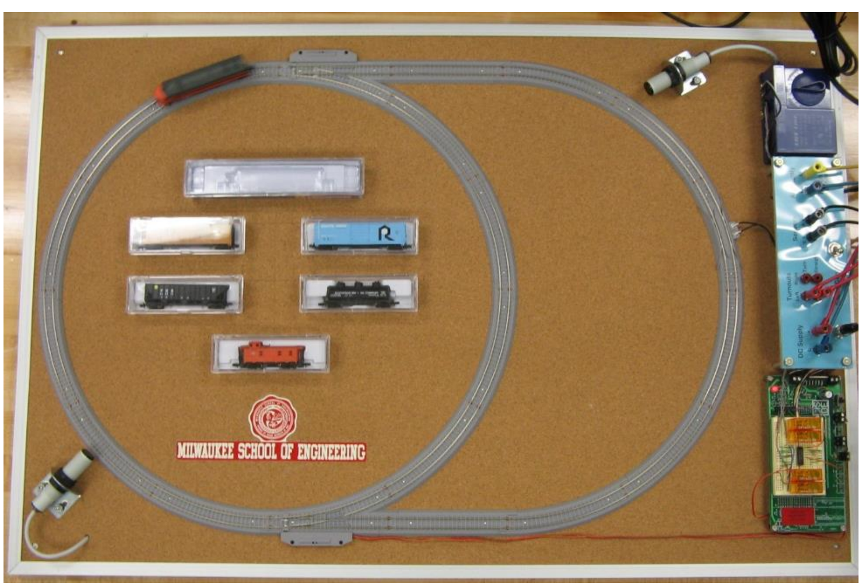

Figure 2. Initial System

Track Voltage Controller

The input/output analog module on the PLC has a ±10 volt analog output that can provide at most 0.021 amperes[1]. This is not enough to drive the locomotive. Therefore, an interface must be used. The initial system used pulse-width modulation (PWM) to provide the driving voltage. This system is shown in Figure 3. It was found that the motors on the locomotives would overheat after about an hour using this system. Through discussions with model railroading enthusiast, Dr. Russ Meier, it was learned that this problem had been known for some time N-Scale community. The PWM system was replaced with a high-voltage, high-current operational amplifier based system shown in Figure 4. The parts list for the controller is given in Table 1.

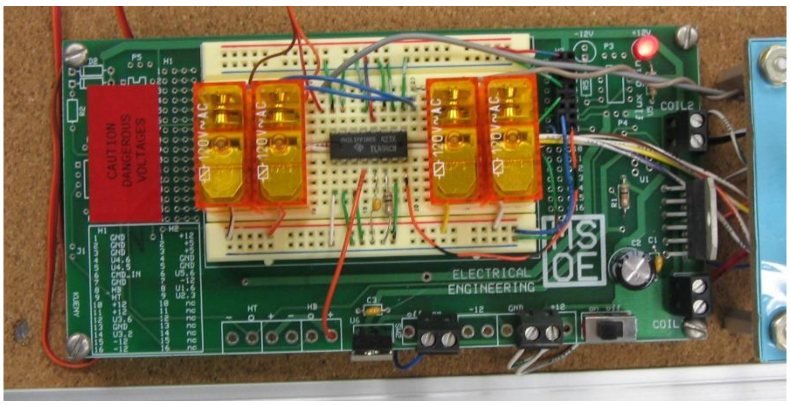

Figure 3. Initial Controller System Using PWM

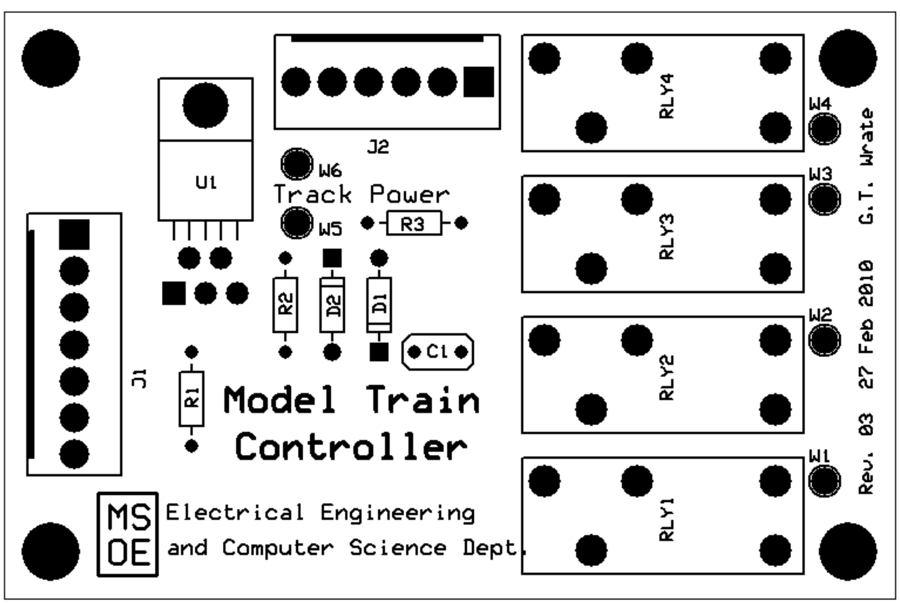

Figure 4. Final Controller Design

Table 1. Parts List for Controller

Part Designation	Value / Part Number	Description
C1	0.01µF	Capacitor
D1	MUR420	Diode
D2	MUR420	Diode
J1	Molex	7 pin Connector
J2	Molex	6 pin Connector
R1	10 kΩ	Resistor
R2	10 kΩ	Resistor
R3	1.0 Ω	Resistor
RLY1	40.51.8.120	Relay
RLY2	40.51.8.120	Relay
RLY3	40.51.8.120	Relay
RLY4	40.51.8.120	Relay
U1	OPA544	Power Op-Amp

Track Switching

The track switches, known as turnouts, are operated by two 18 volt AC coils. When one coil is energized the track is switched to the straight or through position. Energizing the opposite coil moves the switch to the turn or diverge position. Energizing both coils at once causes a damaging oscillation and buzzing sound. If either of the coils are energized for more the a few seconds the coils overheat and are permanently damaged. This gives a very realistic constraint for the students to design the system – the switching must be interlocked and timed so as to not damage the turnouts. Interposing relays are also used with the turnouts since the PLC outputs are 120 V. The interposing relays have 120 volt AC coils. The single-throw contacts are used to energize the turnouts via the 18 volt AC supply that came with N-Scale train set. The remote controlled turnouts are shown in Figure 5 and the interposing relay is shown in Figure 6.

Figure 5. Remote Controlled Turnouts

Figure 6. Interposing Relay

Use in Student Projects

In addition to the traditional classroom, the system was also used for special project classes at the undergraduate and graduate level. An example of the system being used by a group of Mechanical Engineering students is given in Figure 7.

Figure 7. N-Scale Train Used in Conjunction with a Robotic Arm by Mechanical Engineering Students

Senior Design Project

As a senior design project, the base system was expanded into an elaborate system with four optical sensors, two inductive proximity sensors, and a limit switch that could allow two trains to operate simultaneously. This expanded system is shown in Figure 8.

Figure 8. Expanded System Developed as a Senior Design Project

Student Feedback and Learning Assessments

The initial student response to the system was very positive. The first class, in 2008, consisted of 17 students. Their comments of the project that utilized the system were universally positive, with more than one student stating that was the best course they had taken. The last class using this system, in 2013, was not as positive. Their complaints ranged from hardware failures to the level of difficulty of the project. As far as the lab hardware is concerned, the complaints were well-founded. The lab was using Windows 98™ vintage computers and five of the eight benches failed during the course of the term. The complaint about the project being too hard, impossible according to some, has more to do, I believe, with the academic maturity of the students. The project requirements were only changed slightly from year to year. But, in 2008 all of the students taking the course were senior standing, while in 2013 there were juniors and at least one sophomore taking the course.

Table 2. Number of Undergraduate and Graduate Students Taking the Course and Overall Student Satisfaction

Term	Number of Undergraduate Students	Overall Course Satisfaction (5.0 highest)	Number of Graduate Students	Overall Course Satisfaction (5.0 highest)
Fall 2008	17	4.36	0	
Spring 2010	19	4.41	7	4.81
Fall 2010	28	4.40	0	
Fall 2011	20	4.14	3	4.29
Fall 2012	22	4.36	5	4.92
Fall 2013	23	3.06	5	N/A

Lab Assignments

The objective of the first lab assignment was to design a simple on/off and a simple start/stop control system using just the PLC and the basic switch panel shown in Figure 1. This assignment introduced the concept of tags and ladder logic. Some of the safety aspects of starting devices in an industrial environment were also addressed. The suggested process to follow to complete this lab was:

1. Create a hardware configuration file you can use throughout the term
2. Define the tags you will be using in your ladder logic program
3. Design the ladder logic
4. Test your logic and verify correct operation
5. Write a memo to your instructor detailing your ladder logic

The objective of the second lab was to design a user interface for a simple start/stop control. This assignment introduced user interfaces, also called Human Machine Interfaces (HMIs). In this assignment the student replaced the pushbuttons and indicating lamp used in the previous assignment with a user interface on the VersaView touch screen display. The suggested process to follow to complete this lab was:

1. Create a simple PLC ladder logic program for start/stop control using the skills from the first assignment
2. Design a user interface using FactoryTalk View Studio
3. Test your interface in interactive mode on the PC
4. Download your interface to the VersaView and verify correct operation
5. Write a memo to your instructor detailing your ladder logic and user interface

The objective of the third lab was to design a PLC-based system that monitors the speed of an N-Scale train. In this assignment the student used the two optical sensors and PLC-based timers and counters to count the number of times a train passes a certain point and to determine the time the train takes to go for one point to another. Based on this data, the student's ladder logic program will calculated the average speed of the train. The suggested process to follow to complete this lab was:

1. Use the template created in the first lab assignment to start your project
2. Define the Counters and Timers needed for the project
3. Design your ladder logic
4. Test your ladder logic
5. Design your HMI
6. Test and confirm proper operation of the complete system
7. Write a memo to your instructor detailing your ladder logic and user interface

Course Project

Over last half of the term, the students designed and implemented a PLC/HMI based control system for the N-Scale train sets in the lab. The project requirements were as follows:

- The design must consist of at least two HMI screens, one of which should display the speed and location of the train and another that allows the user to select one of at least three different schedules (sequences of operation).
- Some examples of different schedules are:
    - a local train that stops at each sensor
    - a unit train that completes five loops before it stops
    - a local train that travels once on the inner loop and then once on the outer loop
- Your design should not allow the user to operate the train in an unsafe mode and it must check for proper operation of the train – has the train left the tracks or stalled.

The student was required to demonstrate the operation of their design to the instructor during the last two weeks of the term. Demonstrations times were randomly assigned. To receive a letter grade of "B" for this portion of the course the student needed to demonstrate that their system met the minimum project requirements within the allotted time slot.

A formal project report on the project was due by Thursday at 5:00 pm of final exam week. The report requirements were given in exhaustive detail in the project handout and the grading metric for the report is shown in Figure 9 below.

EE-474/EE-574 Project Report Grading

Task	Points Possible	Completed / Correct?	
		Yes	No
Page numbering	2		
Heading styles	2		
Table of Contents	2		
Table of Figures	2		
Table and Figure captions and numbering	2		
Title page	2		
Executive summary	4		
Introduction: (1) provides the context for your project	2		
Introduction: (2) states what function your project is designed to perform	2		
Background	3		
Project description	5		
Results and discussion	2		
Conclusion and recommendations	4		
References	1		
Appendix	5		
Total	40		

Figure 9. Grading Metric for Formal Project Report

Conclusions

The use of an N-Scale model train in the laboratory setting of a PLC course is a very effective tool. The student response, when the rest of the equipment in the laboratory was working correctly, was very positive. This is seen in the average student satisfaction of above 4.0 for those terms. The initial cost of the systems are very low, and most parts are available at your local hobby store. The only caveats are using the correct type of voltage controller (not PWM) and interposing relays for the track accessories (the switches).

References

1. Rockwell Automation Publication 1756-TD002H-EN-E - December 2014