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Work In Progress: A PLC Trainer With Hands-on Wiring

Dr. Hugh Jack P.E., Western Carolina University

Dr. Jack is the Cass Ballenger Distinguished Professor of Engineering and Department Head of the School of Engineering and Technology within Western Carolina University. His interests include robotics, automation, and product design.

Dr. Paul M Yanik, Western Carolina University

Dr. Paul Yanik is an Assistant Professor of Electrical and Computer Engineering Technology at Western Carolina University. His research interests include human-robot interactions, assistive devices, pattern recognition, machine learning, and engineering education.

Mr. Jerry N. Denton Denton, Western Carolina University

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Abstract

A low cost Programmable Logic Controller (PLC) training platform has been designed, built, and used in an introductory undergraduate PLC class. Instead of providing pre-wired equipment, the trainers supply industry standard components. Students are taught to interpret industrial wiring diagrams and connect hardware in the first week of a semester long course. Throughout the semester the students are constantly modifying the wiring. The result are students that are better prepared for industrial design and build of PLC controlled manufacturing equipment.

The paper outlines the design and construction of these low cost trainers. The trainers are presented as independent of PLC vendors and may be constructed for less than $700 per station without the PLC. A low cost PLC may be purchased for a hundred dollars or more to create a fully capable trainer. An example of lecture materials and student work are presented.

Introduction

Programmable Logic Controllers (PLCs) are widely used in customized control systems and are used in most manufacturing facilities. Estimates for the current global controls market fall around $10 Billion per year [1]. Given that PLCs are one small component of the systems they control, the automated equipment industry revenues are significantly higher. The equipment making industries are heavily reliant on higher education. Entry level work for automation typically requires electrical and machining knowledge. Associates degrees are typically the minimum requirement for lower level system design, programming, debugging, and testing. Engineering and Engineering Technology graduates typically do mid- to high-level research, design, programming, debugging, and testing.

The approach to teaching PLC based controls varies by program type. Bachelor’s degree programs will frequently survey many aspects in one higher-level course. Associates degree programs may offer a series of in-depth courses. Of course, the program focus is critical in determining the extent of the coverage. Fields that typically address PLCs include Mechatronics, Manufacturing, Electrical Technology, and Chemical Engineering. Naturally this includes the underlying specialties, such as licensed electricians.

Pedagogically, PLC courses have a few complimentary topics including wiring, applications, basic programming, advanced programming, specialized sensors, feedback motor control, networking, and communication. At the Bachelors level, Mechanical and Manufacturing programs have limited space in the curriculum and electrical wiring often gets removed to allow more time for programming and advanced topics. To facilitate this approach schools purchase PLC trainers that are prewired with lights, buttons, pneumatic valves, and motors. The students that use these can have a good programming experience, although this comes at the expense of exposure to the hands-on basics of wiring safety, sensors, and actuators.

For those schools seeking pre-wired solutions there are many excellent suppliers including Edibon[2], Armfield[3], Festo[4], and many more. These systems often provide very clean interfaces with an array of capabilities, prepared curriculum, and specialized options. This paper describes non-commercial PLC trainer units that provide a framework that allows students to do basic wiring and modify the electrical design on a weekly basis. The instructor is then free to add components as needed. In situations that are budget constrained, as is ours, more expensive components may be purchased as funds become available.

ET 472 – Integrated Control Systems

The School of Engineering + Technology has a B.S. degree in Engineering Technology with a concentration in Applied Systems Technology. The focus of the program is to prepare student for roles as designers and/or manufacturing engineers. Student in this program learn a broad set of topics related to manufacturing. In the fourth year of the program students have a course that focuses on PLCs. The semester long course is a lecture/lab format with 2 hours of lecture mixed with 2 hours of lab.

In the past, the course has focused on programming Siemens PLCs that were integrated with prebuilt mechanical and electrical hardware. In 2017 the school received a donation of much newer generation of Allen Bradley PLCs. This prompted a re-visioning of the course experience. In the Fall of 2017, planning began for a refresh of the course and laboratories. New laboratory stations were designed and built. Lecture and laboratory experiments were updated to use the Allen-Bradley PLCs. The stations were first used in January 2018.

The new laboratory structure delayed the start of programming topics by a week. In the first lectures and labs, students used a basic system wiring ladder diagram including safety circuitry. In lab they learned the fundamentals of electrical controls wiring and performed basic wiring for sensors and actuators. This was facilitated by a lab station design where the students began with a rolling cart that had a back panel with DIN rail mounted. (Note: DIN is the acronym for a German standards group that developed a standard mounting rail for electrical equipment.) Students were provided standard DIN rail mountable hardware and guided through mounting and the wiring for the basic disconnect, fusing, and start/Estop with MCR. Other first week wiring tasks included a DC power supply, PLC, and a sensor.

The General Design

In brief, the design concept was to have highly portable trainers that students could move for wiring and programming, and the department could move for storage. Two of the trainers are shown, from the side, in Figure 1. They are positioned beside tables with computers for programming, but can easily be unplugged from the outlets and Ethernet cable for wiring elsewhere. Similarly, each student team could program and test on their local trainer, and download via Ethernet to a central test station for evaluation by the instructor.

All of the components were purchased to minimize construction time. The carts, were purchased from a wood working equipment supplier. The carts have lockable wheels and tilting tops. The horizontal tilting configuration is used when wiring, and the vertical configuration is used when programming. The top holds a metal backplane with mounted DIN rail and wire trays. A plastic enclosure box is mounted to the right to hold inputs and outputs. Both the backplane and enclosure were connected to the frame with Velcro.

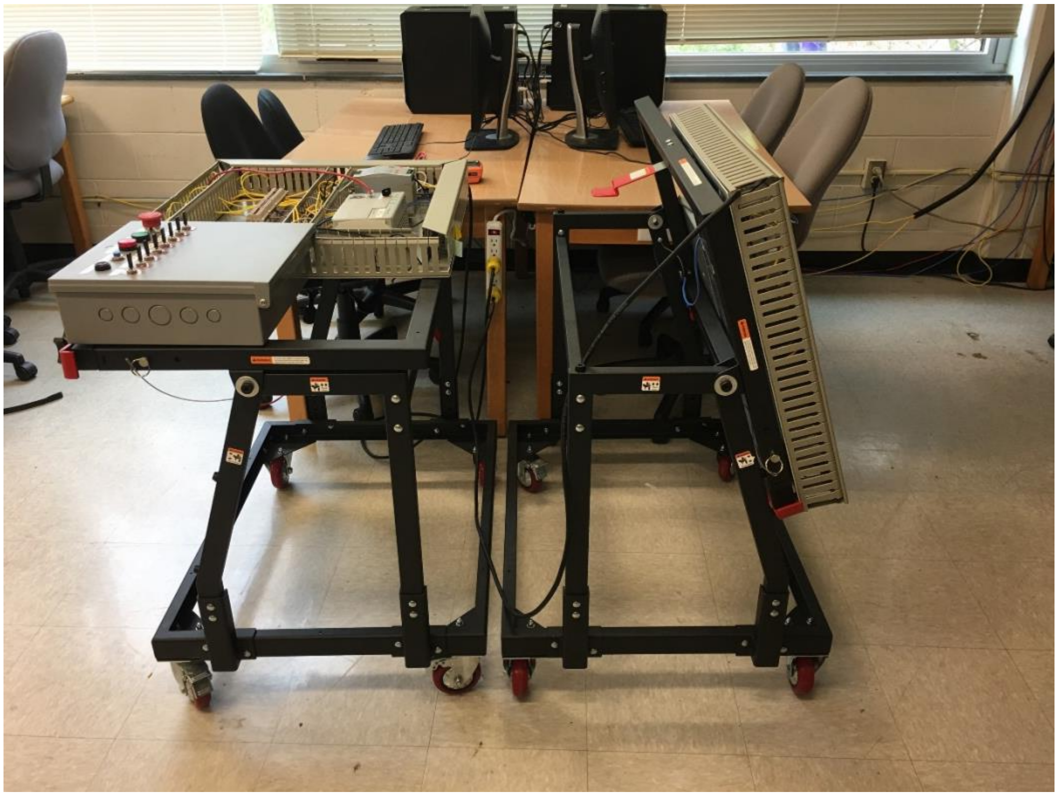

Figure 1 – Two Trainers Positioned Back-to-Back

Table 1 shows the major equipment purchased for each cart, an approximate cost, and suppliers. Given the nature of industrial automation, all of these components have alternate options. Although the carts use Allen Bradley PLCs, there are excellent alternatives from Siemens, Mitsubishi, Automation Direct, and many more.

Table 1 – Equipment List Per Cart

Item Description	Quantity	Price, each	Our Supplier
Allen Bradley L23 PLC (Note: Donated)	1	[[$3530]]	Donated
Rockler Material Mate Panel Cart and Shop Stand	1	$249.99	Rockler.com
Rockwell Software Education Kit	1 seat/yr	[[$175/yr]]	Reseller
Interface Control Relay	1	$10.99	Amazon
Enclosure Plastic 12”x12”x4”	1	$39.98	Amazon
120Vac to 24Vdc 5A Power Supply	1	$37.72	Amazon
Back Panel 24” by 24”	1	$62.14	Amazon
Open Slot Cable Raceway (3” x 3”)	2	$36.98	Amazon
15A DIN Mounted Circuit Breaker	1	$20.54	Amazon
DIN Rail Terminal Block Kit with 20 positions	2	$32.99	Amazon

DIN Rail (35mm x 40cm)	1	$7.68	Amazon
Mushroom Head Red E-Stop Button	1	$4.00	Amazon
PNP Inductive Proximity Sensor	1	$7.12	Amazon
PNP Diffuse Optical Sensor	1	$12.99	Amazon
Red Momentary Pushbutton	1	$12.82	Amazon
Green Momentary Pushbutton	1	$12.82	Amazon
Toggle Switches	10	$25.98	Amazon
Power Cord 120Vac, grounded	1	$5.00	Amazon
Misc: Screws, wires, etc.		$50.00	
Total (Without PLC and Software)	1 station	$629.75	

A few compromises were made in the component selection. A full cabinet was not used for the control panel. This reduced bulk and cost substantially, over $200. A control relay was used for the Estop instead of an industry standard Safety Relay that would normally cost over $200. It is also possible to reduce the cost further by buying components in bulk and making some items such as the back plane.

The PLCs that were donated to Western Carolina University normally have a very high cost, well over $3000. However, much lower cost PLCs can be excellent alternatives. A simpler PLC with 24Vdc inputs and relay outputs, with software, can be purchased for a couple of hundred dollars from various suppliers. However, most automation vendors are very interested in working with schools and will offer hardware and software at a discount, or free. Other great sources of parts are local companies that build, maintain, or scrap their own machines. They are often willing to donate industrial components to educators. This may result in components, such as buttons, that are not identical. However, there is a learning advantage to presenting an array of components.

Student Wiring

In the first lab of the semester the students began with the trainer boards with no wiring and a few of the components placed. The lecture outlined the fundamental concept of panel layout. This was followed by a description of the wiring principles including powering the PLC controlled with a start and emergency stop button. Figure 2 shows a panel layout diagram used to explain the component placement to the students. A list of the critical lecture points includes:

- The concept of grounding first using green wire or bare copper.
- Having higher voltage and current wires away from lower capacity wires.
- Using terminals to distribute power and organize wires.
- Using wire raceways, strain reliefs, and cable ties to keep exposed wiring neat and safe.
- Wire length, stripping, and firmly anchoring.
- Fuses and disconnect placement and wiring for safety.

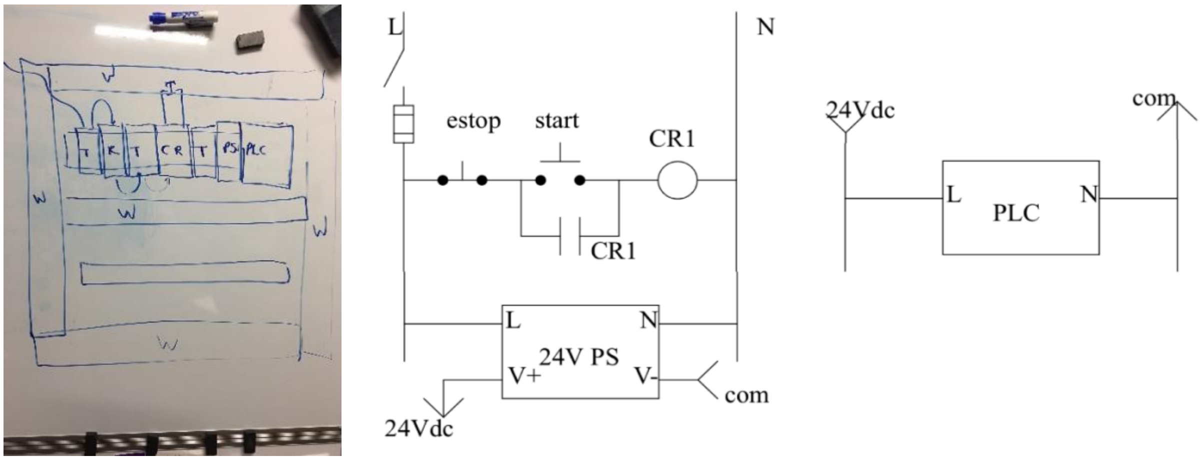

Figure 2 – Basic Panel Layout and Wiring Example

After the introduction to wiring the students were broken into groups of four to assemble and debug the wiring. They moved the stations into an open area in the lab so that they could gather around from all sides. Wire, wire strippers, and small screwdrivers were supplied to each team. The class also had access to a station that was pre-wired for student reference by the instructor.

Examples of the student wiring are shown in Figure 3. Note: The wiring is shown as-is, without staging. In general the students have routed the wires correctly and used colors consistently. The wiring for the buttons and sensors emerges from the left of the enclosure and enters a raceway. Students were directed to connect all to the bottom terminal strips. It was observed that the station design allowed both members of 2-person lab teams to contribute substantively to the success of each exercise. The lab-specific wiring and on-screen ladder design were collocated, and benefited from the team's cooperation to converge on a working program.

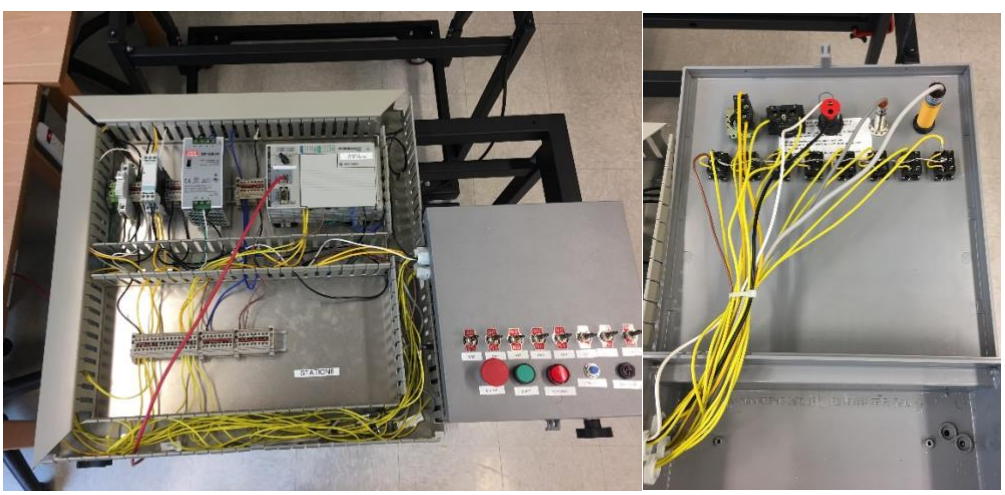
Figure 3 – A Sample of Student Wiring

Figure 3 cont'd – A Sample of Student Wiring

Before applying power, students check continuity on the 120Vac bus and the 24Vdc bus. The wiring was also inspected by the instructor. The inspection involved checking general wiring connections, tugging to find loose wires, grounding, and exposed wires (overstripped). In total there were three lab sections and all were able to successfully apply power before the end of the first lab. These stations were left connected for labs in the future weeks where students added additional inputs and outputs including buttons, sensors, and switches.

Conclusions

Initially there were concerns that the wiring would be problematic and potentially delay lab work the following weeks. However the concerns proved unfounded and the students were able to complete the wiring successfully in teams of four within the 2 hour lab time. To help the process, the instructor station was wired ahead of the lab and left as an example for the students.

After the first week, the wiring was left in place and modified as needed in following labs. In those weeks the students were able to add sensors and actuators to satisfy weekly lab exercises. At the conclusion of the semester students were given more elaborate projects where they needed to connect their station to control a piece of equipment like a conveyor and can crusher.

At the time of final submission the first semester of use was still underway and final conclusions had not been drawn. But, based on early observations there is a pressing need for:

- Students' use of a wire labeling system.
- Expanded discussion of electrical safety and arc-flash protection.
- Future hardware additions of Human Machine Interfaces (HMIs) and Variable Frequency Drives (VFDs.)

This work is in progress, having started in January 2018. The outcomes should be evident at the end of the spring term. At that time a formal comparison of the choice and application of PLCs will be done.

Acknowledgements

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