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Robotic inspection and automated analysis system for advanced manufacturing

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Article Info

ABSTRACT

Companies have developed various systems to improve their processes. These processes' focus has been to produce more quantity in less time. To accomplish this task, it is important to also consider defects. Defective products can cause delays in the production line, rework, and the loss of money, time, and resources. This project focused on developing an integrated inspection system. Previous research has been done regarding types of vision systems, in-line inspections, and feedback data collection. A programmable logic controller (PLC) was used to control when the conveyor belt starts and stops. When the object has reached a certain position, the camera detects if the object passed or failed the process. If the object fails, the robot will pick up the bottle and take it out of the line. Human-machine interface (HMI) was also integrated, which shows how many bottles have passed and failed with a light that will indicate if a certain object has passed or failed. Feedback from the inspection process can help solve potential issues from different machines and processes. The testbed was designed, integrated, and tested in the paper to perform a feedback analysis for the production line. The setup consisted of MicroLogix PLC, Fanuc robot LR Mate 200iD and Cognex camera.

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1. INTRODUCTION

Inspection is a required process in many industries. Among the industries where the inspection was used as a required process is power generation with a total of 23.5%, followed by aerospace, military, and defense with 23.1%. Results from previous research showed that visual inspection errors range between 20% to 30% being caused by human error or limited space [1]–[3]. A different study proved that manual inspection is only 85% efficient [4]–[6]. Human inspection is not one of the most reliable methods of inspection since it can lead to less consistent results due to human error and different levels of expertise [3]. Using vision systems can provide a more reliable system with better inspection results. Automating vision systems also provides cost savings to industries. Inspection by humans is estimated to be only 10% of the workforce which is only around 400,000 jobs, meaning an estimated $8 billion is dedicated to industrial inspection [7], [8]. Investing in vision systems will improve the quality of the products offered to the consumer while reducing costs.

The quality inspection process does come with some benefits. The benefits mentioned by the participants include higher quality products, lower costs, reduction in recalls, regulatory compliance, improved production throughout, less rework, and less waste [9], [10]. The quality inspection can be performed before, during, and after production. During production, other processes occur such as labeling or

capping. Detecting defects before a product is manufactured is an important step. It can help employees to implement corrective actions before delivering to the consumer. It can help reduce rework, improve consumer dissatisfaction, and prevent disruption in the manufacturing line and delay of products to customers [11]–[13].

Feedback from an inspection process can help the operators detect a potential error in one of the machines. Enhanced self-inspection is an inspection type that uses devices to automatically detect defects by giving the operator feedback, which helps to prevent defects and achieve 100% inspection [14]–[16]. This analysis can be made by having a range of failed items and analyzing which number it will consider abnormal. Having separate inspections from different processes can facilitate the process of looking at which process is causing defects and which machine will be responsible for causing these actions.

The project focused on the development of an integrated vision system to collect data. To develop this concept, bottles were used to detect defects in the label and in the bottle caps. The system was controlled using an HMI that had "start," "stop," "reset," and indicator lights and provided information about how many bottles passed and failed the inspection. The bottle stops in front of a camera so that it can send feedback to the PLC, and this can start collecting the information. The system also has a numeric control where the user can specify the percentage of efficiency that it requires and if the system did not meet the efficiency, it activates an alarm in the HMI notifying the user that improvements are required in the system during the process.

2. RESEARCH METHOD
2.1. Statement of the problem
To meet customer expectations, quality control is important in the industry. Human operators perform most inspections. This method is not one of the most accurate due that human operators may face fatigue while performing inspections all day long [8]. An inaccurate inspection can bring consequences in the industry such as delays, rework, and waste of time, money, and resources. The benefit of using automated vision inspections is that data can be collected from the processes which can be analyzed and used to improve a process or a machine's functioning.

2.2. Project objective
The main objective of this project is to develop a feedback automated system that can gather data from an integrated inspection process. Results will provide insight into how this can be applied in the production line and how it will improve the quality of the process.

2.3. Definitions
2.3.1. PLC
PLC is a programmable logic controller that uses programmable memory to store different instructions and to implement functions such as timing, logic, counting, sequencing, and arithmetic. These functions are implemented to control processes and different machines. PLCs are similar to computers. However, these are designed for industrial environments and control tasks. The components of a PLC consist of a power supply, a processor unit, input and output interfaces, a communications interface, and a programming device as shown in Figure 1.
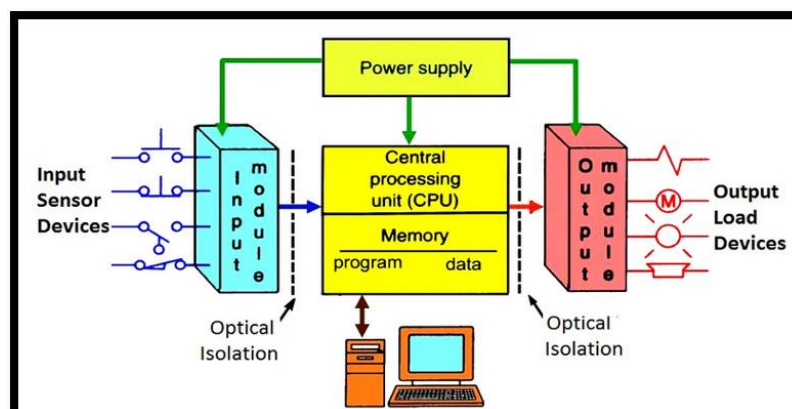

Figure 1. PLC architecture [10]

2.2.2. Sinking and sourcing

Devices that communicate with the PLC can be wired to the DC in two different ways, which are sinking and sourcing [10]. During sourcing, the input module becomes the current source, meaning that the device receives current from the input from positive to negative. During the sinking, the input module becomes the sink of the current, which means that the device supplies current to the input.

2.2.3. Sourcing sinking output

Sourcing occurs when the current flows from the output to the load. On the other hand, sinking occurs when the current flows from the load to the output as shown in Figure 2.
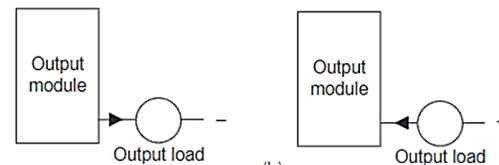

Figure 2. Sourcing output diagram

2.2.4. Teach pendant

Teach pendant is an interface between the operator and the application tool software. The teach pendant is connected to the controller's circuit board. Teach pendant is used to create programs, jog the robot, and check the status, operation, and test execution. The teach pendant has three main switches. The enable switch is used to enable or disable the teach pendant as shown in Figure 3. The emergency stop button is used to stop the robot immediately when it is pressed. The Deadman switch is used to enable the robot's motion if the switch is not gripped properly; it will not let the robot move [17]–[19].
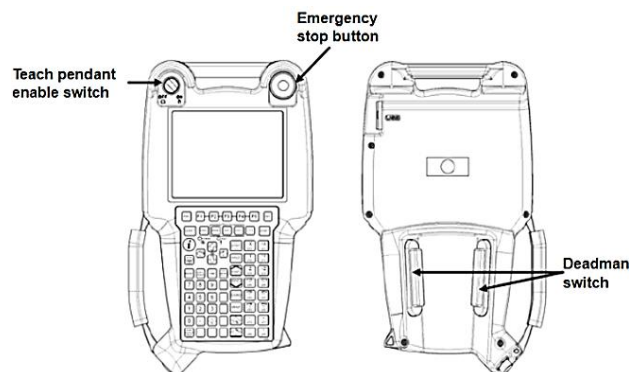

Figure 3. Fanuc robot teaches pendant

2.2.5. Operator panel

The operator panel can perform different functions such as starting a program and releasing an alarm state. The switches that the operator's panel has are an alarm release button that is responsible for releasing an alarm state, a start button that is used to start a currently selected program, an emergency stop that is used to stop the robot immediately, and the three-mode switch that is used to choose from three different operation modes that will be suitable for each different environment as shown in Figure 4.

2.4.   Delimitations

The project took place at the Commercialization and Manufacturing Excellence Center (CMEC). Robots and industrial equipment are available at this facility. The scope of the project was collecting data from inspection. The scenario created to show this concept consists of an inspection where the data results are shown on the HMI. This indicates the number of bottles that passed and failed the inspection. The system prevents the products from continuing with the defects and it helps to notify the operators so that actions can be taken immediately.
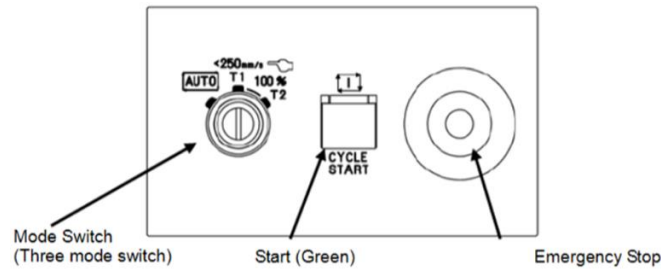
Figure 4. Robot operator panel [11]

2.5. Research methodology

Previous research was conducted to verify all devices were compatible. Since the project is a pass-and-fail inspection, an Insight 2,000 camera was selected because it can perform inspection and send information to the camera outputs. Looking at the conveyor belt parameters, PowerFlex 525 was selected as it met the motor requirements. Different available wiring diagrams were used to properly connect the devices. The Application of Industrial Robots for Advanced Manufacturing (TECH 58100) was a helpful reference in starting this project since many application capabilities were learned regarding the Fanuc operation and integration. It guided the integration design and capability. This class also introduced vision systems which were a helpful guide for the inspection system. The Graduate Professional Practice (TECH 69500) helped students to get a view of the industrial world and its needs in many industries. It also helped with the project planning and development process. The lean six sigma certification classes were a good base for quality, continuous improvement, and statistical analysis. Those classes guided the data collection analysis and how this can improve quality in the workplace. The Analysis of Research in Industry and Technology course (TECH 64600) helped with the proposal design and with analyzing results from previous projects. Literature reviews from previous projects also were a helpful guide for this project.

2.5.1. Fanuc robot

Fanuc Robot LR Mate 200iD was selected to be in this project since it's available in the lab. Fanuc robot has six controlled AC servo motors; the maximum payload for this particular robot is 4 kg, a mechanical weight of about 20 kg, a 0.01 mm repeatability error, and the maximum reach of the arm is 550 mm. Figure 5 shows the operating space for this robot [20], [21].
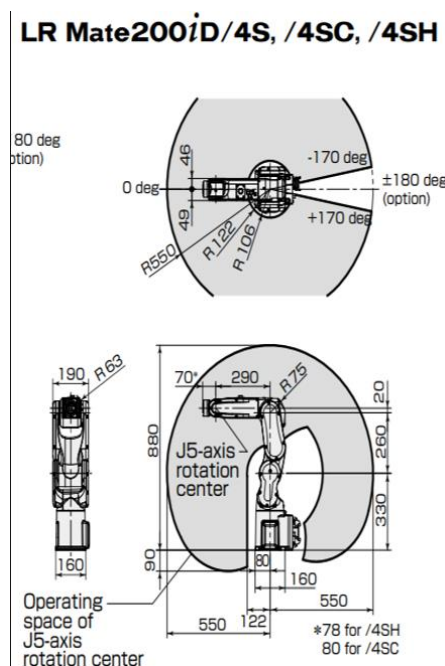

Figure 5. Fanuc robot specifications

.5.2. Insight 2000 camera

A Cognex industrial camera was used for this project. This camera has a speed of 75 frames per second and is powered with the same PLC power supply. The insight camera is shown in Figure 6.

Figure 6. Insight 2000 camera

2.5.3. Conveyor belt

The conveyor belt motor model is a VWDM3538. It has two specifications.
- Network Communication Design: The communication used for this project is Ethernet/IP. Devices are connected to a common switch. The table below shows the IP address used for each device. The subnet mask is 255.255.255.0 and the default gateway is 192.168.1.1.
- Integration of the PLC with the robot: Integrating the PLC with the robot allows better control of the operation because everything can be controlled by the PLC program. Integrating everything into a common program also helps to create synchronization so that when machines stop, the next one can start operating.

Fanuc robots can be connected to peripheral devices by installing a connector converter board. The converter is compatible with the peripheral device control interface as shown in Figure 7. Figure 8 shows how the robot's digital inputs and outputs are mapped to the PLC.
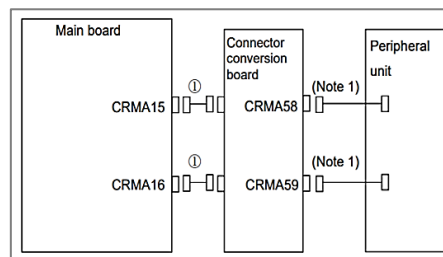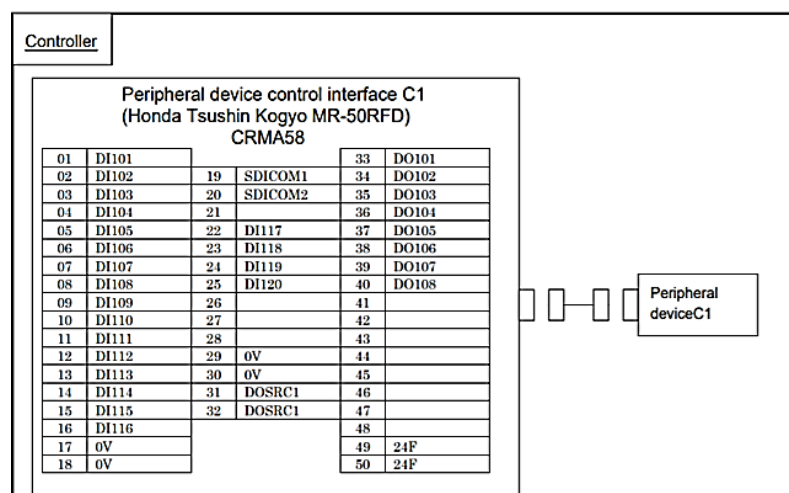

Figure 7. Fanuc Robot connector

Figure 8. Robot IO mapping

2.6. Run the Fanuc robot

The operator panel should be adjusted to move the robot remotely by switching the mode switch to AUTO. Table 1 explains the different modes and how the teach pendant, operator's panel, and peripheral devices operate when is local or remote.

Table 1. Robot operation mode

Mode	Teach pendant enable switch	Remote switch	Teach pendant
AUTO Mode	ON	Local	Not allowed
		Remote	Not allowed
	OFF	Local	Not allowed
		Remote	Not allowed
T1, T2 Mode	ON	Local	Allowed to start
		Remote	Allowed to start
	OFF	Local	Not allowed
		Remote	Not allowed

2.6.1. Integration of the HMI

HMI is used to display real-time information to the user about the inspection results. In this case, it has indicator lights showing when the system passes or fails as shown in Figure 9. It has pushbuttons that allow the starting and stopping of the system just by pressing them. It also shows the total number of items that passed and failed. The PanelView Plus 600 is connected to the power supply 24VDC. The Ethernet port communicates with the Ethernet switch so that the program can be transferred to the HMI.

Figure 9. HMI display

2.6.2. Configuring the powerful

The IP address needs to be configured first before starting to communicate with the system through Ethernet. The parameters for the IP address, subnet mask, and gateway were configured from the drive's keypad. It was made sure the parameters in P046 are set to 5 Ethernet/IP and P047 is set to 15 Ethernet/IP.

First, the C128 needs to be 1 so that the IP address can be configured with the driver's keypad. Researchers then set the IP address values using the parameters from C129 through C132. After that, the subnet mask was configured so the parameters can be set from C133 to C136. Finally, to set the gateway address, the parameters are set from C137 through C140. After changing the values, researchers reset the adapter by power cycling the drive so the values can take effect.

2.6.3. PLC programming

After all the inputs and outputs were wired and assigned to perform different functions, a program was created using the address for each device. The PLC program was designed for the user to enter the number of bottles that are going to be inspected and the percentage of efficiency that the operator expects the

inspection to meet. If failed bottles exceed the minimum acceptable range, then an alarm is activated as shown in Figure 10.

The percentage of minimum failed items is taken based on the number of bottles, which is N7:5, and the efficiency percentage specified by the user is N7:3. Taking this percentage, the total number of bottles allowed to fail is obtained and is represented by N7:7. The result obtained from the calculation is sent to N7:7. After the result is obtained, it is compared with the accumulated value of failed bottles for cap and label defects. If the value is greater than or equal to the calculated value, it will send an alarm to the operator which can help the operator to make improvements to the system or the machine.
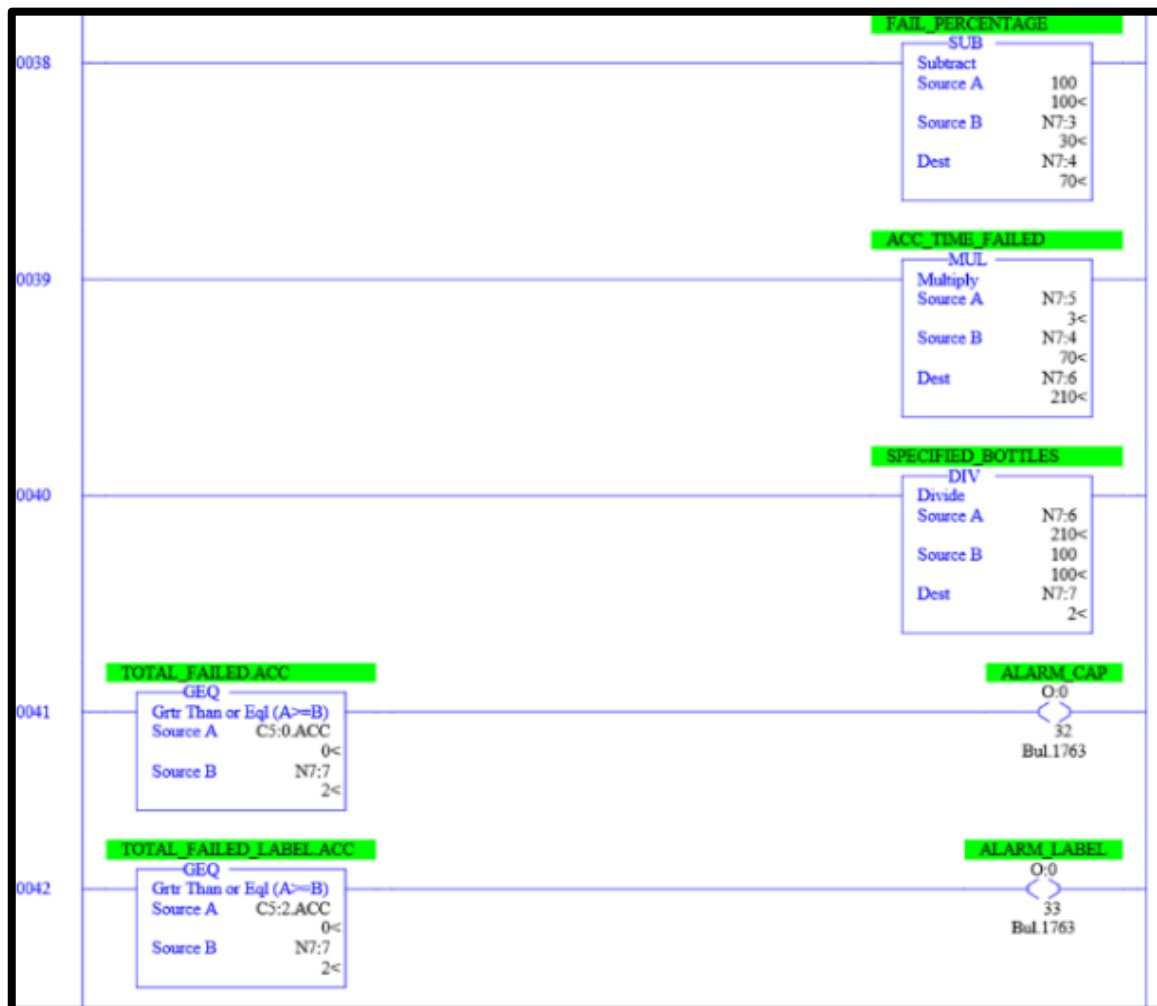

Figure 10. Sample of PLC program

2.6.4. Additional requirements specified by the user

This program is designed for use in cases of continuous defects. If the program detects the same kind of defects repeatedly, it will send an alarm so that respective actions can be taken. It might be a problem involving the machine.

The program has a timer that, if the accumulated value reaches the preset value, will send an alarm for repeated defects. The timer will reset when inspections that pass are produced. The timer preset value is the destination of a calculation created based on the inspection time and the number of defects that the company specified as the maximum that can fail in a row. The same logic is applied to both defects. In the test, three bottles with different label defects were used to verify the program operation. After specifying the minimum number of bottles allowed to fail, the user will get an alarm after three bottles have failed the inspection. The cap defects were also included in the testing. The defects used for the caps were two darker colors and no cap present on the product.

2.7. HMI designing and programming

Before programming the HMI, it is required to assign the path from which the tags are dragged into the functions for the HMI programming. That step is accomplished by going to the communications setup under FactoryTalk Configuration setup. Momentary push buttons were used to start, stop, and reset the conveyor belt as shown in Figure 11. The address assigned to the start pushbutton is B3:0/1, to stop the B3:0/0 and reset the B3:3/3. Two indicator lights were used to display when a bottle passed or failed. The addresses assigned to the lights are the ones coming from the camera; the I: 0/1 for a pass and the I:0/0 for a fail. On the right-side screen of the HMI, the information feedback for the bottle inspection is displayed. The total bottles that passed and failed the cap inspection as well as the total bottles that passed and failed the label inspection are listed.
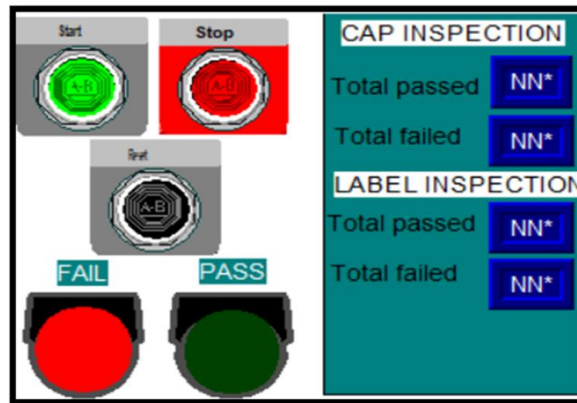

Figure 11. HMI display layout

After the program has been created, it is transferred to the HMI by creating a runtime application using the version that is compatible with the HMI. In this case, the version in the HMI is five so the runtime created was 5.0. The file created is used in the transfer utility to download to the HMI.

2.7.1. Requirements specified by the user

The HMI consists of numeric controls and numeric indicators for the number of bottles. The HMI has numeric fractions that the user can use to monitor repeated failures before the alarm is activated. The HMI has control indicators so that the efficiency percentage can be specified as well as the number of bottles that are going to be inspected as shown in Figure 12. A fraction was included to visualize the number of bottles failing compared with the total for both inspections. Two multistate indicators were included to indicate when an alarm is on.
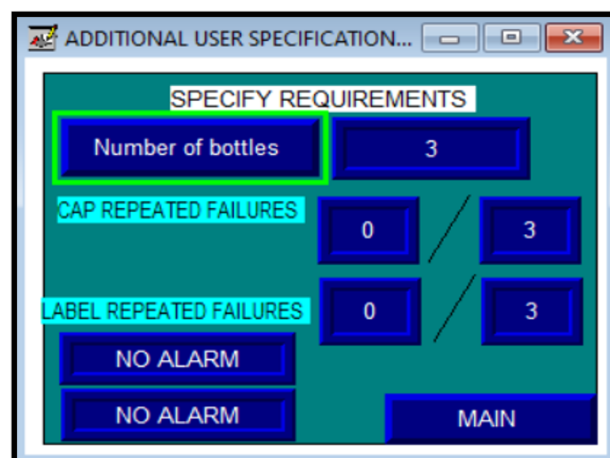

Figure 12. Updated HMI

2.7.2. Camera setup

The insight explorer is required to configure it to get data from the camera and send it to the PLC. The first application step is connected and consists of selecting the in-sight sensor that needs to be connected. On the same page, a saved program can be opened to continue with previous work. The second step is to set up the image. In this screen, the trigger type is selected. Since the camera is connected to the PLC through wiring I/O, the trigger is the camera. The delay chosen is one second so that the camera has time to get a good focus on the object as shown in Figure 13. The lighting parameters are adjusted according to the object and the lighting of the room.

The next application step is the setup tools to locate and inspect the part. Different tools can be used to get an inspection result. The pattern tool is used for this application. Pattern 1 specified is to record the cap requirements as shown in Figure 14. If the cap of the bottle does not have the same color as the specified color, it fails the inspection.
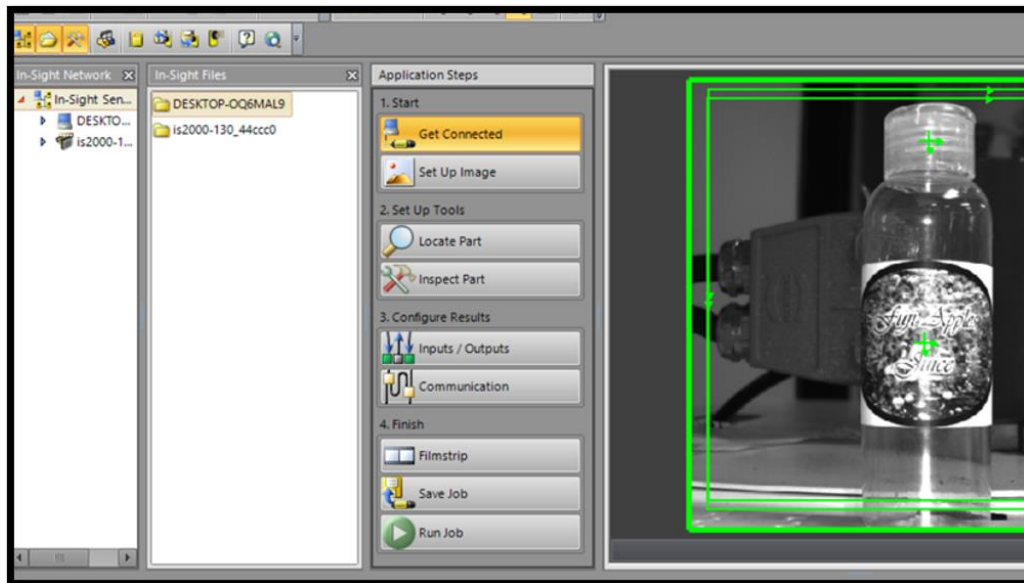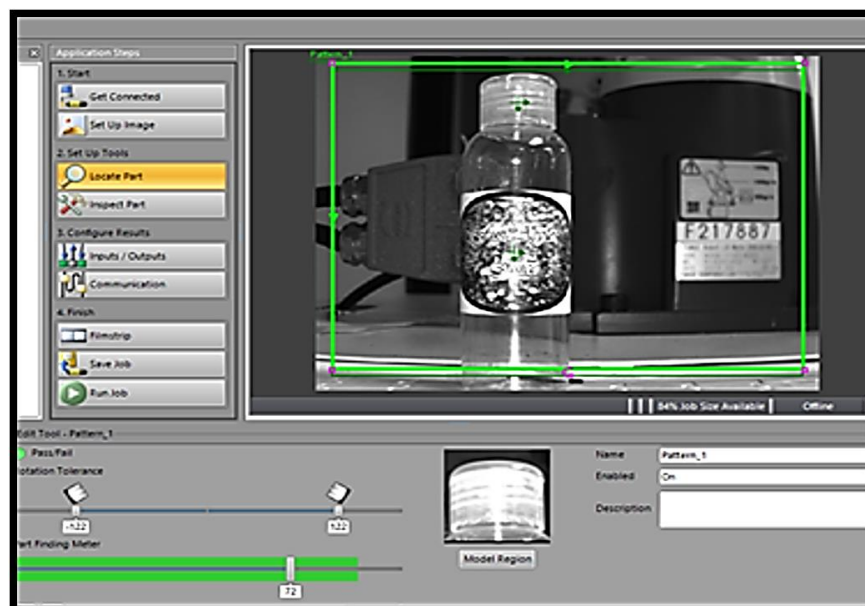

Figure 13. Camera set up

Figure 14. Locate part 1 in-sight explorer application step

2.7.3. Configure I/O

The next step is to configure results for the input and output. The two outputs that are connected from the PLC output to the camera inputs were HSOUT 0 for fail and HSOUT 1 for a pass. The results of the inspection can be seen in the right window. If the inspection fails, the HSOUT 0 will have a value of 1 and if the inspection passes, the HSOUT2 will have a value of 1 as shown in Figure 15.
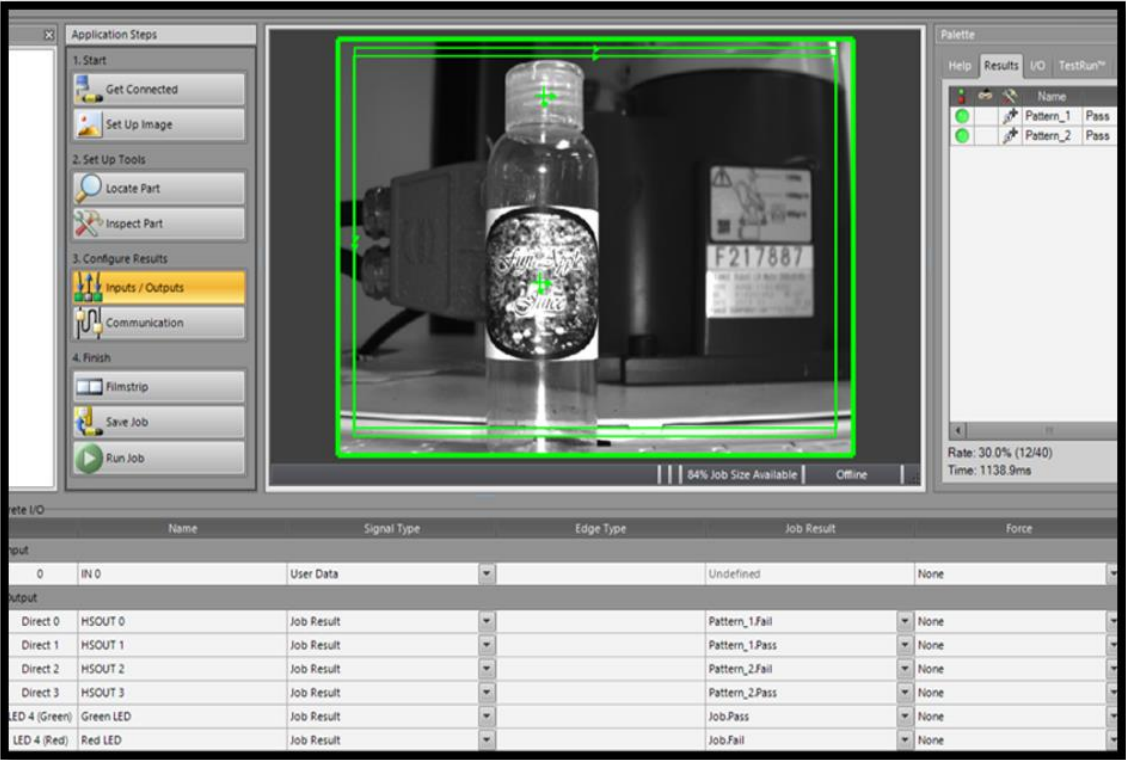

Figure 15. Inputs/outputs in-sight explorer

2.7.4. Testing application

Many scenarios were conducted to validate the accuracy of the system. These scenarios had many combinations and shuffling between good and bad labels and good and bad caps as shown in Figure 16. The good label and good cap are shown in Figure 17. Finally, the robot gets the information from the camera via PLC and sorts the bottles into two different bins. One bin is for good bottles and one is for bad bottles as shown in Figure 18.
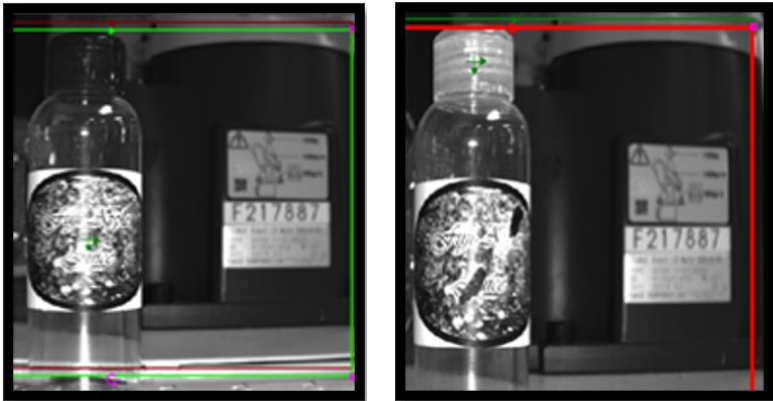

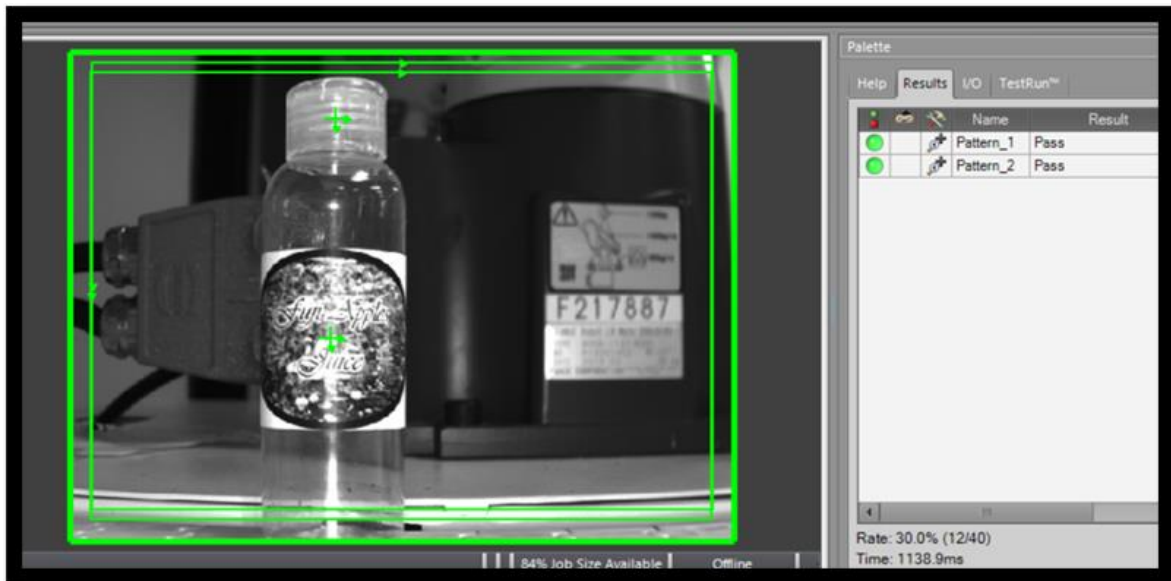Figure 16. Failed inspection due to missing a cap or a bad label

Figure 17. Passed inspection

Figure 18. Automated sorting station

2.7.5. Historian chart

The last design implemented for the inspection system consists of a chart that provides real-time results on the number of bottles that have passed or failed the inspection as shown in Figure 19. The range specified for this application is 10 but the user can change these values depending on the total number of bottles. The pens used for the charts were assigned a tag that counts the total accumulated value for each condition. This screen also has a button to display previous data results. Having this data can help to analyze the different conditions and it is easier for the user to identify when something seems out of normal operation.
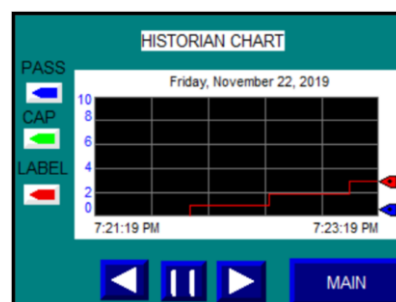

Figure 19. Historian chart for inspection feedback

3.   RESULTS AND DISCUSSION

Creating different programs in the robot to sort the defects helped to visualize the defect that was detected. In an industrial scenario, sorting the defects will reduce the time it will take to rework a certain item; for instance, implementing an automated cart at the end of the line will pick up the defects and distribute them for rework. The program had a delay when trying to run from the HMI; in an industrial setting, a SCADA interface can be used which provides a faster response. The camera needed some calibration and testing to make sure it recognized when something passes or fails. After changing some parameters, the camera was able to get accurate results. In an industrial scenario, the camera needs to be adjusted depending on the items to be inspected and the lighting of the room.

The program designed for the user to select data specifications was successfully tested and the alarms will turn on depending on said specifications. During the test, the efficiency rate was set to 30% and the number of bottles used was three, so the alarm turned on after two bottles had failed the cap inspection. Before the user can input data, it is required to know the process, the machine's normal operation, and the defect rate caused by the system. After these values have been obtained, the efficiency can be inserted in the screen and anything that is beyond the normal will send an alarm. This design will help industries to find a potential problem related to a specific inspection process.

Alarms were created to notify the user whenever some user specification is out of range. The alarm displays a message regarding the problem so that an operator can act and analyze the situation if something is wrong with the machine or the process. The alarm appears even if the user is looking at another screen. Once the alarm is acknowledged, it will automatically close the pop-up notification.

The last design made was the historian chart which was configured to display the total number of bottles that passed and failed due to an issue with the bottle's cap or label. The chart displays real-time data, and a user can use the left arrow to look at previous data information. The chart can be configured according to the number of bottles used in the application and the variables can be configured according to the user's needs. In the first test, the chart showed high values and the data results were at the bottom. After configuring the chart from 0 to 10, the chart got better visibility. The chart was successfully tested with different defects and values which were updated immediately in the chart.

4.   CONCLUSION

This process was controlled by a PLC. A ladder logic program was designed for this operation and to run the machines. Their I/O were connected to the PLC I/O allowing them to include this information in the program. Multiple programs were used to configure the functioning of devices for this application. The use of wiring diagrams was useful to connect all the components to the PLC. The paper contains the connection made to each port of the PLC describing which device is connected. It also contains the IP addresses used for each device and how it will be included in the PLC program. The HMI receives all information from the PLC process and displays all information needed for the operator to use for feedback and to continue improvement. The screen also has indicator lights to show when the inspection failed or passed. The project results can be implemented in an industrial environment by automating all vision systems and having a common network where all the data can be seen from different machines. Analyzing the data and creating specifications for the system can help visualize when something is not working properly, or it can help to identify a potential problem related to the machines or the process.

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