Implementation of a Laboratory Learning Module for Process Monitoring and Control

Carlos Aldana, Winston F. Erevelles,
IMSE Department, GMI Engineering & Management Institute

Abstract

This paper describes the development of a laboratory module in automation that presents students with an experience in sensors, data collection and system control. The module features an Allen Bradley Programmable Logic Controller (PLC), a pick and place device with two degrees of freedom and two set point control modules mounted on the gripper and the rotary axis of the pick and place device, a chute and escapement for accurate part feeding and sensors for part-size detection, and the detection of the limits of travel of the pick and place device.

The system is designed to distinguish between and recirculate steel balls of three different sizes (7/32”, 1/4”, 9/32”). Inputs and outputs of the system were examined and the appropriate ladder logic was developed. This ladder logic acts as the main control for the system, however the PLC features a data highway which was used to interface our pick and place device to a supervisory control and data acquisition (SCADA) software and develop a man-machine interface (MMI).

During the development of this module, students were exposed to a series of different fields, from the mechanical design of the system, wiring of the set-up, implementation of the ladder logic and development of the man-machine interface.

Description of the work-cell

The plan view of the basic layout of the workcell appears as Figure 1. The pick and place device is a PHD multi-motion actuator with two degrees of freedom. The base of the actuator is a rotational joint with 180^o of motion in the horizontal plane. The second degree of freedom is provided by a linear actuator with a 4” stroke in the vertical plane. The actuators are equipped with magnetic bands on the pistons that activate externally mounted Hall effect sensors. This helps to interface the actuator to various logic systems - an Allen Bradley SLC 5/02 PLC in this case. Using a collet adapter, one end of an aluminum arm is attached to the end of the linear portion of the actuator. A miniature parallel gripper has been mounted to the other end of this arm. A special purpose Hall effect sensor is mounted upon the gripper to track the sizes of the balls acquired by the gripper.

An elevated platform supports a feeder track that houses and feeds the steel balls. One end of the track is elevated slightly with respect to the other -this enables the use of gravity for feeding the balls toward the escapement. The location of the escapement is designated as "downstream" for this system. The escapement is an internally ported device that allows both double-acting rods to be operated by a single four-way valve.

The sequenced rod motion isolates each steel ball prior to releasing it from the track to the pick-up position. The pick-up location is located downstream with respect to the escapement. This location is equipped with a proximity sensor that is used to detect the presence of a steel ball.

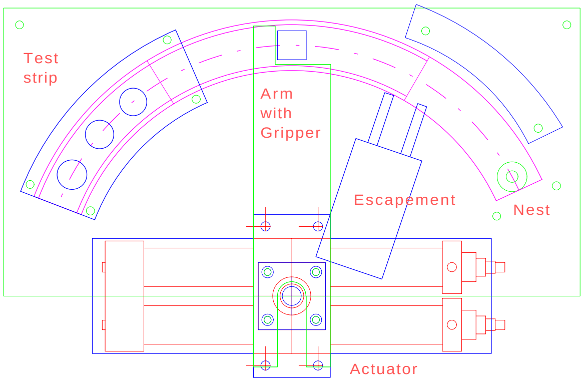

Figure 1: Cell Layout

The rotational cylinder of the actuator and the miniature parallel gripper are connected to two solid-state set-point modules. For the rotary cylinder, the purpose of the set-point is to differentiate between various rotary positions at the upstream end of the feeder as whereas for the gripper, the purpose is to differentiate between the three sizes of the balls, this is accomplished by adjusting the set-points of the modules. Depending upon the position of the rotary actuator or the position of the gripper, different outputs or combination of outputs are asserted by the set-point modules. These outputs are connected to the input module of the PLC and complete the interface to the system. Various four-way valves are ganged together and derive the actuator, the gripper and the escapement.

A nylon test strip is mounted at the upstream end of the feeder track and on top of it. This nylon strip features three chamfered and precision-machined holes to receive the steel-balls that are dropped by the actuator. The three holes reflect the three sizes - nominal (1/4"), oversized (9/32") and undersized (7/32") balls that the system is designed to handle. The function of the plate is to establish a one-to-one relationship between the parts being recirculated and the sizes of the holes in the strip. This provides students with the opportunity to check the accuracy of their programming and experiment with the settings of the set-point modules.

An Allen Bradley SLC 5/02 PLC with a 7-slot rack is used to control the system. One input and one output module are used to interface the PLC to the work cell. A KF-3 interface provides the link between the PLC and a computer host via a DH-485 network. This module facilitates the connection to multiple SLC-500 units in the facility, enables on-line programming and debugging of the PLC's and allows the user to access data from stations on the network. This capability allows for MMI/SCADA operations also. The PLC is programmed using APS (Advanced Programming Software) provided by Allen Bradley.

Control of the work cell

The control of the work cell was achieved through the use of the PLC. Ladder logic was developed for the PLC to activate and synchronize the valves that enable the pick and place device to operate. The PLC program is the core of the project, it is the tool that makes it possible to control the robot and monitor the process functions.

The PLC program was created using the 'State Transition Diagram' methodology as shown in Figure 2. This methodology consists of defining states in which the process may be and then using conditional statements to control it. For example, state 'A' would be defined as robot arm high, gripper open and no ball in pick up position. This state would be referenced afterwards in the ladder logic as follows: 'If state A then go down and pick up the ball'. This eliminates the need for a lot of logic and, when the states are defined correctly, it is easy to make modifications to the program.

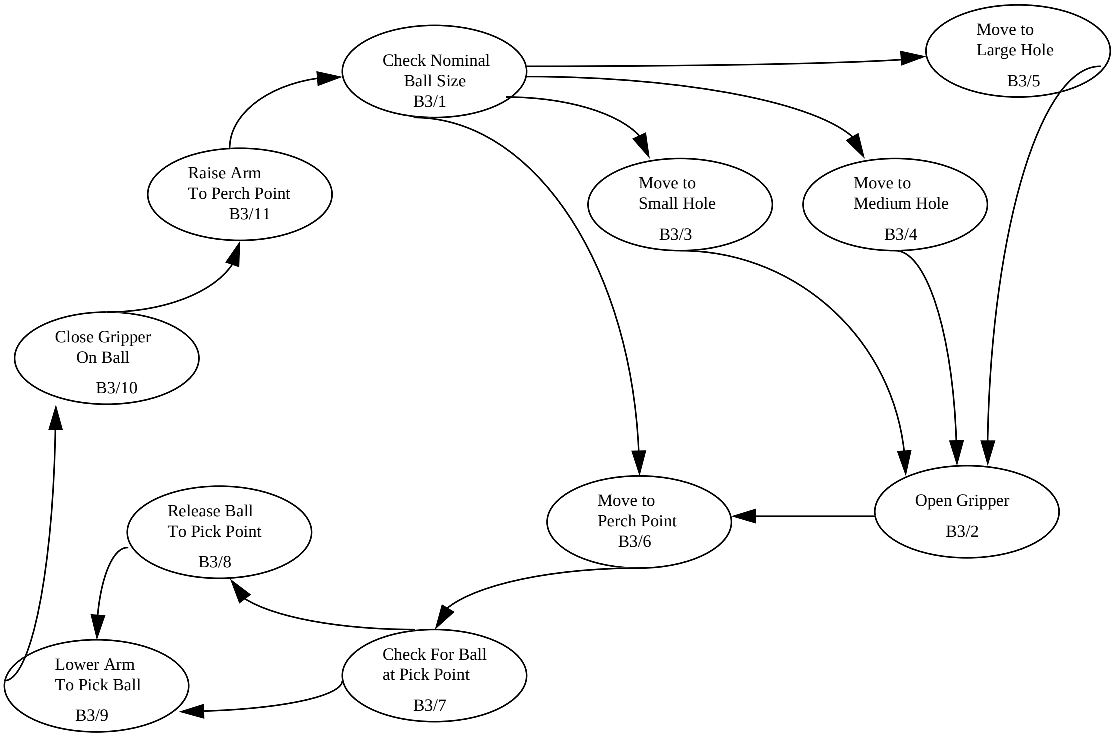

Figure 2. State Transition Diagram for Pick and Place Device

The assumption being made here is that all states have been correctly defined. Failure to do so will result in catastrophic failure of the programs. It is here that the monitoring function comes into play.

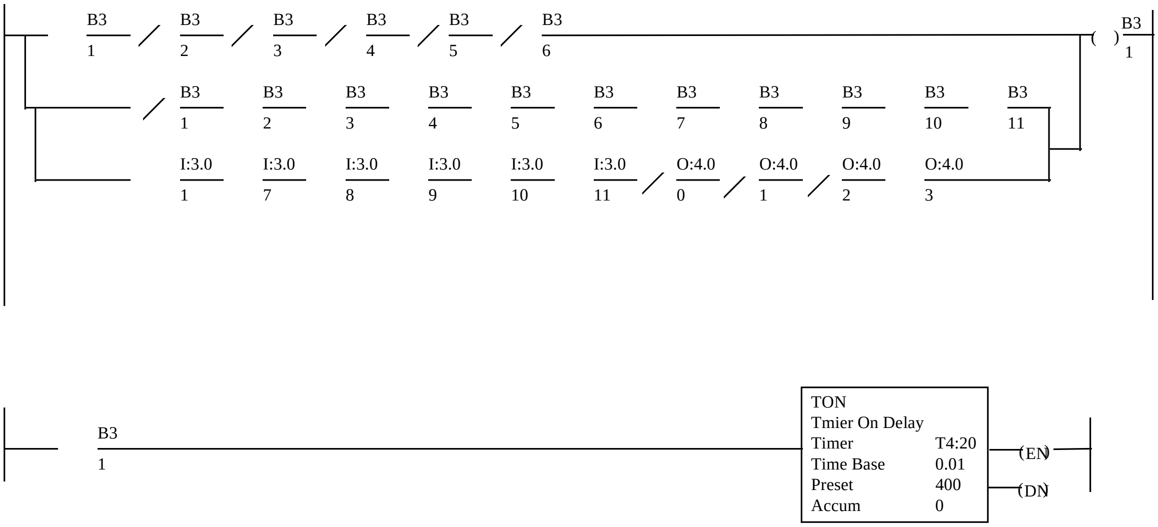

Figure 3. Example of the Ladder Logic Associated With a State Transition Diagram

Monitoring function:

While the main control of the process resides in the PLC, the monitoring function resides on a PC running FIX-MMI software from Intellution Inc. Figure 4 shows how the monitoring function is achieved through a PLC.

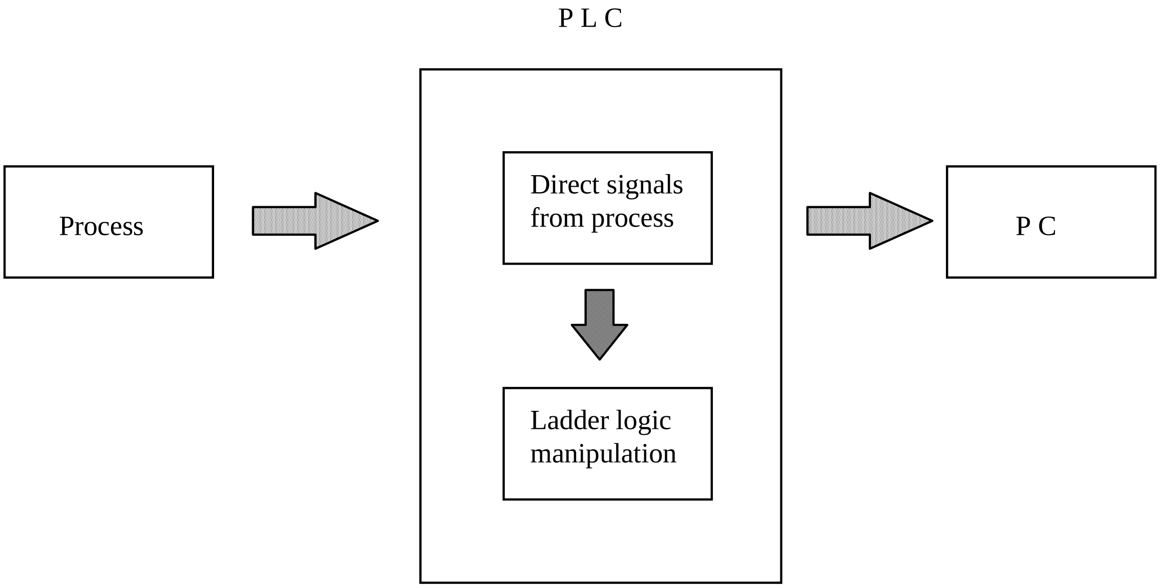

Figure 4. Monitoring function

The FIX software provides users with an interface from the PLC to the computer where they can monitor the internal values on the PLC memory and associate those values with an animated display in the computer. This serves as a window into the process - one that can be viewed at the computer. The process sends voltages (from the sensors) as inputs to the PLC, these inputs are directed from the process and reflect precisely what is happening in the process. The PLC brings these inputs into the ladder logic, manipulates them and computes outputs that the logic considers appropriate.

Two approaches can be used here, users can monitor the voltages coming from the process directly via the PLC (FIX-MMI doesn't allow users to monitor inputs directly) by monitoring a bit in the PLC memory which is directly related to the input or users could monitor a bit which describes a state in the state transition diagram. This is depicted in Figure 5 which shows both approaches. The direct approach uses bits that are related directly to the inputs and outputs while the indirect approach achieves this function by monitoring the 'states'. In theory, the information coming from both approaches should be the same. However, PLC programs do require debugging during the early stages of development. Consequently it was decided that the process would be monitored directly.

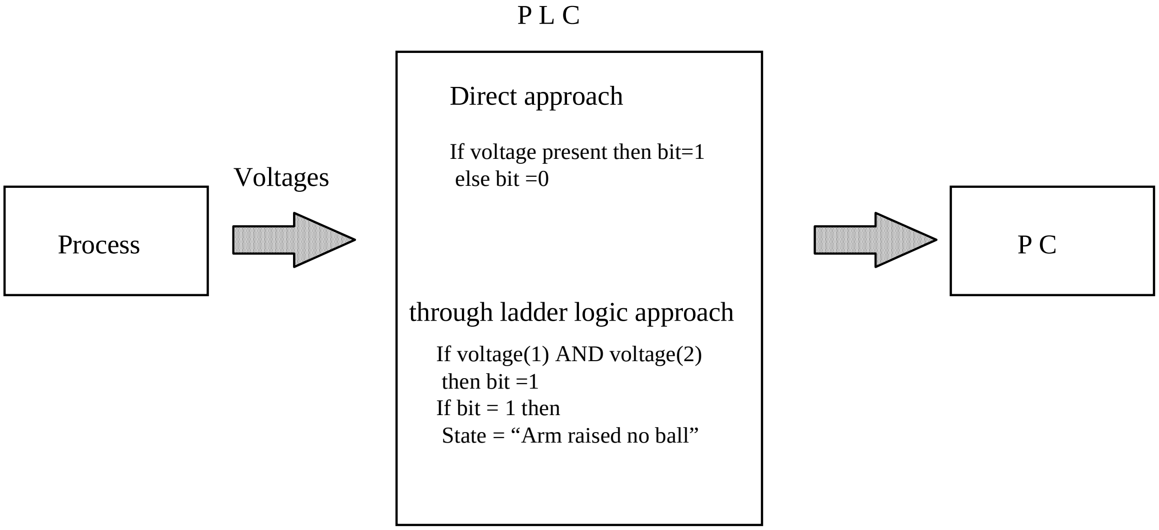

Figure 5. Two Approaches For Process Monitoring.

An animation on the computer screen was created so users could actually see what was happening in the pick and place device. Figure 6 shows a human factory interface that was developed using the Fix/MMI Software. This animated display shows the ball size in the gripper, the ball count, ball in pick-up position, the rotation of the arm, an input window showing inputs to the PLC, the vertical arm position - high or low, and the outputs from the PLC to the process.

A different approach:

As mentioned, the main control of the cell was achieved through the use of the PLC, however, FIX-MMI provides users with capabilities that allow the user to build a flow diagram and create the necessary outputs to control the process. This is achieved by using the PLC as a bridge between the device and the software - some ladder logic is still resident in the PLC. But this ladder logic is extremely simple - it only maps the inputs from the process to bits and maps different bits to outputs. What this means is that when a certain input (for example the arm-high sensor) is activated, a certain bit in the PLC memory will be activated too and when a certain bit is activated in the PLC, a certain output (to control a valve, for example, will be triggered). As one can probably imagine, this is extremely simple logic, and no control is associated with it.

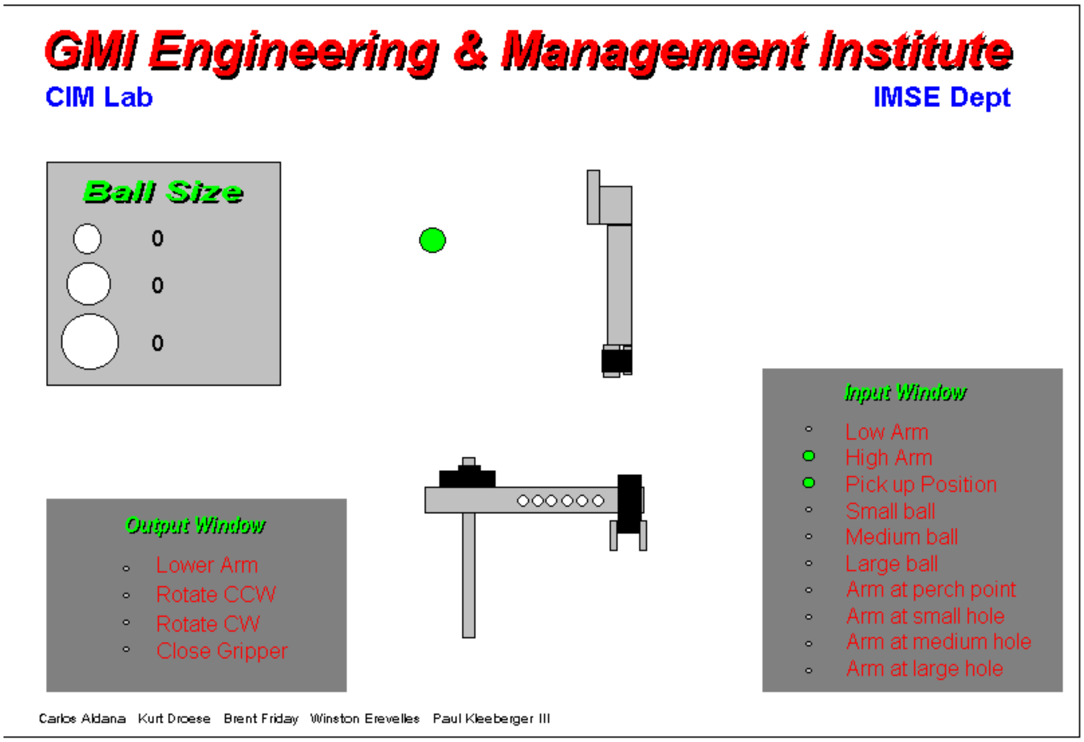

Figure 6. FIX/MMI Screen

The monitoring and control of the bits associated with the process is achieved through FIX-MMI by using the blocks supported by it. These blocks are used as part of a flow diagram which goes through a predefined logical sequence to calculate what outputs have to be triggered and at what time.

There are certain advantages with this approach, once one control strategy has been developed in Fix/MMI, it can be easily transported to a different application using a different PLC by only getting the appropriate interface for the new PLC (usually the interfaces or device drivers are provided by Intellution). This can mean a significant savings in terms of time spent in developing and debugging PLC programs. This is especially true in the case of machine builders or systems integrators where a wide variety of hardware supplied by several manufacturers is used to develop applications.

It may be also easier for some people to use flow-diagrams than to learn ladder logic (this may be true in a computer science course). It was our experience that the blocks supported by FIX-MMI were easy to understand and to manipulate. However, there were certain disadvantages associated with this approach - the most important of which is the lack of speed. The ball sortation system requires extreme precision in the dropping of the balls - this precision was readily achieved under PLC control. In the Fix/MMI environment this was a little harder to achieve. Here several tasks were running - the animation, the control logic (Fix/MMI running under Windows), and communications from and to the PLC (probable bottleneck of the system). On occasion this overhead caused near misses or misses by narrow margins.

Learning experiences

By using this pick and place unit and its associated workcell it is possible to introduce students to concepts such as monitoring and control. The students actually see how the different areas in their curriculum, such as mechanical engineering (in the design phase of the device), electrical engineering (in the wiring and sensor installation), and computer science (in the development of the man-machine interface) are integrated.

Such a work-cell provides an opportunity to test simple PLC programs and move to more advanced programming such as state transition. It provides the students with tools where they can evaluate different control and monitoring strategies, either using the PLC or the computer as their primary control tool and it also develops the logical thinking of the student. The work-cell is suited for use in stand-alone courses where there is a focus on the constituent components of the work cell but the real benefit is to see the system as a fully integrated array of disciplines.

Biographical Information

Carlos Aldana is a candidate for the M.S. degree in Manufacturing Systems Engineering at graduate student GMI Engineering & Management Institute. He has a B.S. in Industrial and Systems Engineering from the Instituto Tecnologico y de Estudios Superiores de Monterrey, San Luis Potosi, Mexico. He has worked for the 3M Adhesive Tape Plant, ABG International, Industries Philadelphia, and Allied signal Corporation in San Luis Potosi, Mexico. He has also worked for KTL Turnkey, a company based in Copenhagen, Denmark. Most recently he has been employed as a Graduate Research Assistant in the Computer Integrated Manufacturing facility at GMI.

Dr. Winston Erevelles is an Associate Professor of Manufacturing Systems Engineering at GMI Engineering & Management Institute. His teaching and research interests are in the areas of CIM, Robotics, and Manufacturing Systems. He has a B.S. in Electrical Engineering from Bangalore University, India, and M.S. and Ph.D. degrees in Engineering Management from the University of Missouri-Rolla. He has worked as a Service Engineer and Plant Manager at Mykron Engineers, India. He is an active member of SME, ASEE, and AAAI. He is a recipient of the 1996 Society of Manufacturing Engineer's Philip R. Marsilius Outstanding Young Manufacturing Engineer Award. He is also a recipient of the 1996 GMI Alumni

Association Award for Outstanding Teaching in Manufacturing Systems Engineering. Dr. Erevelles serves as the Chairman of the Saginaw Valley Chapter of the Society of Manufacturing Engineers and as the Program Chairman and Chair-Elect of the Manufacturing Division of the American Society of Engineering Education.