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MAKER: Remote Control of Festo Modular Production System for Education on Programmable Logic Control (PLC) and Robotics

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Motivation

The Manufacturing sector in the Alamo Region has an annual economic impact of approximately $22.5 billion and has been one of the major economic drivers in San Antonio for more than a decade [1]. The San Antonio Manufacturers Association (SAMA) Alamo Region Manufacturing Industry Workforce Assessment Report published in November 2015 identified that Electro-Mechanical Technician is on the list of top 3 high-demand manufacturing vacancies for the manufacturing sector in San Antonio, with 28% vacancies and is identified by the Alamo Workforce Solutions board as a Demand Occupation [2]. San Antonio Manufacturers, such as Toyota, have to recruit outside the state of Texas and nationwide in an effort to find qualified Electro-Mechanical Technicians.

To confirm this, Alamo College invited 55 local companies in the Greater San Antonio area to participate a survey to specify the technical skills they need for their work. Based on their feedback, three primary areas were specified as having the instructional gaps and inefficiencies for their current work duties and were identified as the most important skills. These top three areas are: Electrical and electronic components and systems, automated systems operation and control – specifically Programmable Logic Controller (PLC), and Maintenance and repair of electrical and electronic equipment. This finding was consistent with a larger scale study of about 155 companies reported by Hsieh [3] to investigate skill sets needed for industrial automation careers.

Robotics and PLC applications have become an integral part of many automated manufacturing and production systems. Many menial, repetitive, and extremely hazardous tasks are now conducted by robots in the industrial automation setting. Robotics Industries Association (RIA) states that there are five million job openings in the U.S. labor market, making it the best availability since 2001 [4]. It also states the majority of jobs are technology related, which requires a Science Technology, Engineering, Mathematics (STEM) background, and how there is a very limited number of qualified candidates to fill these positions.

Some aspects of the robot functions and other related aspects are often controlled by PLC's. Chetan Kapoor with Yaskawa Innovation states that "An engineer or technician must know the factory's programmable logic controller (PLC), which is the factory's language, and learn a robot language to put a robot to work" [5]. In addition, with the development of the internet, remote control of automated robotic system has been built and designed to provide students more flexibilities to access the system [6-7]. The local industrial survey found that industries expressed a need for a greater focus on instruction in robotics and PLC applications in automation. Based on this finding we decided to pursue the Robotics Fundamentals course in our dual-credit Advanced Technology Manufacturing Academy (ATMA) as our core curriculum for this project.

ATMA Robotics and IST Course Overview

In this course, we applied an innovative Integrated Systems Training (IST) approach which provides instruction encompassing the entire integrated system in our curriculum core. It included robotics, electrical and electronic, pneumatic, mechanical, PLC, and control systems and devices. Students gained an understanding of how these components and subsystems work independently and also how they interact with the other related sub-systems of an automated manufacturing system, including PLCs.

In addition to providing this instruction and hands-on learning experience to the ATMA students, a web-accessible automated system was developed. The system was made accessible and operational in real-time through the web portal. This system made the hands-on learning experience more accessible to students with limited instructional resources.

The robotics course introduces students to robotics, conveyance, and parts feeders as individual sub-systems and how they interact together to form an integrated system. Topics include: 1) history of robotics, 2) robotics impact on production and the labor force, 3) general robot characteristics, 4) physics of robot motion, 5) use of teaching pendants, 6) different types of robot control systems, 7) robot end-of-arm tooling, 8) applications of robots, 9) sub-systems of an IST and how the robot interacts with the system, 10) control devices in the system, and 11) PLC control of the IST.

The IST approach utilizes various training systems including: Festo MecLab Systems [8], Lab-Volt 5150 robot arms [9], and an Automotive Manufacturing Technical Education Collaborative (AMTEC) Integrated Manufacturing System Simulator [10]. Starting from the fundamentals of learning system, students start to identify and differentiate between various fundamentals such as electrical, pneumatic, hydraulic, and basic cabling and between various control lines in the electrical system such as multiple conductor cabling, servo power and feedback cabling, various power conductors, and grounding conductors. They also learn about the devices used in the various sub-systems and how they interact with the process to provide inputs and outputs to the process. Based on these, students need to know about movement of parts through the process including robotic motion, motor control, hydraulic control, and pneumatic control. Then they need to connect the MecLab sub-systems and learn about each of the three units: conveyance systems, feeders, and pick-and-place robots. Students are then challenged with an assignment to produce two products: a black base with a black cap and the other is a metal (chrome) base with a black cap. They must produce an individual plan with a drawing of the production line layout using the conveyance, feeder, and robot sub-systems. Additionally they will provide a 3-5 minute presentation of their system to the class. Then a group drawing and presentation will be developed. Finally the class, as a whole, discusses the various ideas and determines one final plan. From this plan students begin disassembling the sub-systems and using them to build their production line. During the construction process it was noted that students engaged in active critical thinking, team work, collaboration, and active problem solving. Students were able to complete the feeder station, sorter conveyor with diverter, metal w/black cap assembly robot station, exit conveyance for metal w/ black cap, conveyance for the black base w/black cap, and installation of control center with PLC.

This system is designed to model an automated assembly process that produces two different products. Following is a detailed description of the project including the overview of the system operation, overview of remote operations, MecLab Easy Port to I/O pin and cable layout, I/O port assignment, system schematics, ladder logic, survey results and class activities, and future direction of the program.

Overview of System Operations

The automated system consists of Festo MecLab sub-systems including: two conveyance, one pick-and-place robot, and two feeders. The automatic control system consists of three Allen Bradley (A-B) Micrologix 1000 PLCs with RS Logix 500, one DC power supply, one Lenovo Think Server TS140 with Windows Server 2009 Enterprise Software, Festo MecLab Easy Port interconnects with cabling, and various pushbuttons, sensors and indicators.

Festo MecLab station automated systems are controlled by three A-B PLCs, as shown in Figure 1. The PLC's are connected to the Festo MecLab system stations through ribbon cables via the Festo Easy Ports and then to the field devices as shown in Figure 2.

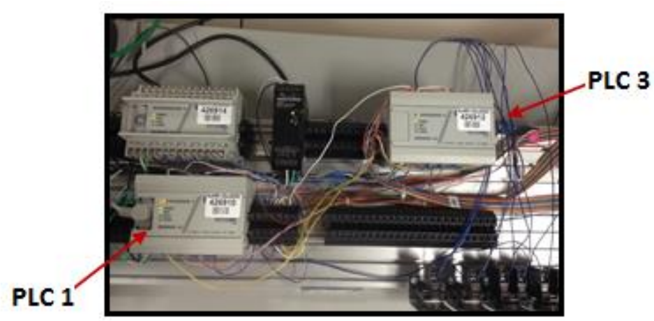


Figure 1. Three A-B PLCs used in System

Figure 2. Ribbon Cable Connections between Easy Port and Field Devices

PLC1 primarily controls the base feeder, sorting conveyor and the diverter gate solenoid for the feeder/sorting station. When the PLC receives the remote control signal, the feeder fiber optic sensor (FOPT) detects bases in the feeder, and when all other permissives are satisfied the feeder cylinder extends and pushes a base into the path of the infeed Optic Photo Eye (OPT). When the OPT detects the part it energizes the sorting station conveyor motor (K2). The sorting conveyor moves the part and passes it in front of an Inductive Proximity Switch (IND). If the part is plastic it is passed on through to the plastic base assembly station, however, if it is metal the IND detects this and causes the diverter gate solenoid (SOL) to energize and diverts the metal base to the metal base assembly station. The PLC then retracts the base feeder cylinder, which completes the cycle of this station.

PLC 2 is primarily used for sensor inputs, to control the cap feeder, and to control the transfer cylinder for the metal assembly station. When a metal base enters the assembly station another FOPT detects that it is present and PLC2 extends the cap feeder and provides a cap to the robot of the metal assembly station. At the end of the robot arm cycle PLC2 retracts the cap feeder cylinder and the PLC causes the metal part transfer cylinder to extend, which transfers the part across a chute and onto the outfeed conveyor. This is the end of the metal assembly station cycle.

PLC3 primarily controls the pick-and-place robot assembly process in the metal assembly station. When a metal base is present and a cap has been fed from the cap feeder the pick-and-place robot arm: moves down to pick up the cap, closes the jaws to grasp the cap, moves to the top/home position, moves to the extended/top position, moves to the extended/down position to place the cap on the base, opens the jaws to release the cap, moves to the extended/top position, returns to top/home position.

In order to provide control for the operation, the PLC utilizes inputs from various sensors to monitor the operation while sending outputs to various devices to control the operation.

Remote Operation

Remote control is accomplished through a dedicated server which allows guests to log in to a local host and remote "Start" and "Stop" the system while viewing the operations in real time through a camera that is mounted above the system, as shown in Figure 3.

The system is remotely accessed and operated through dedicated Lenovo Think Server TS140 and Windows Server 2009 Enterprise software. The system uses Apache 2.2 software to create access and remote control via the internet, as shown in Figure 4.

Figure 3. Google Chrome Local Host Screen Shot

Figure 4. Real-Time Camera Controls

MecLab Easy Port to I/O pin and Cable Layout

The Festo MecLab sub-systems use port interfaces called "Easy Ports" to interface with the input and output field devices. Each Easy Port interface consists of six input ports, six output ports, and 24 V DC buss supply distributed to each port. Students were required to use a multi-meter and determine the pin configuration and layout of these Easy Port interfaces so that proper cable connections to the PLC could be made. The port configuration and wiring layout shown in Figure 5 is what the students developed.

The Easy Port interfaces directly with the I/O field devices in the system, however, it requires connection to the PLC's to all control through the various I/O field devices connected to the Easy Port interface. To accomplish this, the ribbon cable with a 15 pin sub-D connector was used to provide the interconnection to the PLC. The illustration in Figure 6 below shows the ribbon cable orientation. Easy Port 001 interface was located at the base feeder and sort conveyor location, Easy Port 002 was located between the sort conveyor and the metal assembly location, and Easy Port 003 was located between the metal assembly and outfeed conveyor location.

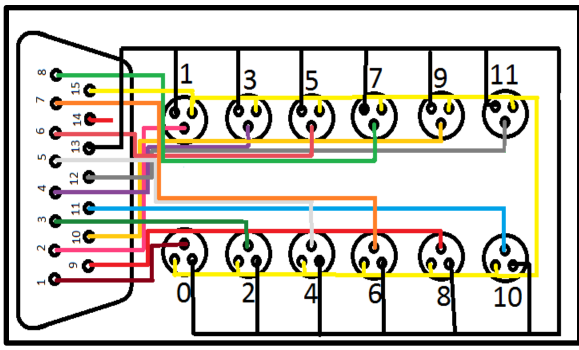


Figure 5. Easy Port Interface Wiring and Port Configuration

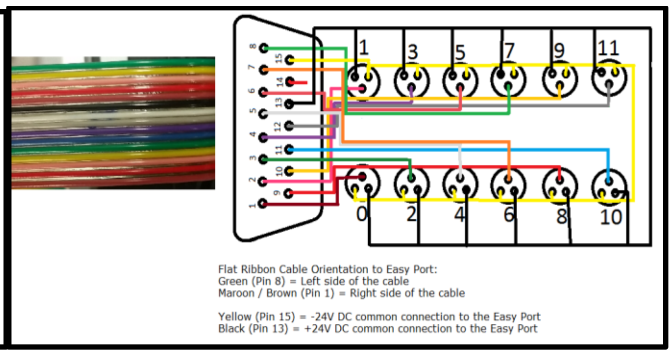


Figure 6. Easy Port Interface and Ribbon Cable Interconnection

I/O Port Assignments

Three Allen-Bradley Micrologix 1200 PLC's are used in the system. Each PLC has ten inputs and six outputs. The output configuration works well with the six outputs on the Easy Port interface. PLC I/O and I/O cable to Easy Port interface port assignments and addressing are shown in the following tables (Easy Port (EP) Cable & Wiring ID 001 (Table 1), 002(Table 2), and 003(Table 3)).

Table 1. Easy Port Cable & Wiring 001

EASY PORT (EP) CABLE & WIRING ID						
EASY PORT CABLE 001						
CABLE ID: EP CBL 001						
WIRE COLOR	**PLC NO:**	**INPUT**	**OUTPUT**	**DESCRIPTION**	**EP PIN #**	**EP NODE #**
Maroon (R)	001	I:0/2		HES – BF1S1 Base Feed Cyl. @ Extended Position	1	0
Red (R)	**002**	**I:0/0**		**HES – PT1S2 Product x-fer Cyl. @ Retracted Position**	9	8
Pink (R)	001		O:0/1	SOL 1 M1 – DCV for Base Feeder Cyl. Extend	2	1
Yellow (R)					10	9
Green (R)	001	I:0/5		HES – BF1S2 Base Feed Cyl. @ Retracted Position	3	2
Blue					11	10
Purple	001		O:0/2	SOL 1 M2 – DCV for Base Feeder Cyl. Retract	4	3
Gray					12	11
White	**003**	**I:0/6**		**HES – CF1S2 MA Cap Feeder Cyl. @ Retracted Position**	5	4

Black (+24V DC)				24V DC Source Voltage	13	(+24V)
Maroon (L)	001		O:0/3	SOL M1 – Metal Sort Diverter Gate Down Solenoid	6	5
Red (L)				NOT USED	14	
Pink (L)	**002**	**I:01**		**HES – PT1S1 Product x-fer Cyl. @ Extended Position**	7	6
Yellow (L)				24V DC Voltage Common	15	(-24V)
Green (L)					8	7

Table 2. Easy Port Cable & Wiring 002

EASY PORT CABLE 002						
CABLE ID: EP CBL 002						
WIRE COLOR	**PLC NO:**	**INPUT**	**OUTPUT**	**DESCRIPTION**	**EP PIN #**	**EP NODE #**
Maroon (R)	001	I:0/3		OPT – Part Entering Conveyor	1	0
Red (R)	**003**	**I:0/7**		**HES – RB2S3 Robot Arm @ Down Position to Place Cap**	9	8
Pink (R)	**002**		**O:0/1**	**SOL 2M1 – DCV for Product Transfer Cyl. Extend**	2	1
Yellow (R)	001		O:0/0	K2 – Sort Area Conveyor Run	10	9
Green (R)	001	I:0/4		IND – Prox. To Detect Metal Parts @ Sorting Area	3	2
Blue	**002**	**I:0/5**		**IND – Prox. to Detect Metal Parts @ Outfeed Area**	11	10
Purple	**002**		**O:0/2**	**SOL 2M2 – DCV for Product Transfer Cyl. Retract**	4	3
Gray					12	11
White	001	I:0/1		FOPT1 – Base Feed Tube, Part Present Detection	5	4
Black (+24V DC)				24V DC Source Voltage	13	(+24V)
Maroon (L)	**003**		**O:0/5**	**SOL 3M1 – DCV for MA Cap Feeder Cyl. Extend**	6	5
Red (L)				NOT USED	14	
Pink (L)	**001**	I:0/8		OPT – Part Stack Up – Plastic Area	7	6
Yellow (L) (-24V DC)				24V DC Voltage Common	15	(-24V)
Green (L)	**002**		**O:0/0**	**SOL 3M2 – DCV for MA Cap Feeder Cyl. Retract**	8	7

Table 3. Easy Port Cable & Wiring 003

EASY PORT (EP) CABLE & WIRING ID						
EASY PORT CABLE 003						
CABLE ID: EP CBL 003						
WIRE COLOR	**PLC NO:**	**INPUT**	**OUTPUT**	**DESCRIPTION**	**EP PIN #**	**EP NODE #**
Maroon (R)	**003**	**I:0/0**		**HES: RB1S2 – Robot Arm @ Extended Position**	1	0
Red (R)	**003**	**I:0/4**		**HES: CF1S1 – Cap Feeder @ Forward Position**	9	8
Pink (R)	**003**		**O:0/0**	**SOL 3M1 – DCV for Gripper Closed (Spring Return to Open)**	2	1
Yellow (R)	**003**		**O:0/4**	**SOL 1M2 – DCV for Robot Arm Retract**	10	9
Green (R)	**003**	**I:0/1**		**HES: RB1S1 – Robot Arm @ Retracted Position**	3	2
Blue	**003**	**I:0/5**		**FOPT2 – Part Present @ Metal Assembly Area**	11	10
Purple	**003**		**O:0/1**	**SOL 2M1 – DCV for Robot Arm Down**	4	3
Gray	**002**		**O:0/5**	**K2 Outfeed Area Conveyor Run**	12	11
White	**003**	**I:0/2**		**HES: RB2S2 – Robot Arm @ Down Position to Pick Cap**	5	4
Black (+24V DC)				24V DC Source Voltage	13	(+24V)
Maroon (L)	**003**		**O:0/2**	**SOL 1M1 – DCV for Robot Arm Extend**	6	5
Red (L)				NOT USED		
Pink (L)	**003**	**I:0/3**		**HES: RB2S1 – Robot Arm @ Up Position**	7	6
Yellow (L) (-24V DC)				24V DC Voltage Common	15	(-24V)
Green (L)	**003**		**O:0/3**	**SOL 2M2 – DCV for Robot Arm Up**	8	7

Ladder Logic

The major challenge for controlling the PLC-controlled automated sorting system was having adequate I/Os to control the system without adding additional PLCs, as well as for space consideration. Another challenge was getting the RSLinx software (Allen-Bradley communication port configuration software) to maintain an open link to the remote internet link with the Apache 2.2 software. There seemed to be a continual port conflict with the server.

1) Sorting Area (Primary Program PLC001 (Festo_Sys_Alamo_Sort)

The PLC001 program, titled Festo_Sys_Alamo_Sort, is provided in Figure 7. Some permissives must be provided locally before the program can be operated remotely. Power must be supplied to the system, the air compressor must be on and up to pressure, the program must be running in the "remote program" mode, and the selector switch must be on the "start" position. With these permissives set the system can then be operated remotely.

2) Metal Assembly Area and Additional Control (Primarily PLC003 & 002)

The PLC003 & PLC002 program, titled Festo_Sys_Alamo_Metassem, is provided in Figure 8. The primary function of PLC003 is to control the operation of the assembly robot. PLC002 provides extra I/O to accommodate the system requirements.

System Schematic

The system was powered by a standard 110V AC power source. Three MicroLogix 1000 PLC's were powered directly from the 110V AC source. Power for the I/O was provided through the PLC onboard 24V DC power source. An Omron 220/110V AC to 24V DC, 2.5A adjustable power supply was used to provide 24V DC power to devices not connected to the PLC outputs. Devices used to provide "input" signals to the three PLC's included: eleven HES's, two OPT's, two FOPT's, and two IND's. Devices controlled by "outputs" from the three PLC's included: twelve SOL's for Directional Control Valves (DCV), one remote control indicator, one locally accessible Selector Switch (SS) for Start/Stop control, and two relays (K2) for motor control of the conveyors. The PLC Interconnection Schematic shown below illustrates these input and control devices and their interconnection to the three PLC's. Please see system schematics in Figure 9.

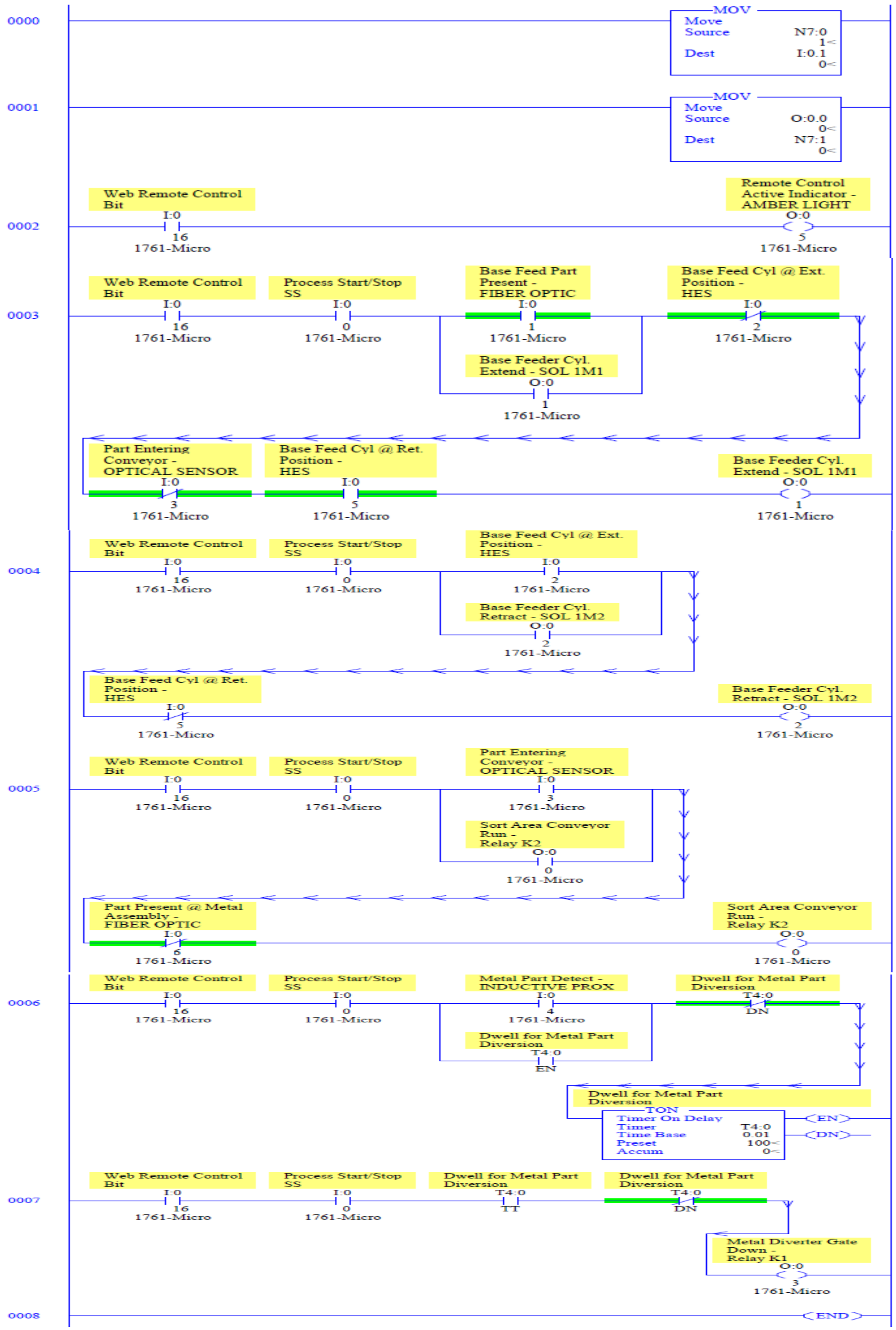


Figure 7. PLC 001 Program: Festo_Sys_Alamo_Sort

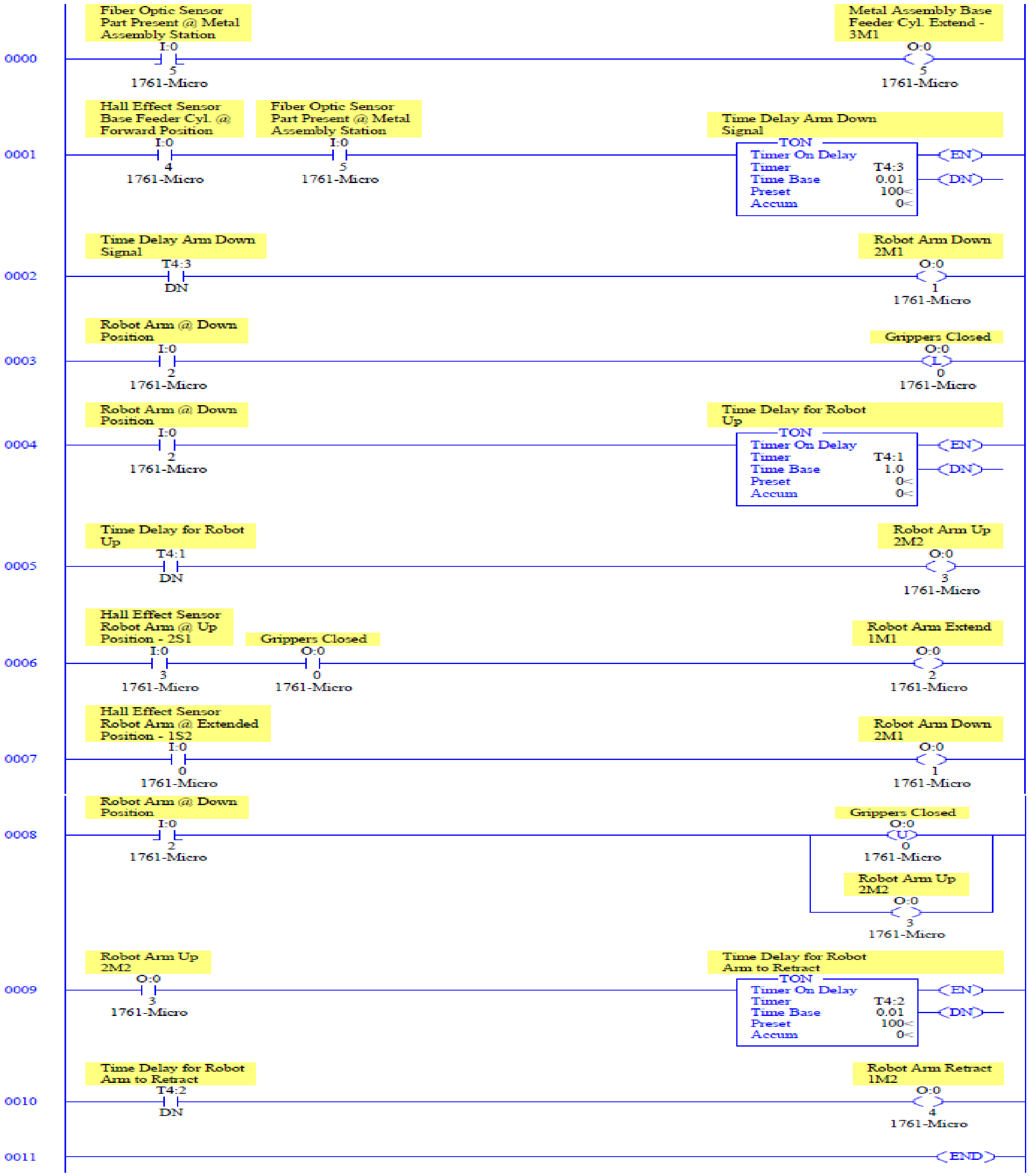


Figure 8. PLC003 & PLC002: Festo_Sys_Alamo_Metassem

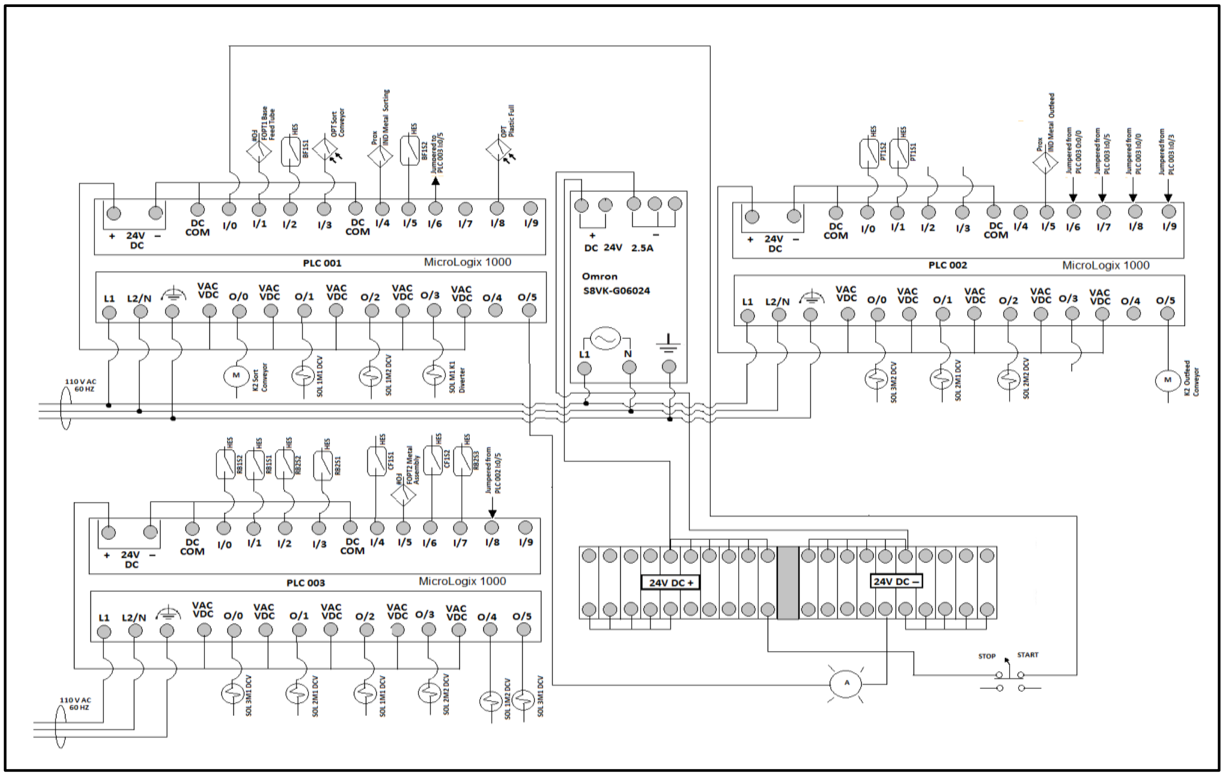


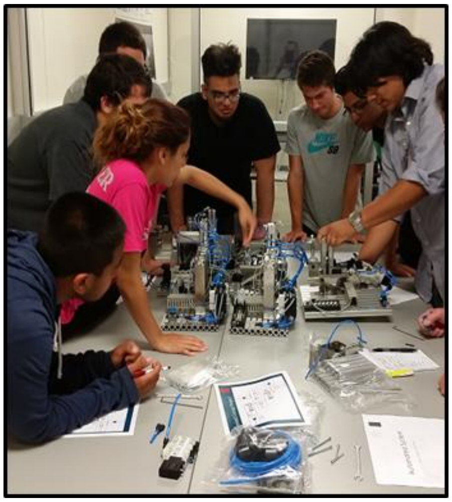
Figure 9. System Schematics

Student Activities and Survey Evaluations

The IST approach was used for Robotics Fundamentals class since 2014. Totally thirty-eight students completed the course. All students enjoyed the class and a survey was conducted to gauge student response to the teaching methods used. The survey indicated that the hands-on portion of the training greatly helped them understand and visualize programming using the robotics teach pendant. Figure 10 shows the class activities students were involved in during the class and opinion survey rating various aspects of their experience using IST approach with Festo system on a 5 point Likert scale (1=strongly disagree; 5=strongly agree).

Future Directions

The ATMA is an ongoing dual-credit pipeline for the Alamo College certificate and degree programs. The robotics course will continue to be taught to the ATMA students using the IST model. The model will continue to be reviewed each semester and continual improvements will be made to the curriculum and labs. Due to monetary restrictions the curriculum will be developed so that it can be migrated to an online platform. This curriculum should be available to students so that they can use it to help them learn the concepts being taught using a virtual platform. The online platform will eventually provide students with lessons related to robotics and PLC control of automated systems that will be accessible via the remote control.



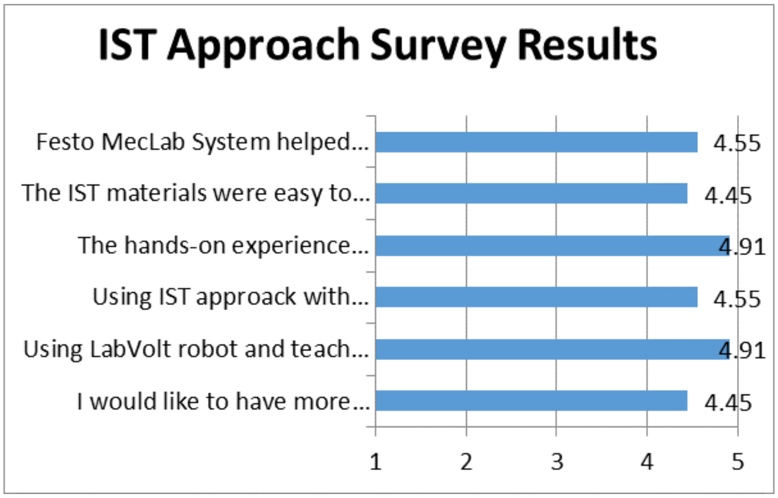


Figure 10. Student Activities during class and IST Approach Survey Results

In the upcoming semester students will be instructed using the IST teaching model. Students will be challenged with building on the current system to expand it to include the plastic assembly station feeder and pick-and-place robot. Students will also be expected to learn PLC programming and assist in interconnection and programming of the PLC control.

Future plans also include to incorporate remote access to one of the robots in our lab including remote control and access to online lessons related to robotics and robot control in automation. Two robots are under consideration, one is the LabVolt 5150 and the other is the Kawasaki industrial robots.

Acknowledgement

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