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A Platform for Teaching PLC System Integration and PLC Systems Data Access

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A Platform for Teaching PLC System Integration and PLC Systems Data Access

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Abstract

The Programmable Logic Controllers (PLCs) are the industrial controllers of choice among control, automation, and design engineers. Therefore, automation and mechatronics engineering and technology programs to focus on teaching PLC programming. However, in real industrial systems PLCs are usually not installed or integrated alone on automated machines. Instead, third party products such as servomotors, variable frequency drives, vision systems, testing equipment, or robotics are often used to complement PLCs. In this paper we present a platform for teaching PLC system integration. To match the training needs of industry, our platform is a fusion of the following components that are based on different technologies: vision system, programmable logic controller (PLC), Human machine interface (HMI), and a gantry robot that is equipped with sensors, as well as vacuum suction and open-close gripper units. This has created a realistic system for teaching the principles and practices of integrating various technologies in a PLC based systems. The paper also presents how we use the platform to teach unit or machine integration as well as group control, where multiple PLC systems are networked and controlled together by transferring input/output triggers among them. In addition, the platform is used to teach access to data of remote automation systems using OPC technology. Finally, this paper describes how we strategically deploy our platform to enhance student's skills in PLC machine integration. Finally, the paper presents examples of students' work to demonstrate the educational effectiveness of our platform.

Keywords: PLC System Integration, PLC System Data Access, Manufacturing Automation, Teaching Industrial Systems Integration, PLC System Integration Laboratories

Introduction

Programmable Logic Controllers (PLCs) are ruggedized, digital computers designed for automated control of industrial systems. They are considered the hidden "workforce" that silently executes logic instructions behind closed electrical cabinet doors to deliver automation functionalities of industrial systems. However, PLCs are usually the "master' controllers that sequence the main logic and manage the data of the automated system. They need to be integrated with third party components such as variable frequency drives, Human Machine Interfaces (HMIs), servomotors, vision systems, testing equipment, and robots in order to deliver a wide range of functionalities that are usually required of industrial automation systems. These components that are usually referred to as 'slave" devices, work in harmony within the automated system and are controlled by the PLC in a master-slave relationship (Elston, 2018). The integration of PLCs and third party devices usually consists of either discreet wiring I/O to handshake signals between the PLC and third party controllers; or sharing of memory mappings between a master PLC and its slave devices using fieldbus or backplane communication.

A review of automation courses and programs in Canada revile that universities and colleges appreciate the need to teach skills in integration of PLCs with slave devices. The Automation Engineering Program offered by the School of Engineering Practice and Technology (SEPT) in the Faculty of Engineering at McMaster University, covers courses in robotics, industrial networks, and system integration in addition to two PLC programming courses (SEPT, 2019). The Robotics and Manufacturing Automation course offered in the department of Mechanical Engineering at Waterloo University covers topics in automatic production and assembly, sensors, actuators and drives, mechanization of part handling, industrial robots, and vision systems. Emphasis of the course is on the planning, design and implementation of automation systems (Buchal, 2019). The Electrical Engineering Technology program at Mohawk College covers control systems and variable speed drive systems and industrial network systems in addition to Programmable Logic Controllers (Mohawk College, 2019). Algonquin College offers a Bachelor of Automation and Robotics program that focuses more on the sciences, but still covers offers interdisciplinary courses like industrial robot cells in which students examine the functionalities of PLCs, pneumatic circuits, as well as position and perception sensors. In addition, students integrate electro-mechanical components used in industry such as motors, automation belts, pneumatic cylinders and lines, sensors with robots and PLCs (Algonquin College, 2019). In line with the general agreement among educators that it is necessary to teach the integration of PLCs with other industrial automation devices, we have developed a platform for teaching PLC system integration. The platform is made up of following components that are based on different technologies: vision system, Programmable Logic Controller (PLC), Human Machine Interface (HMI), and a gantry robot that is equipped with sensors, as well as vacuum and open-close gripper units.

The rest of this paper is arranged as follows: Section 1 presents the implementation of our platform for teaching PLC system integration and PLC system data access. In section 3 we deal with how the system is deployed in one of the courses in the Automation Engineering Program in the School of Engineering Practice, Faculty of Engineering at McMaster University. Section 4 covers a general discussion of our platform, while Section 5 presents the conclusion and future work.

Platform Implementation

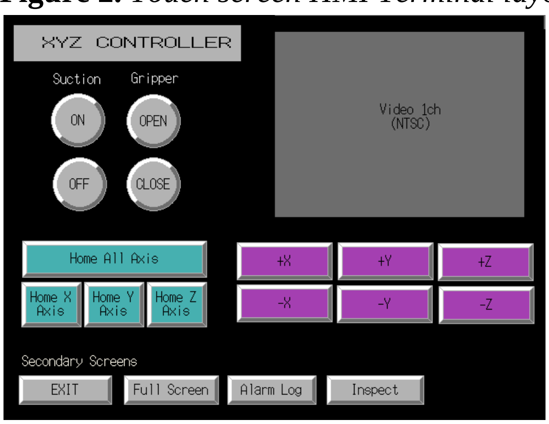
Our platform is based on a XYZ gantry robotic setup shown in Figure 1. Each axis on the XYZ gantry robot has an OMRON OMNUC W-Series AC Servo Motor driven by R88D-WTA3HL servo drive. The servo drives receive command signals from an OMRON C200HW-MC402-E motion controller that is programmed using Motion Perfect 2 Integrated Development Environment (IDE) from Trio Motion Technology. In addition, the IDE allows the programmer to send test commands directly to the motor drives from the programming PC. The motion controller is a module on the PLC backplane and it communicates with the PLC microprocessor through the paradigm of shared memory.

An OMRON NS-Series Human Machine Interface (HMI) touch screen terminal shown in Figure 2 is used for manual control of the system by operators. The screen is programmed to have customizable inputs that can be integrated into the PLC ladder logic. For example, the HMI buttons can be used to control the movement and home positioning of the robot axes, and to control each end-effector attached to the z-axis of the robot.

Figure 1. *XYZ Gantry Table Setup*

The vision system of our platform for teaching PLC system integration and PLC systems data access has and OMRON F160 vision sensor that uses an OMRON F160-S1 camera to capture videos and still images. The videos and images captured by the camera can be displayed on the HMI (Figure 2). The OMRON F160 vision sensor controls the functions of the F160 Camera, including setting up the reference images, and adjusting the camera parameters. The vision sensor can comparing the current image to the stored reference image to determine the differences and similarities according to the selected inspection option.

Figure 2. *Touch screen HMI Terminal layout*



The OMRON F160 vision sensor has the following seven different inspection options (Reference Manual):

- Conformity inspection checks whether or not the workpiece matches the reference image.

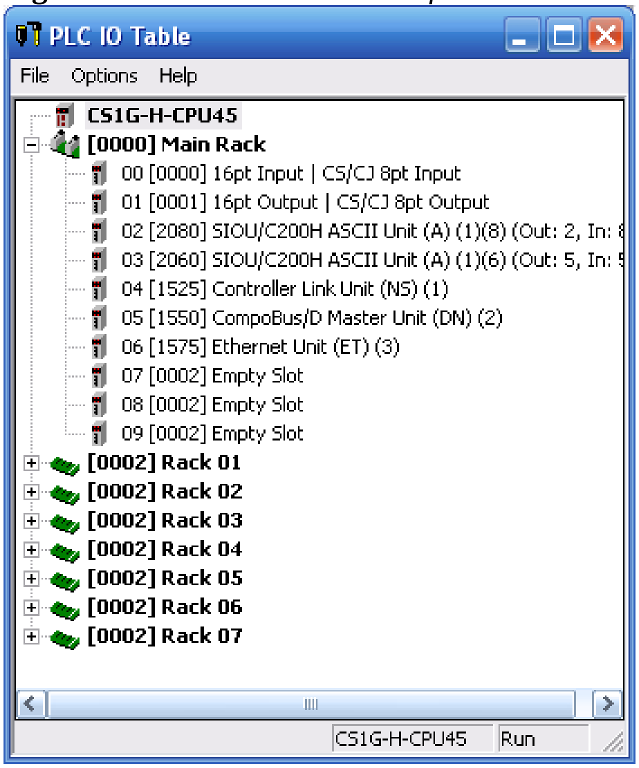
- Orientation inspection detects the orientation of the workpiece to see if the workpiece is facing the correct direction with respect to the reference image.
- Position inspection finds the position of a specified mark, hole, or other feature and determine whether or not it is within the correct range.
- Presence inspections finds the presence of a specified mark, hole, or other feature with respect to what is present in the reference image.
- Dimension inspection inspects the relationship (distance) between two specified points to see if it is within a range.
- Chip and bur inspection checks for chips and burs on the circumference of workpieces.
- Surface inspection checks for defects and impurities within a specified range.

The vison sensor can be operated either by a console or by digital inputs. The inspection output is displayed on the HMI and can be monitored from the digital outputs. Therefore, the communication between the vision sensor and the PLC is though inputs and outputs handshake signals.

The gantry robotic system has two end effectors on the Z-axis (Figure 3). The first is a pneumatically operated gripper, and the second is a vacuum suction. Both effectors are controlled by the PLC digital outputs. The platform uses an Omron CS1G-CPU42 PLC that is programed using CX-Programmer IDE. The PLC has one rank on which there are input-output modules, as well as Ethernet and Devicenet communication modules (Figure 3). This PLC is the master of all devices on the gantry robot it sequences operations to deliver the system wide functionalities. Figure shown the configuration of modules on the rack of the gantry robot PLC in Omron CX programmer IDE

Figure 3. *XYZ Gantry Robot PLC Rack and End Effectors*

Figure 4. *Modules on the Rank of the Omron CS1G-CPU42 PLC*



Deployment of the Platform

The course PROCTECH 4AS3/SEP6AS3: Industrial System Components and Integration in which we use our platform for teaching PLC system integration and PLC systems data access runs as both a 400 series and a 600 series course for which students get credits towards postgraduate studies. The 400 series students use the platform to do eight laboratories, while the 600 series students use it for laboratories and course project.

We use the platform to run a series of laboratories that do not only teach students the principle of PLC system integration, but also teaches how the PLC system integration relates to the Computer Integrated Manufacturing (CIM). We have classified the functions of CIM into six categories associated with the following levels of automation systems hierarchical model:

1. Field: This level deals with data acquisition and command execution (Sensors & Actuators), and data transmission. Usually no processing is carried out here, except measurement correction and built-in protection
2. Unit (Cell): The unit level controls (regulation, monitoring and protection) part of a group. It is closed loop except for maintenance. This is where the following basic operations are carried out:
   - Measuring: Sampling, scaling, processing, and calibration.
   - Controlling: regulation, set-points and parameters.
   - Commanding: sequencing, protection and interlocking.
3. Group or Area: This level controls a well-defined part of the plant by coordinating individual subgroups, and adjusting set-points and parameters and commanding several units as a whole.
4. Supervision: This level supervises the production and optimizes the execution of operations. It also deals with plant visualization, storage of process data, as well as data log operations and historical data access
5. Manufacturing Execution: The manufacturing execution level manages resources, workflow, quality supervision, production scheduling, and plant maintenance.

6. Administration and Enterprise: this level deals with finances, human resources, documentation, and long-term planning. It sets production goals, plans enterprise and resources, coordinate different sites, and manages orders

While our platform can be used to teach all the categories of the functions of CIM systems, we use to teach system integration from level 1 to level 4 of the CIM systems functions. At level 1, the platform has grippers as output field devices and the vision sensor as an input filed device. All the components of the platform are integrated into a unit or cell (level 2) with a HMI to support human-machine interactions. We have developed ten units; therefore multiple units can be integrated into a group or area level (level 3) control system, and supervisory (level 4) control can be implemented for individual units or a group of units, allowing data access of the resulting level 1 to level 4 integrated automation system.

PLC System Integration Laboratories

PLC system integration can be implemented at the unit level or at the group level. Our platform supports laboratory work that teaches both levels of PLC system integration.

Unit Level System Integration Laboratories

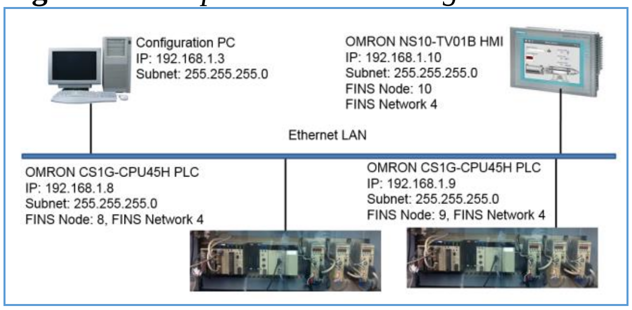
PLC System Integration laboratories teach students how to build a unit control system that uses a PLC as the master controller to sequence the operation of various slave devices so as to deliver system functionalities. The laboratories focus on CIM level 1 and level 2 system integration. They involve the use software to integrate industrial sensors, actuators and controllers into a single system that accomplishes tasks that the individual components are incapable of accomplishing alone. The following are the four PLC system integration laboratories that we run in the course PROCTECH4AS3/SEP6AS3 (ref):

- *Unit Control Lab 1 - Motion Control:* In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo motors and Servo Drives (R88D-WTA3HL) are controlled, first, directly through a PC using Motion Perfect 2 software application, and then by a software program developed using Motion Perfect 2 IDE and downloaded to the motion controller. The laboratory has the following goals: to teach an understanding of the different commands required to move the table actuators through the terminal command window, and to write programs which are stored in the motion controller, and enable the PLC to control the actuators.
- *Unit Control Lab 2 - Integration of PLC and Motion Controller*: In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo Motors and Servo Drives (R88D-WTA3HL) are integrated with an Omron CS1G-CPU42 PLC. The motion controller runs a program that is sequence by the PLC logic through shared memory data access. The main objective of this laboratory is to teach students how to use a PLC to sequence the operations of a gantry robot.
- *Unit Control Lab 3 - PLC Servo Motor Control via Programmable Terminal:* In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo Motors and Servo Drives (R88D-WTA3HL) are controlled using the Omron NS-series Programmable Terminal (PT) HMI through the PLC. This brings the ability to integrate human actions in the automated process. This is something that is common at unit automation level of the CIM hierarchical model.
- *Unit Control Lab 4 - Integration of PLC, Motion Controller, Vision System and HMI:* In this laboratory the Omron F160 Vision Sensor is configured directly through the console. Thereafter, the PLC, motion controller, HMI, and the vision system are integrated to form a sorting machine. The machine inspects a deck of cards, and sorts them based on the image stored in the vision system.

Group Level System Integration Laboratory

In this laboratory students integrate two gantry robots to create a group control system using EtherNet IP fieldbus communication. The robots share their control information to ensure coordinated operation of the group. For example students may want to share servo motor speeds such that one gantry robot runs at half the speed of the other. They may have one of the machines to be a master, or they operate them in a peer-to-peer relationship. Figure 5 shows the Local Area Network created by interconnecting two gantry robots using the Ethernet communication protocols. Under EtherNet IP protocol, one PLC can be setup as the data producer and other as a data consumer, or explicitly messaging can be used through the PLC logic.

Figure 5. *Group Level LAN Settings*



PLC Supervisory Control and Data Acquisition (SCADA) Laboratories

There are two main activities at level 4 of the CIM hierarchical model, namely: supervisory control and data acquisition. Supervisory control is a control scheme whereby a computer controls or monitors and intermittently downloads programs, sets sub-goals, or adjusts control parameters of a lower level automatic controller; whereas data acquisition is the process of collecting data from the system for the purpose of producing reports for operating, supervisory, maintenance, or accounting disciplines. Our platform support laboratory work for supervisory control and for data acquisition. We call our data acquisition laboratories PLC data access labs because we interested in accessing current data to use it in remote HMI; yet the terminology “data acquisition” is usually associated with just historical data access.

Supervisory Control Laboratory

This laboratory is done after the data acquisition laboratories because we need the data collected through the data acquisition process to provide supervisory control. In this laboratory students develop a fuzzy logic controller that modulates the speed of the gantry robot based on the frequency of product imperfections reported by the vision sensor.

PLC Data Access Laboratories

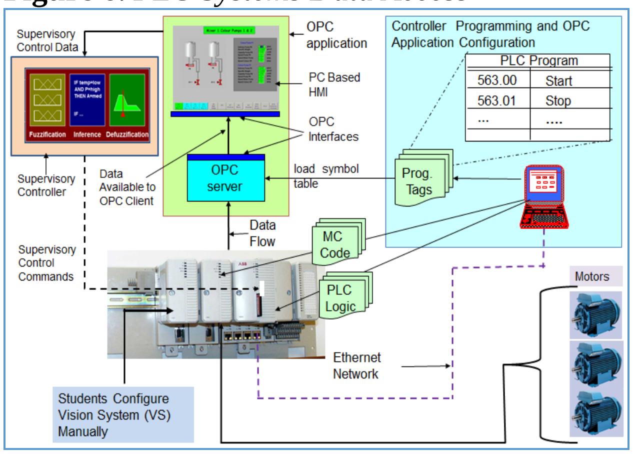
The PLC data access laboratories are based on the principle of accessing PLC data using Open Process Control (OPC) technology. The following laboratories are carried out in this category:

- *Data Access Lab 1 - OPC Sever Configuration:* In this laboratory, students access the motion control data using OPC technology (KepServerEx V6 OPC server). The laboratory builds on the first four laboratories. Figure 6 shows that the PLC program tags generated during integration laboratory 2 are loaded into the

KepServerEX V6 OPC server after creating a channel in the server and adding the Omron PLC to the server.

- *Data Access Lab 2 - OPC Client Applications:* The purpose of this laboratory is to develop OPC based data access applications using DataHub software application. DataHub is an OPC client that accesses the PLC system data through KepServer OPC server. It is a powerful OPC application development tool that was developed by Cogent Real-Time Systems of Georgetown, ON. Through this laboratory, students learn the various data access technologies supported by DataHub such historical data access and trends, alarms and events management as well as HMI development.

Figure 6. *PLC Systems Data Access*



System Integration and SCADA Projects

The 600 series students are introduced to the platform by carrying the four unit level system integration laboratories. Thereafter, the students are required to propose system integration project that is based on the platform. The project has to fall within the following guide lines to ensure that it covers the same learning outcomes covered by the labs that are done by the 400 series students:

- Use OPC technology to access data from the PLC of gantry robot as shown in Figure 6, and build a remote HMI using wonderware, Ignition OPC client, or LabVIEW software application. Use the guidelines presented in the paper, A High Performance HMI: Better Graphics for Operations Effectiveness, by Bill Hollifield, available at http://isawwsymposium.com/wp-content/uploads/2012/07/WWAC2012-invited_BillHollified_HighPerformanceHMIs_paper.pdf
- Integrate the gantry robot control system with another unit controller of hand held device.
- Implement supervisory control of the gantry robot using fuzzy logic of any other method (Figure 6).

Discussion

Our platform for teaching PLC system integration and PLC data access allows students to either carry out laboratories or projects to learn the same set of concepts, namely: OPC data access, PLC configuration and programming, PLC system integration, integration of device connected on different industrial networks, and HMI configuration. This implies that the platform provides a means for deploying and managing experiential learning activities for the entire breadth of topics covered in the Advanced Components and System Integration course of the Bachelor of technology program at McMaster University. In fact, the platform can be used to teach how to implement all the functions of CIM systems.

The 600 series students are introduced to the platform through a series of laboratories. That is, we prepare the students to do their project work through laboratories, allowing the laboratories to share time with projects. We believe that this is an efficient way of utilizing learning time. Moreover, using our platform to carry out a mix of projects and laboratories has proven to have potential because both laboratory and project work have 100% completion rate, with all students scoring above 80%. We have also gotten a lot of positive feedback from the students. We also would like to mention that using our platform to carry out projects allows students to practice problem solving, project management, teamwork, and systems design without any direct project cost to the school. Usually students practice these skills when learning through open-ended problem-based learning – a learning paradigm that is generally known to be very resource intensive.

Conclusion

In this paper we present a laboratory platform that can be used to carry out laboratory work or course projects. The platform can be used to teach all levels of the Computer Integrated Manufacturing hierarchical model that we presented in in Section 3.1. However, for our course PRCTECH4AS3/SEP6AS3 - Advanced Components and System Integration we use it to teach concepts covering four of the six levels. This speaks to the flexibility of the platform; in fact, the platform can be used to achieve the same learning goals through a series of laboratories or through managed open-end projects. Although we have not yet carried out a formal research to determine the educational effectiveness of the platform, we have received a lot of good feedback from students. In addition, we have 100%completion rate for both laboratory and project work over that last six years, with all students scoring over 80% in the projects. In the future we would like to carryout research to determine the effectiveness of the platform in teaching and learning.

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