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PLC Multi-Robot Integration via Ethernet for Human Operated Quality Sampling

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Abstract

In automation, quality control inspection is a critical requirement to ensure product standards. The goal of this work is to insure product quality without interrupting the production line flow. The multi-robot system presented, connects a programmable logic controller (PLC), as the main controller, to a conveyor belt and two FANUC industrial robotic arms via EtherNet/IP. Human interaction is implemented to pick a work piece from the moving conveyor and return it with a quality label. This label is used by the PLC to execute the correct robot action; either to return the inspected part to the conveyor or discard it into the rejection bin. The operator uses a custom control panel connected to the PLC, which controls the conveyor and robot actions. The results show the feasibility of the presented multi robot automation line controlled by a PLC that allows human machine interaction to enable manual quality inspection during production. This paper details a student project developed in the advanced programmable logic controllers class. It is part of the master program in mechatronics. Students work in groups in a creative setting, where they learn to integrate various automation technologies and learn to write scientific publications.

Keywords: Multi-robot; Industrial robots; Programmable Logic Controller (PLC); Communication, Quality Inspection, human ma- chine interface (HMI)

Introduction

In industrial automation, Programmable Logic Controllers (PLCs), and intelligent connected devises form the basic building block for Distributed Control Systems [1, 2]. Robot arms, for example, have their own control systems, while the main PLC oversees the entire manufacturing process. A multi-robot work cells, such as developed in this work, can boost industrial productivity and flexibility. For multi-robot systems, collision avoidance, task planning, communication, and performance evaluation are all research and development themes [3]. Robots can now perform more difficult activities with greater flexibility, such as assembling, welding, and material handling, thanks to the development of new computer technology, sensors, and vision systems. [4, 5] The automated manufacturing facility with an automated material handling system is called a flexible manufacturing system. It is important to make sure that components moving within the plant from one production unit to the next do not have to be rejected at any point during the assembly process due to a mechanical fault. An accurate geometric examination can prevent assembly flaws, thus ensuring product quality, and be cost effective in the long run. If the number of produced parts is are very high, an exhaustive part inspection is not possible. Hence, a random sample is inspected in a Flexible Manufacturing System is developed in this work [6].

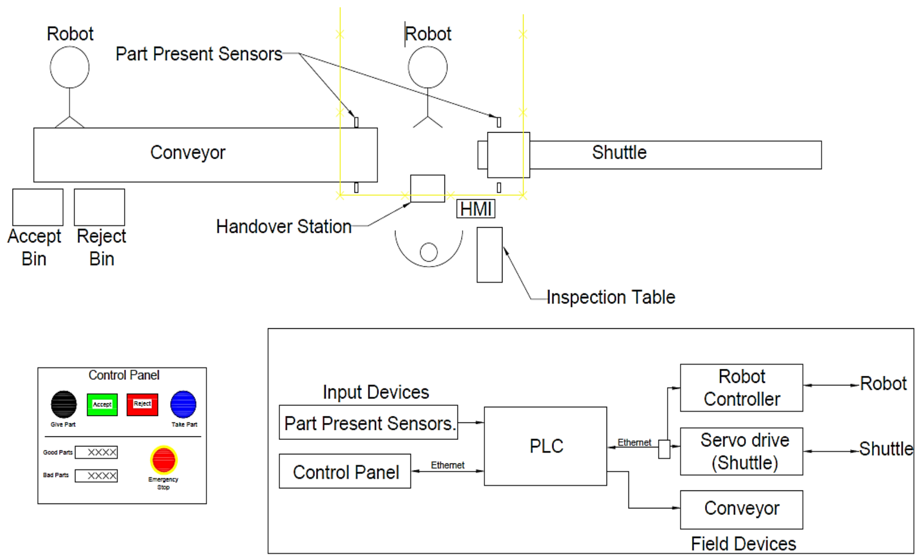


Figure 1. multi-robot inspection cell control architecture

This paper is the result of an advanced PLC class project for master students in mechatronics. In the course, this assignment is designed to allow groups of students to think creatively, and gain experience in authoring research publications. The rate of papers that are published is about 40%, as previous publications show [7-11]. Typically, each paper is written by a group of 4 or 5 students. Since this is a new experience for most students, the assignment is divided into three stages. First, a project proposal is due a few weeks into the course (week 3 of 15). In this stage, students form groups, brain storm a project, then write a proposal in the form of a publishable paper using a conference template. In it, they have to perform a literature review, develop a system architecture, and elaborate on each team member’s contribution. The second component is due towards the end of the semester (week 14/15). Here the students complete the project and write the paper describing following the conference template. The final part, is due in the last week of the course and entails creating a presentation using the university template, as well as recording a demonstration video, with the intention of sharing it on social media. Naturally, the instructor has to work with students after the course ends to manage all the conference presentation procedures. This type of assignment entails a large amount of effort on part of the students and the instructor. Nonetheless, the reward is proportionally large as well. It makes the course more creative and exposes students to academic research and publishing.

System Architecture

The working schematic of the planned quality inspection cell using Allen Bradley PLC and FANUC LR Mate 200iC is depicted in Fig. 1. The control panel was created in such a way that a part may be reviewed in the middle of the manufacturing process. SolidWorks was used to create the schematic. The working environment of the system is shown in the Fig. 2. We are using a regular suction gripper for this prototype, but the grippers can be upgraded by the already designed in house grippers which can detect the size of the parts [7], which can manipulate the force of the grip [8]. The FANUC robot can be also be replaced by the in house designed Pneumatic Robot System [9].

Conveyor System

The conveyor [12] framework was chosen based on the numerous functionalities that would be necessary to construct industrial scenarios for the robotic vision course's lab activities. For improved vision identification and maintenance, the black belt was chosen. The system transports a inspection assembly block which depicts a industrial assembly part. In the forward motion, the conveyor can be run at four different speeds, or at one constant speed in both directions. Multiple speeds can be set up using the variable frequency drive (VFD) placed on the control panel [13]. Table 1 lists the conveyor's and its parts' specs in detail.

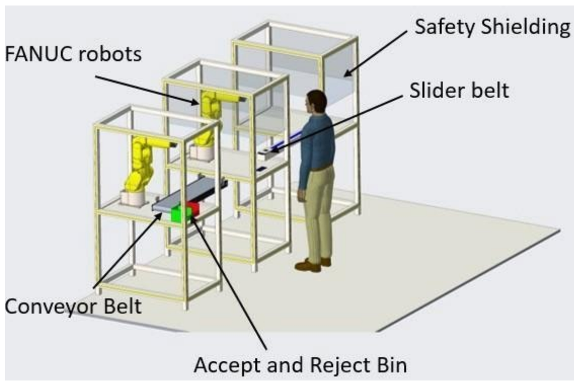


Figure 2. human operator controlling the inspection cell

Table 1. Detailed Specifications of the Conveyor

Specifications	Description
Conveyor	Manufactured by Mini Mover Conveyors, LITE series model Width – 10", Length – 84", Speed 3-43 feet/min
Conveyor frame	Hard black anodized aluminum frame with integral 0.070" high side guides
Belt	Black, PVC (polyvinyl chloride, low friction cover)
Geared-Motor	Manufactured by Oriental Motor Co. Ltd., Brushless DC Motor, Model No. BLM460SP-GFV2, Single phase 100-120 V, Output Power-60 W
Variable Frequency Drive	Manufactured by Oriental Motor Co. Ltd., 115/60 VAC input variable speed Digital Display, Model No. BMUD6o-A2

Part Presence Sensors

Most automation systems have sensors that detect items and provide feedback to the system's controller. A through-beam photoelectric sensor [14] has been mounted on the conveyor. It is made up of an emitter (which emits infrared light) and a receiver. When the transmitted beam is impeded and thus not collected at the receiver's end, the sensor identifies an object. In one of the laboratory exercises covered in the study, the sensor is used to detect the presence of a marker. The camera sensor is installed on steel brackets and may be modified to accommodate various object heights. It is a Sony grayscale charge coupled device (CCD) camera with a 600 by 494 pixels array, and 6 mm focal length lens.

PLC Setup

An Allen Bradley PLC [15] (1769 CompactLogix L32E) as sown in Fig .3 with one input (1769-IQ16) and three output (1769-OB16) modules, as well as a conveyor VFD and an Omron SMPS (24V DC, 1.1 A). The PLC interacts with sensors, the conveyor system, and the robot controllers to regulate the conditional and sequential functioning of the complete work cell in production mode. It serves as the system's master controller, providing digital I/O signals to the robot controllers to begin program execution.

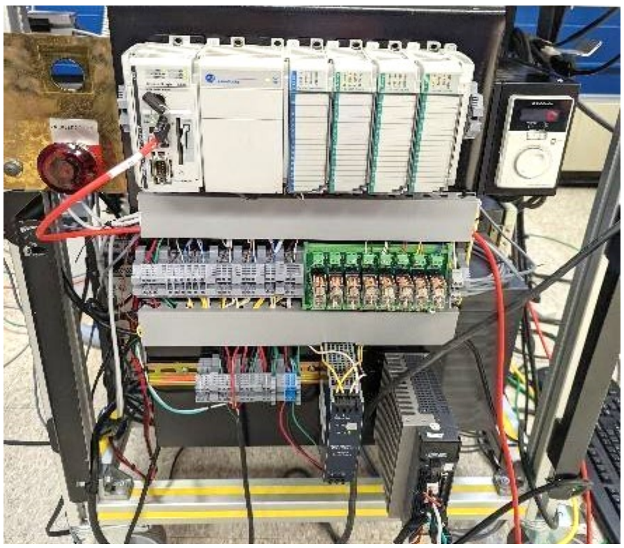


Figure 3. Allen Bradley PLC

Figure 4. FANUC robot LR Mate 200iC

Control Panel

Control Panel is the interface for the inspector for accepting and rejecting parts. Give part button is used to move the part from the shuttle to the handover station from which the particular part is inspected. After a thorough inspection of the part, the accept button is pressed if it satisfies the requirements, or reject button is pressed if the part does not meet the requirements. Then, the part is placed back on the handover station, and the take part button is pressed so that the part is picked by the robot and placed back on to the conveyor. Moreover, the control panel also keeps track of all good parts and bad parts count. For safety purposes, an emergency stop button is also provided to shut down the system completely in case of emergency.

FANUC Robot LR Mate 200iC

In this project, the FANUC Robot LR Mate 200iC was used for Pick and Place operations [16]. FANUC robots have unique features and benefits such as 5 or 6 degrees of freedom, high repeatability at full payload and full speed, two, double acting solenoid valves integrated in the forearm simplify End of Arm Tooling (EOAT), and it is small in size and convenient to use in compact spaces, as shown in Fig. 4. It boasts a high degree of rigidity and the most advanced servo technology, as well as advanced communication capabilities via Ethernet and serial interfaces.

Working Schematic

The process begins with a production mode of the FANUC robot, where with a press of a push button the working production of the plant starts. Figure 5 shows a flow diagram of the control whole system. The program begins by checking if the part is required for an inspection which would imply the robot to hand over the part to the handover station. If Yes, then the part is picked and placed in the inspection/handover bin, where the user inspects the part and enters if the part is acceptable or not. If the part is not required for inspection, then the part is picked from the Station 1 (Slider) and places it on the conveyor system. The part is then detected by the part presence sensor which in turn activates the conveyor to move. The part reaches at the end of the sensor where the robot arm 2 picks the part from the unloading station and checks if the part is accepted or rejected. If the part is accepted, the part is then put in the accept bin, and if not then put in the reject bin.

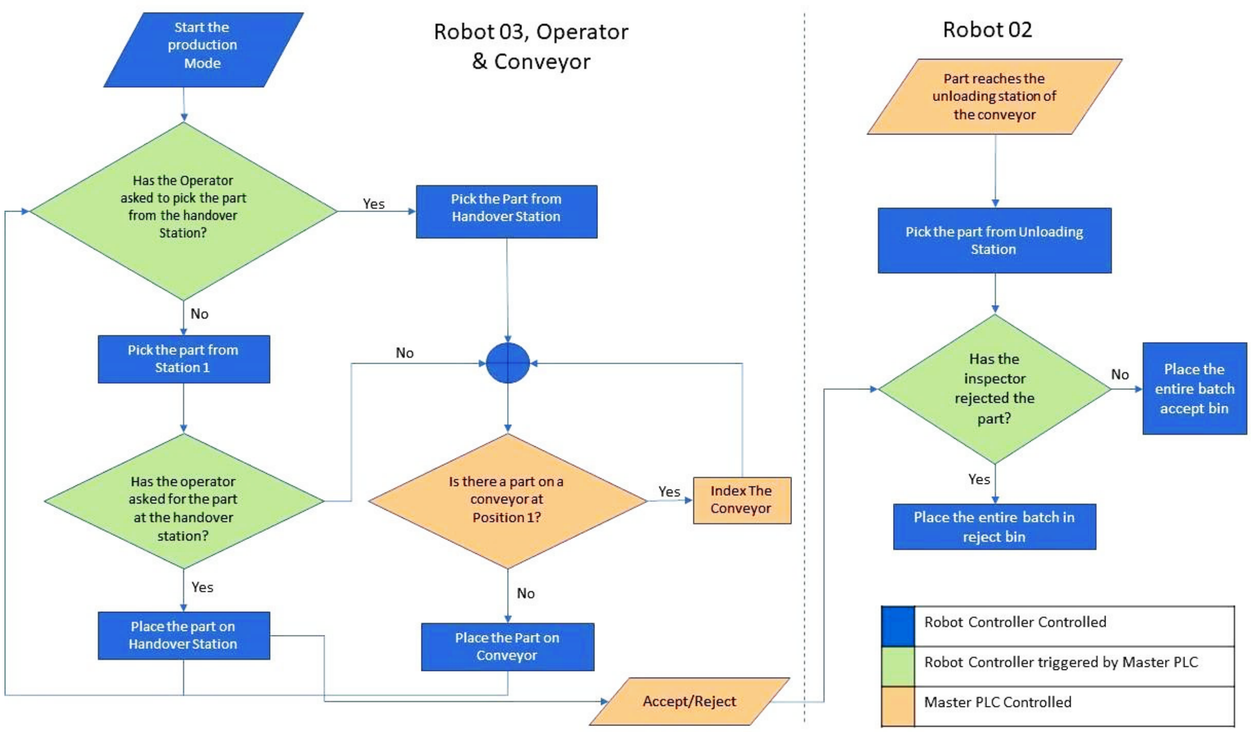


Figure 5. System control flow diagram

PLC-robot Connection

The Allen Bradley PLC is connected to the FANUC robot with the help of Ethernet cable through TCP/IP though the following steps as displayed in Fig.6. The PLC's input and output connections to the robots, conveyor and operator panel as shown in Fig. 7.

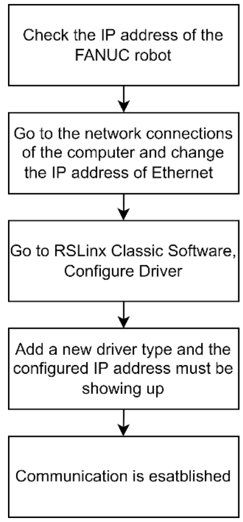


Figure 6. connection workflow from Robot to PLC and vice versa

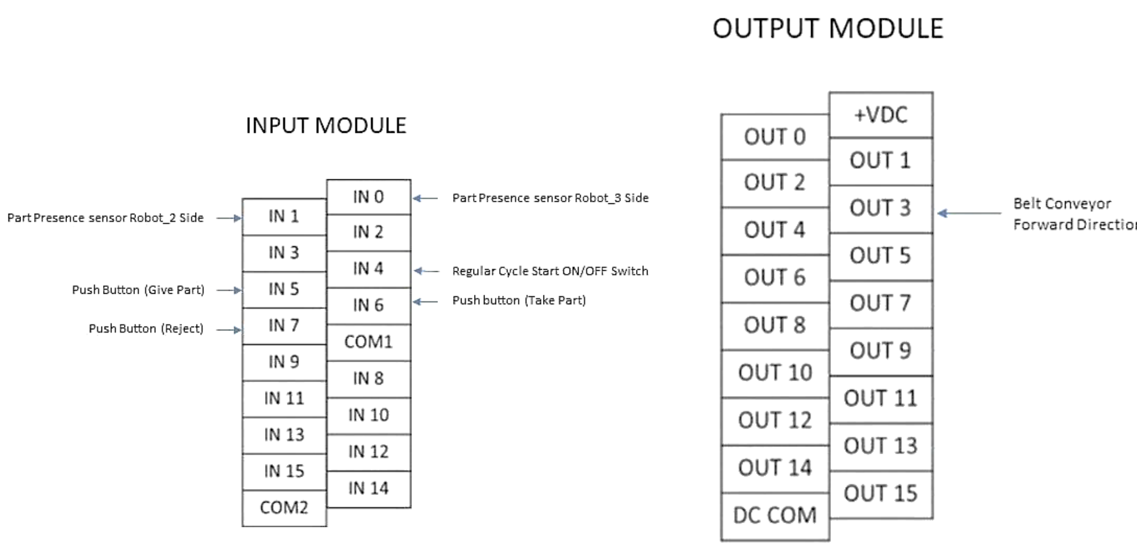


Figure 7. PLC input and output module connections

The proposed project aspires to integrate numerous modules and generate a framework for node-to-node communication through the use of a communications infrastructure. Inter subsystem signal synchronization is enabled by the network connection in order to receive device and program status in order to coordinate the process [17, 18]. Ethernet communication protocols, including a local area network (LAN) or a wide area network (WAN), are shared by the majority of subsystems. The EthernNet/IP communication protocol is supported by all FANUC robots, servo drivers, the master PLC, and the laptop. It is one of the most generally utilized protocols for receiving and sending I/O data. The robot controller server are connected over 24 Ethernet TCP, while the belt conveyor driver is connected to the PLC via a wiring connection to exchange 24VDC signals.

Configuring EthernNet/IP with FANUC Robots

To enable communication between the PLC and the robots, FANUC provides an EthernNet/IP adapter option (ID R538) that is placed on all robot controllers. To install and enable the EthernNet/IP communication protocol on the robot teach pendant, the procedure is start by verifying the correct version of core system software is used:

- MENU > FILE > S/W Install
- Go to F4 > CHOICE > USB(UD1:)
- Go to F3 Done > 25
- Select the option from the window, then Enter the PAC code
- Go to F4 > AUTH]
- Go to F2 > INSTALL
- Press F5 > AUTOUPDT if required
- Cold start the robot

The robot is configured for communication through EthernNet/IP after installing the EthernNet/IP adapter option on the controller. The procedure to configure the IP address using the teach pendant are:

- MENU > SETUP > Host Comm, then Select the TCP/IP
- Name the robots: Robot 1 and Robot 2.
- Enter the IP addresses for both the robots
- Enter subnet mask as 255.255.255.0
- Enter the IP address of PLC
- Enter the IP address under the second entry as the personal computer
- Press F4 to ping each IP to confirm connection
- If the device is available, then the ping will go through

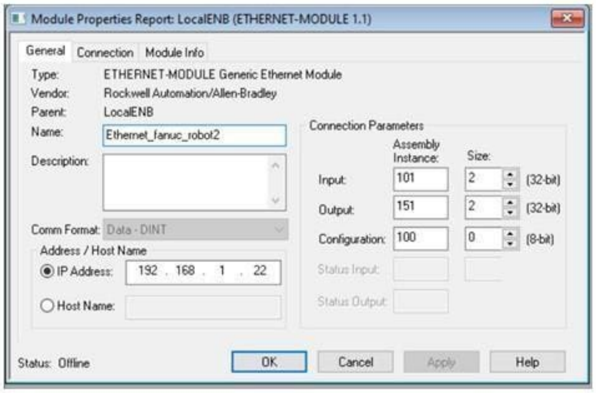
Configuring EthernNet/IP with Master PLC

RSLinx Classic software, the communication driver for all Rockwell Automation PLCs, provides EthernNet/IP connections by configuration on the master PLC. RSLinx Classic enables the PLC to search for any ports on the Ethernet interface and access all of the devices. Figure shows how to link via EthernNet/IP. RSLinx Classic's configurations may be found here as shown in Fig. 8 and Fig. 9. The procedure for finding the IP address is:

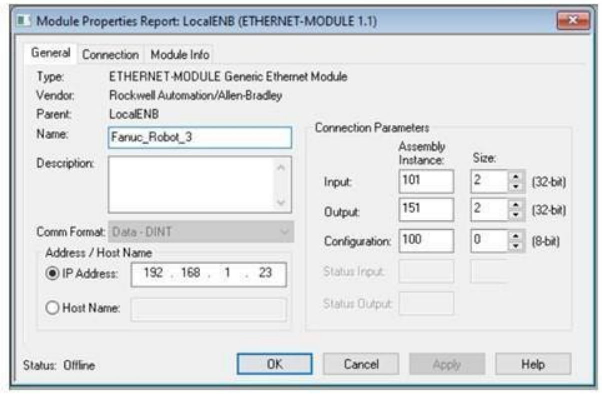
- Under Windows setting open Ethernet,
- Change adapter options such that the network connections window opens.
- Select Ethernet on the new window > Select Internet Protocol Version 4(TCP/IPv4)
- Enter the IP address from the Host comm settings.

RSLinx Classic is setup after configuring the Laptop IP address a followes:

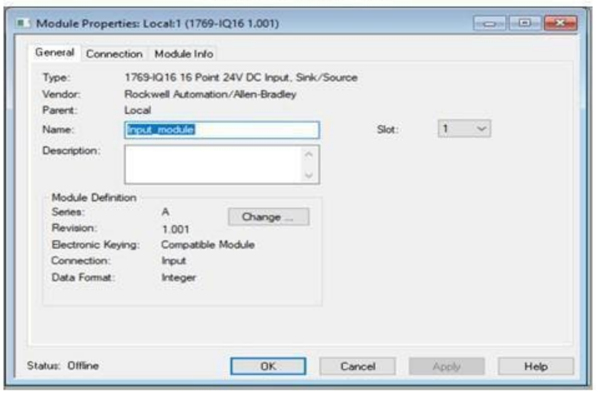
- From the start menu, select RSLinx Classic.
- In the software, go to position one and click configure driver to open a new window.
- To create a new window, select EtherNet/IP Driver from the Available Driver Types menu and click Add at position two
- In a new window, select your laptop's IP address and click OK to exit
- Properly configured Ethernet IP drive will show all devices connected to Ethernet IP from error. The source cannot be found. The number of input output bits should match on the PLC as well as the FANUC robot, which is very important to take care of, as hown in the Fig. 10



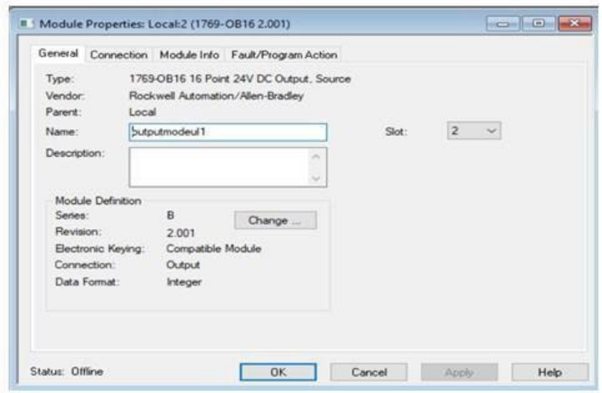
Ethernet Module – Robot_2



Ethernet Module – Robot_3



PLC Input Module



PLC Output Module

Figure 8. PLC Ethernet module configuration

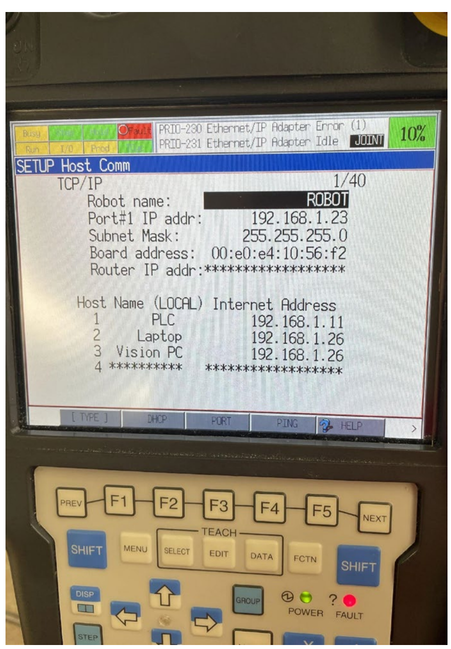


Figure 9. Robot teach pendent communication setup screen

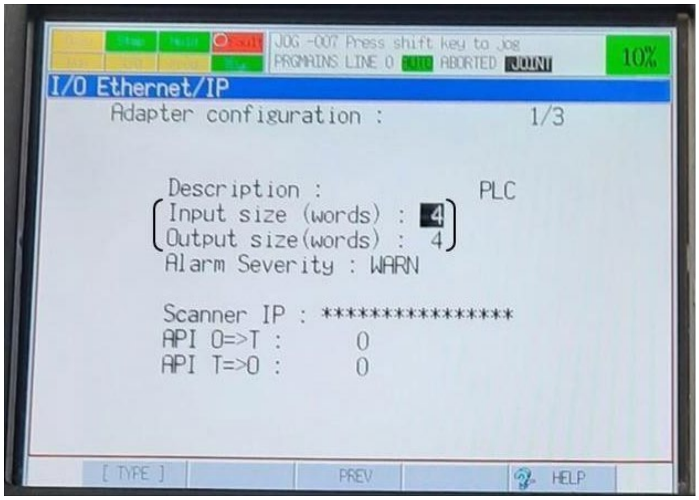


Figure 10. Communication protocol settings on the robot teach pendant

PLC Ladder Logic Programming

Ladder logic, function blocks, sequential function charts and a text language are all defined in the IEC 113 1 international standard. Ladder logic is perhaps the most used programming language. The relay ladder logic wiring design was used to create the ladder logic symbology [19]. We used RSlogix 5000 for the PLC programming of the system. As shown is Fig. 11 different rungs were utilized.

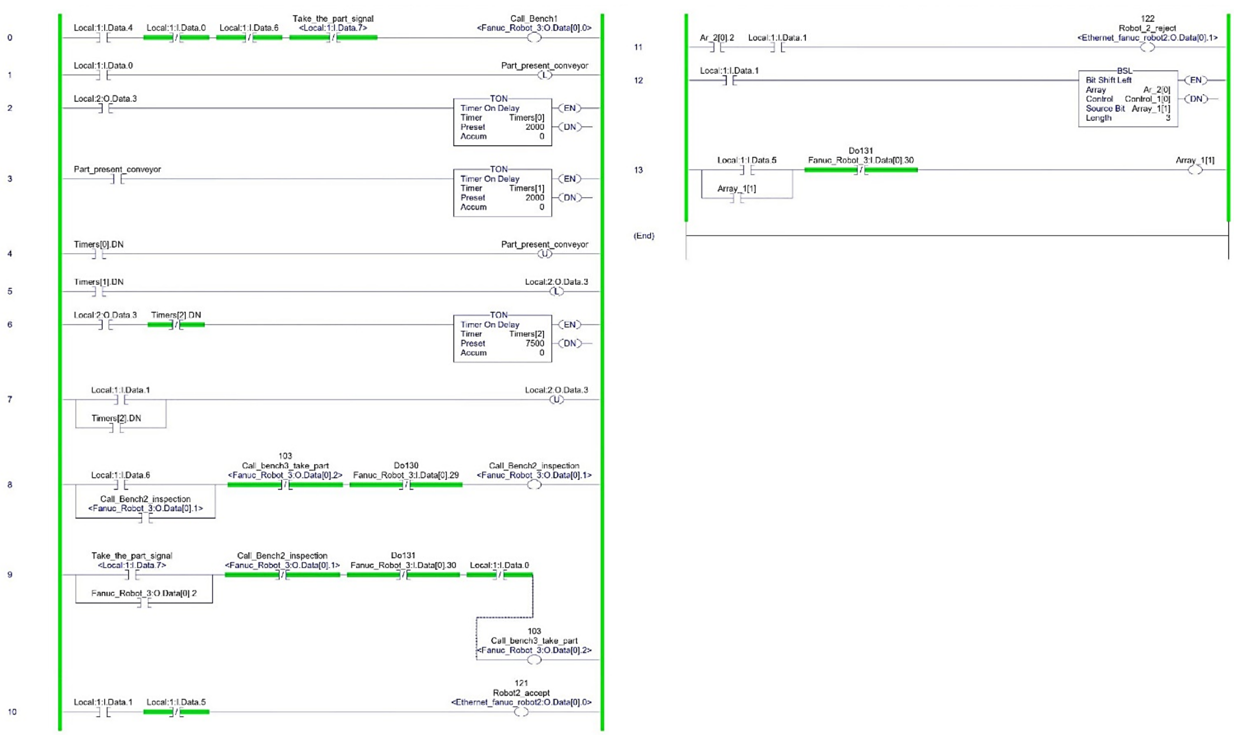


Figure 11. PLC control ladder Logic

The following list explains the functionality of each of the ladder logic rungs:

- Rung 1: When on-off switch is turned on, it turns on the FANUC robot output Data 0.0 energizes. Which starts the regular cycle of robot 1. Conditions: Part is not present on the conveyor (Local1:I:Data.0 is off). Button “Give part (Executes BENCH2)” (Local1:I Data.6) or “ Take Part (Executes BENCH3)” (Local1:I Data7) is not pressed
- Rung 2 Rung 4: Give the signal that part is present on the conveyor. It should be on for at least 2 sec when the data input (Local1:I:Data.0 is off)
- Rung 3: Wait for 2 Seconds Timer[0]
- Rung 5: Conveyor Start after 2 sec (Rung 3) the part present turned on.
- Rung 6: Conveyor on starts the timer of preset value 7.5 sec Timer[2]
- Rung 7: Conveyor stops if the timer[2] is done or the part is present at the other side of the conveyor. Note. : The conveyor is programmed in such that a maximum of 3 parts can be present on the conveyor. 4 th part cannot be placed on it by the robot.
- Rung 8: When the “Give part” button is pushed on “Call bench 2 Inspection” (Fanuc Robot 3: O: Data[0].1) energizes which will signal the robot to give part for inspection. Conditions: “ Take Part” (Local1:I Data7) is not pressed Once the robot gives the part. Robot gives the signal (Fanuc robot 3:I. Data[0].30)
- Rung 9: When the “take part” (Local1:I Data7) button is pushed on the “Call bench ” (Fanuc Robot 3: O: Data[0].2) energizes which will signal the robot to take the part from the handover station. Conditions: 1. There should be no part on conveyor station 1. 2. Button “Give part” (Local1:I Data.6) is not pressed Once the part is placed on the conveyor , the take part signal is switched off until it is pressed again.
- Rung 10: When the part is is present at the other end of the conveyor it will trigger the accept part cycle of the robot 2 (Fanuc Robot 2: O: Data[0].0)
- Rung 12: Bit shift Left register: The bit shift uses array Ar 2[0]. Control is stored in register Control 1[0]. It takes the bit from the source Array 1[1]. The bit shifts when it gets the signal from part present on conveyor station 1. The length is 3 as there can be a maximum of 3 parts on the conveyor.
- Rung 13: When the operator presses “reject” (Local:1:I.Data.5 on). It places 1 in Array 1[1].
- Rung 11: Ar 2[0].2 turns on when the rejected part reaches at the other end of the conveyor(Local:1:I Data.1, on). It calls robot 2 to reject the part.

FANUC Robot Programming

Robot programming is creating a set of commands that will allow an industrial robot to communicate with its surroundings in order to complete a task. Creating precise control systems gives articulated robot the autonomy they need to maximize and finish production tasks. FANUC robots are among the most commonly employed in the manufacturing industry. They’re adaptable, intelligent, and exceedingly long-lasting. FANUC robots may be programmed to do virtually any production task. The two robots execute seven different motion programs based on the PLC commands. Fig. 12 shows the program names and their functions. The first Program in Robot 1 (BENCH2) is to pick the part from the shuttle, and place it in the inspection cell. This program is executed for a random part of every batch to check for its design accuracy in the inspection cell. The second Program in Robot 1 (BENCH3) is to pick the part from the inspection cell after the operator has inspected the part, and place it on to the conveyor towards the second Robot. In the third Program in

Robot 1 (BENCH1), the parts are directly picked up from the shuttle, and placed directly on the conveyor. These parts are of the batch in which the initial part was inspected in the inspection cell. The first Program in Robot 2 (ACCEPT) is executed when the operator presses the accept push button on the control panel. The parts are placed in the accept box from the conveyor when this program is running. The second Program in Robot 2 (REJECT) is used when the reject push button is pressed. The parts are picked up from the conveyor and then placed in the reject box. The master program (PRGMAINS) is the main master program in which all the programs are called according to the inputs given from the PLC.

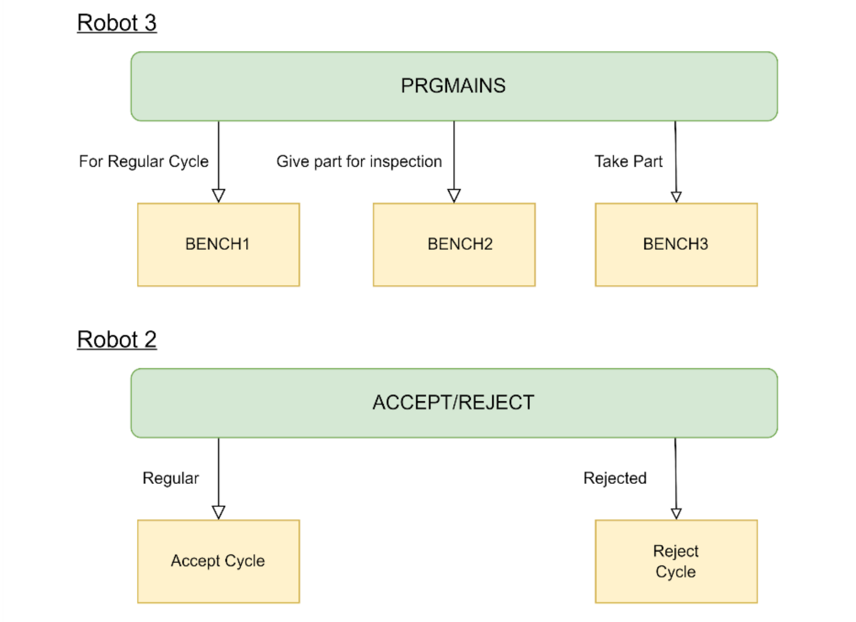


Figure 12. FANUC robot motion programs called by the control PLC

Control Panel

The Control panel is required to provide switches and push buttons to operate the whole process. A 3 printed control panel was prepared as shown in Fig. 13 The 3D modell was first designed using SOLIDWORKS CAD software. This model was then 3-D printed using the Lulzbot TAZ 6 printer. The modell was developed using the Poly Lactic Acid (PLA) material. PLA is a biodegradable polymer with excellent strength and biodegradability, both of which are critical in the fabrication of newer components using 3-D printing [20]. Additionally, PLA's features also include low thermal conductivity, heat resistance and hardness, and biocompatibility. In our case, PLA was used to make a hand-held control panel. The module has six different slots, each of which for a unique purpose. First one being the largest one, for holding the whole module. Then, there is an on-off switch for turning on and turning off the whole equipment. Furthermore, there are four push buttons provided. One of them is an accept button, which is pressed when the operator feels that the part satisfies the requirements after examining the part in the inspection cell. On the contrary, if the operator is not satisfied with the part, the reject pushbutton is provided to reject the particular part. The other two push buttons are the give part and take part buttons which are used to place the part in the inspection cell and pick the part from the inspection cell respectively.

Figure 13. custom made human operator controller

Results

A cycle time as shown in Table 2 of the robot was created with the total production speed of 20% about 1.2ft/sec and the total cycle time of the process was about 9.5 sec. The speed of the handling system should match with respect to the bottleneck machine in order to establish a fully automatic production line. By changing the speeds of the robot and the conveyor, one can easily change the cycle time of the process that gives some flexibility for the production line. This change over does not take much time when the timings are controlled by the master PLC.

Table 2. Cycle times of system components

Cycle Time Diagram (regular Cycle and the Inspection Cycle)										
Robot Speed (Both Robot) 1.2 ft/sec										
Conveyor Speed 0.2 ft/sec										
Activity	Time	5	10	15	20	25	30	35	33
Robot 1									
Pick the part from Position 1	5.5		5.5		15		24.5		
Place on conveyor	2		7.5'				26.5		36
Back to Home	1.5		9		16.5		28		37.5
Pick the part from handover station	5.5							34	
Give the part for inspection	2				17				
Conveyor 2									
Index (by 1 position out of 3)*	7.5		5.5		15		24.5	34	
Inspection Cell									
Inspection	(10.5)				17				
Robot 2									
Pick The part from the conveyor	2	5.5	7.5	15	17	24.5	26.5	34	36
Accept or Reject	2		9.5		19		28		
Cycle Time = 9.5 sec									

Conclusions

The main aim of the project was to use the PLC as a Master control. We have successfully established the Robot connections with the PLC. Two robots successfully communicated with the PLC and each other through the PLC. The inline quality check application can be used as a solution in the continuous flow manufacturing industry. The process can be controlled by using master control PLC. As robots and the PLC communicate using ethernet protocol, wiring is reduced. This paper demonstrates how important it is to understand the PLC master control principle and the operating procedure of the FANUC robot. This paper demonstrates that it is useful in the design of a Master control PLC control system and the proper implementation of the quality check application. Future work includes new features for the vision system in the process to make the quality inspection automatic and without manual interaction. Currently, the robot actions are triggered using the PLC. Further, the alarms and mode control of the robot can be triggered using PLC. By establishing the connection between SCADA and the master PLC, one can directly get supervisory control over the entire process. By making the structure more rigid for the FANUC robot, vibrations can be reduced, and higher production speeds can be achieved and reduce the cycle time of the process.

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