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# Programmable Automation Controller Mechatronic Experiment

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**ABSTRACT**

This paper describes the use of the OPTO-22 Programmable Automation Controller (PAC) Learning center in the undergraduate control systems course at California State Polytechnic University at Pomona (Cal Poly Pomona). The OPTO-22 PAC System is an integrated system of hardware and software used for industrial control, remote monitoring, and data acquisition applications. The paper compares the pros and cons of using a PAC versus Programmable Logic Controller (PLC) or Field Programmable Gate Array (FPGA) systems. The paper introduces the flowchart based programming environment used in PACs. The paper includes an illustrative example of how the OPTO-22 PAC system can be interfaced to an industrial based Mechatronics pick-and-place robot station. This example details the input/output interfaces of the OPTO-22 PAC unit and the SUN Equipment Mecahtronics pick and place robot unit. Details of the flow chart programming and I/O interfacing protocols are given in the paper. The I/O configuration dialog in the OPTO-22 PAC development environment are also presented in this paper.



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## 1. INTRODUCTION

This paper describes the use of Programmable Automated Controllers (PAC) and robotic pick-and-place mechatronics experimental hardware for use in an undergraduate controls laboratory instruction setting. The ME 439 “Control of Mechanical Systems” is a senior level project based course included in the core curriculum for students enrolled in the Mechanical Engineering program at California State Polytechnic University Pomona. Part of the laboratory experience exposes the students to the use of Programmable Automatic Controllers (PACS). Numerous learning institution have implemented project based learning using Programmable Logic Controller (PLC) [1-2] and Field Programmable Gate Array (FPGA) [3-5] based controls in their curriculum. The article of [6] offers a comparison of the PAC to the PLCs, PC-control and Embedded Control such as the FPGA. In summary, PLCs are good at tasks like counting and timing, and managing Input/output (I/O).

Although a PLC can handle a few axes of motion, the update rates can be too slow for any but the most basic applications. The PACs include multiple processors to address a variety of functions beyond just basic logic and I/O. These capabilities include digital (e.g. motion control), analog (e.g. process control), and serial (I/O from test equipment, keypads, scanners, etc.) tasks. Because PACs already include these functions, they eliminate the time and effort involved in integrating a PLC with the motion controller, for example. Today’s industrial PCs have been ruggedized, top to bottom, with environmental protection and removal of any moving parts. Hypervisors like VMware allow a single core to be divided into multiple discrete partitions that run independently of one another, right down to the operating system. This enables a motion application to run on a partition with Linux or a robust proprietary real-time operating system (RTOS) while remaining completely isolated from a Windows partition supporting the HMI or a machine vision system. At the opposite end of the spectrum lie embedded control systems that leverage FPGAs to customize performance using hardware rather than software. FPGAs can be used to offload tasks like control logic and I/O triggering in highly complex systems, freeing CPU cycles to handle more complex tasks like trajectory generation. When the application encompasses an entire plant or factory floor, a situation that typically calls for distributed I/O in large numbers, along with extensive loop control functions better suited to a PAC than to a PLC or FPGAs. The various pros and cons of the PAC, PLC and FPGA are summarized in Table 1.

Table 1. Pros/Cons of PAC, PLC and FPGA

| | PAC | PLC | FPGA |
|---|---|---|---|
| PROS | Integrated logic and I/O<br>Multiple Processors, Digital, Analog, Serial Tasks | Counting, Timing, Managing I/O | One-off / high performance / complex systems<br>Frees up CPU cycles<br>Hardware not software |
| CONS | May be difficult to use in unique situations | Slow update rates, motion controllers | Not conventional |

In addition to PLCs and FPGAs other technologies on the market include the Remote Terminal Unit (RTU) and the Distributed Control System (DCS). The RTU are microprocessor-controlled electronic devices that interface objects in the physical world to a distributed control system or Supervisory Control and Data Acquisition (SCADA) system by transmitting telemetry data to a master system, and by using messages from the master supervisory system to control connected objects. The DCS is a computerized control system for a process or plant, in which autonomous controllers are distributed throughout the system, but there is central operator supervisory controller.

This is in comparison to a non-distributed control system that use centralized controllers; either discrete controllers located at a central control room or within a central computer. The DCS concept increases reliability and reduces installation costs by localizing control functions near the process plant, but enables monitoring and supervisory control of the process remotely. The discussion of [7] compares the PAC features to those of the PC, PLC, DCS and RTU. Academic textbooks dealing with Programmable Controllers include the works of [8] and [9]. Recent examples of industrial useage of the PAC framework are given in [10] where a coal preparation plant is autmoted using the PAC, and [11] where tide simulations are carried out using the PAC framework. Research on using the FPGA based controller is found in [12-13]. Applications of PLCs in automation settings are found in [14-17].

The primary focus of the study of [14-15] is the use of a PLC to control an elevator. In the research of [16] the PLC is used to control an electro-pneumatic actuator base on puslse width modulations (PWM). In the work of [17], the automation process of manufactureing galvanized nuts is accomplished using the PLC platform. Clearly there are notable differences between the PAC, PLC, FPGA, DCS and RTU platforms. Also there are similarities between them. There is also a wealth of applications using each controller platform. Notwithstanding is the fact that the PAC is becoming more and more proliferate in today’s industrial sector. Consequently, in order to keep our graduate’s current on state-of-art technology, the Mechanical Engineering Program at California State Polytechnic University at Pomona (Cal Poly Pomona) has integrated PACs as part of the hands on learning experience for the ME 439 “Control of Mechanical Systems” coursework.

## 2. RESEARCH METHOD

Figure 1 shows the OPTO-22 SNAP-PAC [18] unit hardware which consists of a PAC, I/O modules, power supply, and on-board integrated first-order thermal control system based plant. The current paper extends the work of [19] by demonstrating how the OPTO-22 PAC units can be integrated with a mechatronics pick-and-place robotic assembly station [20].

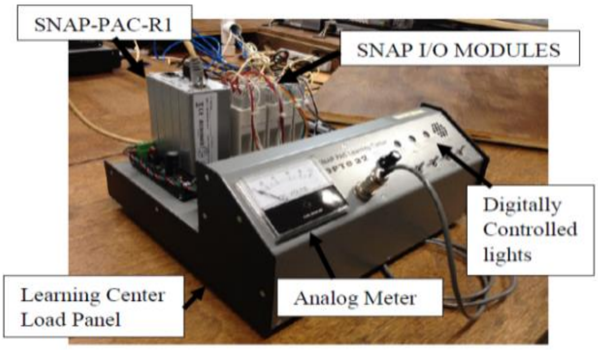


Figure 1. OPTO-22 SNAP-PAC hardware [18]

## 3. RESULTS AND ANALYSIS

In this section the application of programming the OPTO-22 PAC to interface with a robotic mechatroinic plant is discussed. The plant chosen is the SUN Equipment Company CML-61600 “Mechatronics Load based Material Selection and Sorting Station” process plant [20] as shown in Figure 2.

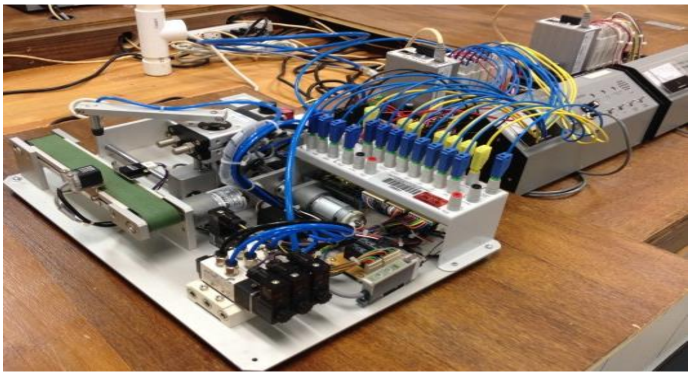

Figure 2. OPTO-22 and SUN Equipment Co. CML- 61600 Compact Mechatronics Load System

The SUN Equipment Co. CML- 61600 Compact Mechatronics Load System is equipped with the following:

a. 13 Digital Inputs (Sensors)
   2x Reflective Photosensor
   Inductive proximity switch
   Fiber Amplifier
   4x Photo-interrupt sensor
   Proximity switch (Reed Relay)
b. 7 Digital Outputs (Actuators)
   2x DC Motors
   Compact Cylinder
   Rotary Cylinder
   Vacuum Generator

Figure 3 shows the input/output interfaces of the OPTO-22.


Figure 3. OPTO-22 I/O interfaces

Figure 4 shows the various components of the SUN CML-61600 Mechatronics Unit.

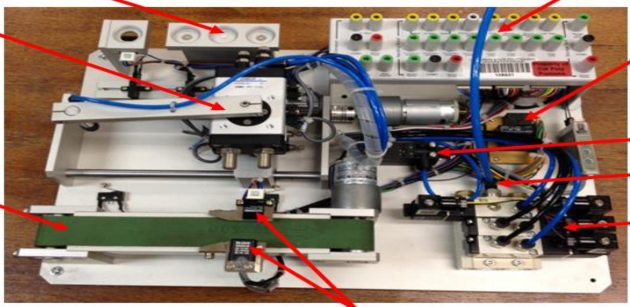


Figure 4. SUN CML-61600 Mechatronics unit

Table 2 lists the pertinent features of the SUN CML-61600 unit itemized in Figure 4.

Table 2. Description of SUN CML-61600 Unit

| No | Systems Description |
|---|---|
| (1) | I/O interface, to be connected with the PLC I/O terminals |
| (2) | Relay control module: Controls the conveyor belt motor and the screw rod motor |
| (3) | Vacuum generator: For the arm to suck up the work piece |
| (4) | Air inlet: To be connected to an air compressor (150 -700 Psi) |
| (5) | Solenoid module: Control arm’s up/down and rotational motion. Controls the vacuum generator valve. |
| (6) | Position, color and material sensors |
| (7) | Conveyor belt driven by a 24V DC motor |
| (8) | Screw-rod mechanism (with pneumatic robotic arm): Driven by a 24V DC motor; 4 micro switches for position control; 2 limit protection switches |
| (9) | Storage rack |

Figure 5 and Figure 6 detail the I/O interfaces of the SUN CML-61600 unit. Table 3 and Table 4 list the I/O protocol used to interface the SUN CML-61600 Mechatronics Load Unit to the OPTO-22 PAC module.

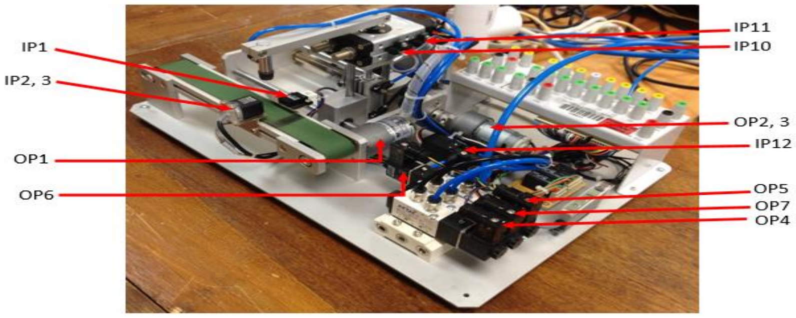


Figure 5. SUN CML-61600 I/O interfaces (front view)

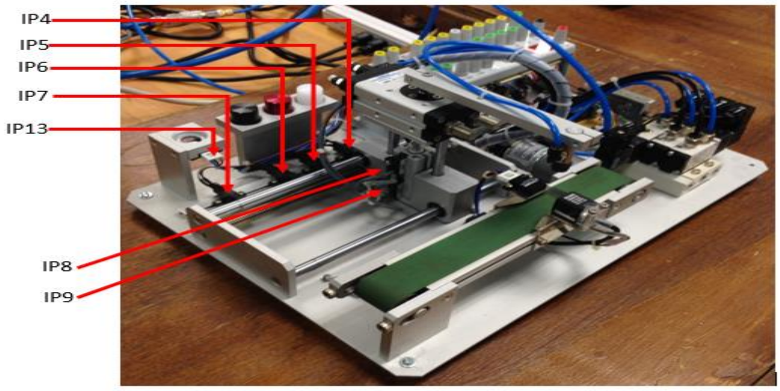


Figure 6. SUN CML-61600 I/O interfaces (side view)

Table 3. SUN CML-61600 and OPTO-22 Input Specification

| | INPUT | |
|---|---|---|
| SUN Interface | PAC IN (Module/Channel) | Description |
| IP1 | 00/0 | Position Sensor |
| IP2 | 00/1 | Color Sensor |
| IP3 | 00/2 | Material Sensor |
| IP4 | 00/3 | Screw Rod 1P |
| IP5 | 01/0 | Screw Rod 2P |
| IP6 | 01/1 | Screw Rod 3P |
| IP7 | 01/2 | Screw Rod 4P |
| IP8 | 01/3 | Arm Upper Limit |
| IP9 | 02/0 | Arm Lower Limit |
| IP10 | 02/1 | Arm CCW Limit |
| IP11 | 02/2 | Arm CW Limit |
| IP12 | 02/3 | Vacuum Verifier |
| IP13 | 03/0 | Storage Rack Sensor |

Table 4. SUN CML-61600 and OPTO-22 Output protocol specification

| | OUTPUT | |
|---|---|---|
| SUN Interface | PAC OUT (Module /Channel) | Description |
| OP1 | 04/0 | Conveyor Belt |
| OP2 | 04/1 | Screw Rod Rotates Fwd. |
| OP3 | 04/2 | Screw Rod Rotates Rev. |
| OP4 | 04/3 | Arm Up/Down |
| OP5 | 05/0 | Vacuum Generator ON |
| OP6 | 05/1 | Vacuum Generator OFF |
| OP7 | 05/2 | Arm Rotates CW/ CCW |

The conveyor belt operation is simultaneous with and separate from the operation of the robotic arm. The conveyor belt mechanism and robotic arm mechanism are coupled through the position sensor. When the position sensor (digital input) point is turned on due to the presence of a work piece the conveyor stops until the point is turned off. Once the point is turned off due to the robotic arm retrieving the work piece from the belt, a small pause is imposed so that the work piece being carried by the robotic arm does not come into contact with the next work piece proceeding along the belt in the situation where the following work piece is immediately after the work piece being retrieved (i.e. no space between work pieces as they proceed along the belt). There are no dark colored plastic work pieces, however the control logic is still set up to accept that option so that there are no dead ends in the control logic. The I/O configuration dialog in the OPTO-22 PAC development environment is shown in Figure 7.

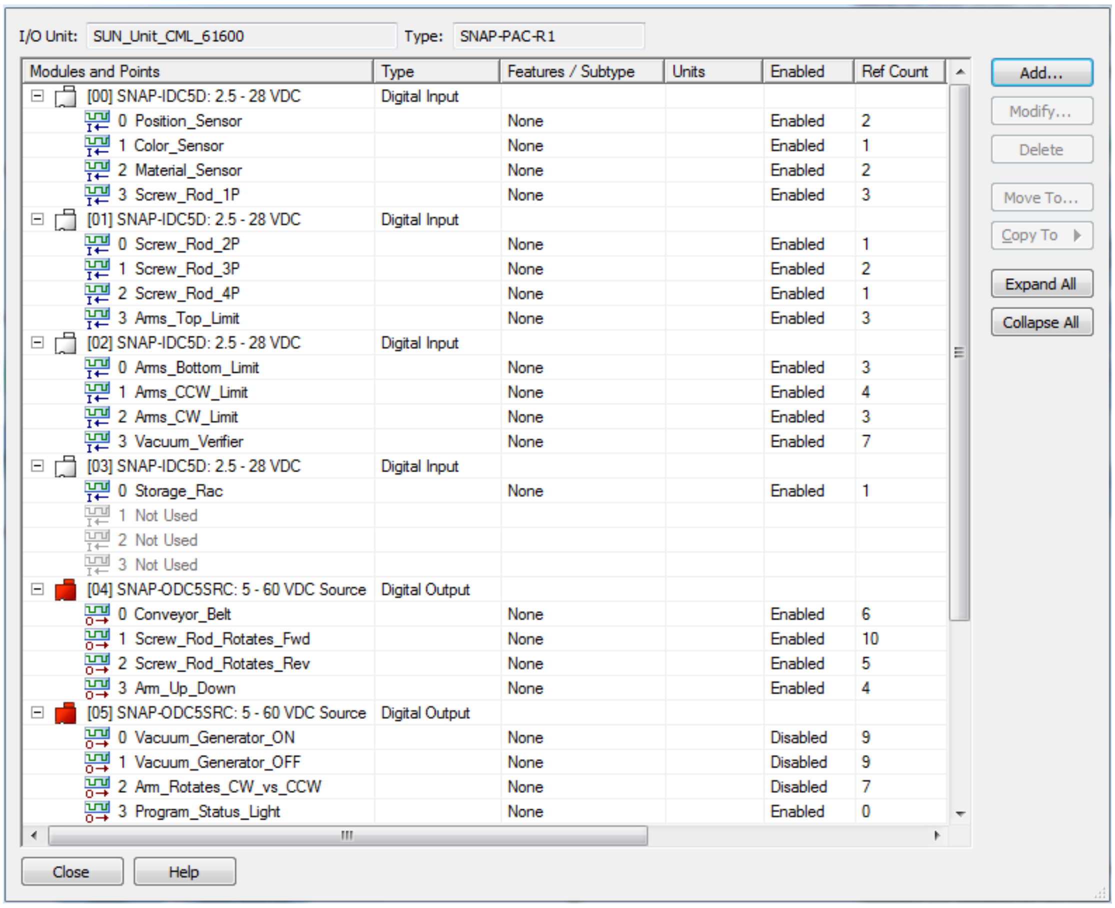


Figure 7. I/O Configuration Dialog in OPTO-22

The software program created when using PACs is referred to as a “strategy”. The strategy is comprised of the following: a control engine which defines the communication between the PAC I/O and the hardware it is being interfaced to (in this case the Mechatronics plant), flowcharts which contain the programming logic of the strategy, variables (integers, floating points, strings, etc.), and I/O configuration information with defines the controllable points of the plant. Since most control applications are rather complex a strategy usually consists of several flowcharts which all work in unision, much like subroutines in a traditional object oriented programming language. The flowchart is built using “blocks”, which include action blocks (which contain action commands), condition blocks (which contain condition commands), OptoScript blocks (which contain predefiened subroutines or scripts of action and command block logic), and continue blocks (which act as connections). These symbols are analogous to the flowcharting terminology used in a traditional computer programming pardagim and are shown below in Figure 8.

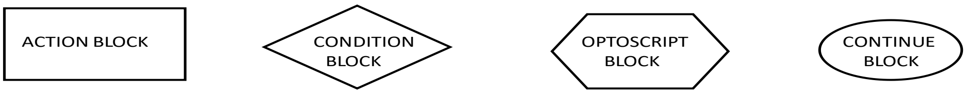


Figure 8. Flowchart Blocks used in PAC Programming

The overall control strategy in the flowchart based programming environment of the OPTO-22 PAC for the mechatronics experiment is shown in Figure 9. Figure 9 illusttraes the use of the PAC flowchart based programming environment whereby various blocks are used to construct the overall logic of the program. In comparion to Figure 9, which is fairly compact, the equivalent PLC ladder program on an Allen-Bradley Micro Logix 1200 PLC shown in Figure 10 [18] requires 46 (fourty-six) rungs of ladder logic or, approximately 10 (ten) pages of printed ladder logic code. Clearly, for this application the compactness of the PAC flowchart based program versus the PLC ladder logic program is apparent. Figure 11 shows a sequence of the PAC mechatronic experiment in run time operational mode.

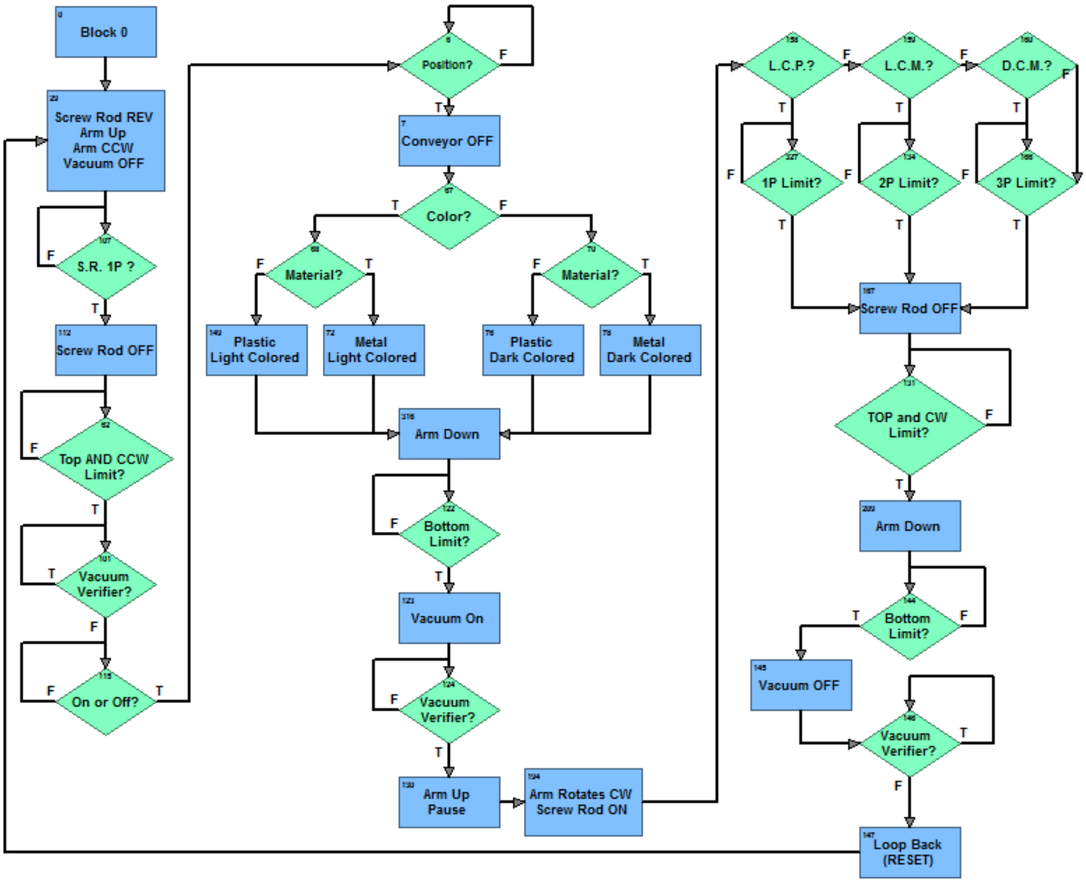


Figure 9. OPTO-22 strategy flow chart logic for robotic arm control and sensor reading

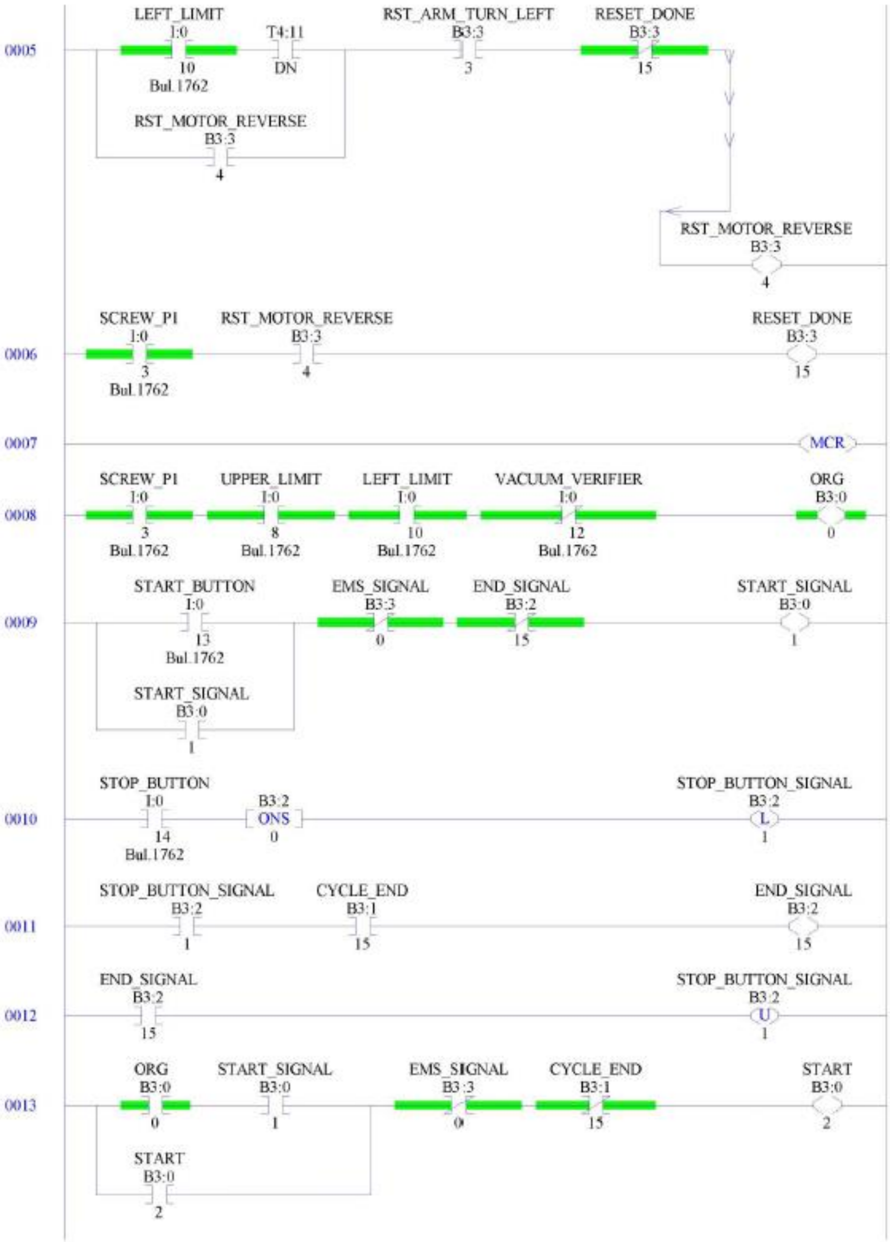


Figure 10. Allen-Bradley Micro Logix 1200 PLC Ladder Logic [20]

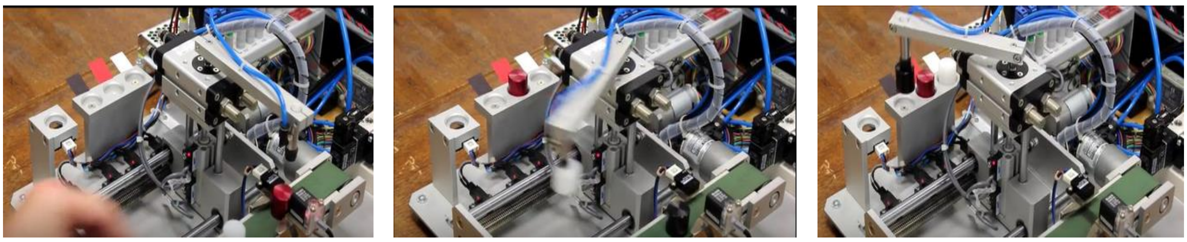

Figure 11. PAC Mechatronics experiment under run-time operation

## 4. CONCLUSION

This paper has presented the use of Programmable Automatic Controllers (PAC) in the framework of teaching controls to undergraduate engineering students using the PAC interfaced to a mechatronics / robotic pick and place manufacturing plants. The OPTO-22 SNAP PAC learning center provides a unique hands-on experience to enable students to become familiar with PLC systems. The pros and cons of using PAC vs. PLC and FPGA based system have been highlighted. The programming structure of interfacing with the PAC is a graphical object oriented flowchart based programming paradigm. The flowchart based programming provided by OPTO-22 allows students to quickly begin programming once they have a basic understanding of the underlying ladder logic. A detailed working example of using the OPTO-22 PAC to interface with an industrial based SUN CML-61600 Mechatronics plant has been discussed herein.

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