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PROGRAMMING A SIX AXIS MOTOMAN HP3C ROBOT FOR INDUSTRIAL SORTING APPLICATION

Mr. Hamza Kadir, Purdue University Calumet (College of Technology) Alumni

Hamza Kadir, M.Sc., currently works as a Controls Engineer in the Packaging Machinery OEM industry. He completed his Masters from Purdue University Calumet, majoring in Mechatronics Engineering Technology. He conducted his M.Sc. Directed Project at the Nick and Nancy Wilson Mechatronics Engineering Technology Laboratory. This project involves integration of modern automation tools for an intelligent part sorting system. He has previously worked with use of High Speed Vision System for troubleshooting at higher machine rates. His earlier works include application of a new SS7-Sigtran protocol interchanger for communication for RTU in SCADA systems; evolution of mobile backhaul to 3G and smart grid solutions. He has received his B.Sc. in Electrical and Electronic Engineering from Islamic University of Technology, Bangladesh. Email: hamza_eee@yahoo.com. LinkedIn: http://lnkd.in/bjhR_qS

Mr. md jubair hossain, Purdue University Calumet (College of Technology)

Md Jubair Hossain, M.Sc. He completed his Masters from Purdue University Calumet, majoring in Mechatronics Engineering Technology. From 2013 he started working for college of technology as a student worker. He was awarded Claude S. Breeden Scholarship in 2013 for excellence and creativity in approaching solution to problems in the packaging industry from Packaging Machinery Manufacturers Institute (PMMI). He had previously worked with SCARA robot that involved enhanced algorithm to maximize throughput for assemble and produce medical devices. He has received his B.Sc. in Electrical and Electronic Engineering from Chittagong University of Engineering and Technology, Bangladesh. His interests are in the area of Robot programming, Cad modeling, industrial process control, modeling and simulation of Mechatronics devices and systems, programmable logic controllers related projects. Email: jubair123123@gmail.com LinkedIn: www.linkedin.com/in/hossain123/

Nirjhar Das Sharma, Purdue University Calumet

My name is Nirjhar Das Sharma. I was born on November 20, 1990 in Chittagong, Bangladesh. I pursued my passion for engineering from my early childhood while I was going through High school education. I completed a four year B.Sc. course in Electrical and Electronic Engineering (2008-2013) from Chittagong University of Engineering & Technology, Bangladesh. The last two years of the Bachelor study introduced me to some real-life learning along with a lot of important experiences. I personally believe that the Industrial training at TICI (Training Institute for Chemical Industries), Narshingdi was the most valuable tour where I experienced about the Industrial Production Technology, sensing and control systems, manufacturing, packaging and Programmable logic controllers(PLC). This training made my decision easier to become a Graduate student of Mechatronics Engineering Technology at Purdue University Calumet, USA (from August, 2013 till present). Now I am learning Electrical controls, PLC (allen bradley), HMI programming and Robot (Motoman) programming as the integral part of my research. Besides, I have been working as an Instructor for an undergraduate level course 'Electricity and Electronics fundamentals' from January, 2014 at Purdue University Calumet. Throughout the journey that I made so far as a Graduate student, I have also experienced to work as a Teaching Assistant, designing PLC trainers and working with several mechatronics projects. At present, I am also working as an Engineering Intern at A Packaging System, La porte, IN (from May, 2014) experiencing different technologies like liquid filling machine, Bottle capping machine in a primary packaging environment. I strongly believe that my experience and education would create excellent opportunities for me and would flourish my knowledge in the future.

Suraiya Jannat Khan, Purdue University Calumet

Suraiya Jannat Khan is a graduate student in the Department of Engineering Technology at Purdue University Calumet. Her focus is on Mechatronics Engineering Technology. At present she is also a student worker for the Department of Engineering Technology. She is currently working with MOTOMAN HP3C robot at the Nick and Nancy Wilson Mechatronics Engineering Technology Laboratory. Her previous works include designing a low noise amplifier, designing voltage surge protector and voltage instability protector and designing a temperature and humidity meter with microprocessor 8086. She has received the Bachelor of Science in Electrical and Electronic Engineering from Ahsanullah University of Science and Technology, Bangladesh. Email: suraiyajkhan108@gmail.com

Prof. Akram Hossain, Purdue University Calumet (College of Technology)

Akram Hossain, Purdue University Calumet Akram Hossain is a professor in the department of Engineering Technology and Director of the Center for Packaging Machinery Industry at Purdue University Calumet, Hammond, IN. He worked eight years in industry at various capacities. He is working with Purdue University Calumet for the past 27 years. He consults for industry on process control, packaging machinery system design, control and related disciplines. He is a senior member of IEEE and he served in IEEE/Industry Application Society for 15 years at various capacities. He served as chair of Manufacturing Systems Development Applications Department (MSDAD) of IEEE/IAS. Currently, he is serving a two-year term as the chair of the Instrumentation of ASEE (American Society of Engineering Education). He authored over 29 refereed journal and conference publications. In 2009 he as PI received NSF-CCLI grant entitled A Mechatronics Curriculum and Packaging Automation Laboratory Facility. In 2010 he as Co-PI received NSF-ATE grant entitled Meeting Workforce Needs for Mechatronics Technicians. From 2003 through 2006, he was involved with Argonne National Laboratory, Argonne, IL in developing direct computer control for hydrogen powered automotives. He is also involved in several direct computer control and wireless process control related research projects. His current interests are in the area of packaging machinery system design & control, industrial transducers, industrial process control systems, modeling and simulation of Mechatronics devices and systems in virtual environment, programmable logic controllers, programmable logic devices, renewable energy related projects, wireless controls, statistical process control, computer aided design and fabrication of printed circuit board.

PROGRAMMING A SIX AXIS MOTOMAN HP3C ROBOT FOR INDUSTRIAL SORTING APPLICATION

Abstract:

Industrial systems efficiency often can be improved by replacing human subjects with robotics technology. With the virtue of automation couple with robotics, this picture is gradually being visible. Accurate inspection of a product in its all stages of production has become a very crucial part of the packaging industry. Nearly 100% accurate inspection and detection can be achieved by using high speed camera vision systems coupled with robotic arms. However the investment-to-yield ratio must make sense. In this research the proposed setup of camera vision system along with robotic arm will inspect multiple patterns of defects with slight modification in the inspection system. The impetus of this research originated from a common problem encountered in the manufacturing and packaging industry. Generally, an inspecting conveyor system requires a human operator to visually inspect the part or in case of an automatic detection, the process is limited in its inspecting ability. In case of human operator inspecting process, the operator requires to be trained in the particular inspection criteria as well as the use of precision hand-tools to determine the defect. This involves training cost, overhead expenditure (higher pay-scale due to training and experience), and other labor fees for a monotonous, repetitive and no-brainer job. In case of existing automatic systems, the detection method is limited and not adoptable to various types of parts and their defects. For packaging industry and its products, quality control is one of the most important steps of manufacturing process. The objective of this research project is to build an automated inspection setup consisting of a high speed camera vision system, an industrial robot, a servomotor controlled conveyor system, and a pneumatic gripper. The control setup will inspect and sort parts based on its acceptability using a high speed machine vision system. In this research project, the inspection system consists of a Motoman (produced by Yaskawa) 6-axis articulated industrial robot, a Cognex[5] high speed camera vision system and a servomotor driven conveyor are replacing an existing error-prone inspection stage that will improve the degree of accuracy by three fold. The proposed inspection system is

intelligent enough to recycle parts that are marginally acceptable and worthwhile to be modified as good parts.

Introduction:

In packaging industrial, sorting, inspections and separations are one of the most extensively researched subject matters. Deflect detection and product separations are considered to be the top priorities in any manufacturing environment. For speeding up sorting operation robots are used extensively in industry. Many industrial sorting applications robotic technology adds special benefits to the process. When it comes to improved level of inspection accuracy and speed of sorting, high speed articulated robot and machine vision system comes to focus. In this inspection system, Allen-Bradley® MicroLogix™ Programmable Logic Controller (PLC) is designed as main controller that controls the MOTOMAN robot, Cognex[5] camera vision system, the servomotor, and ancillary units. The MOTOMAN robot is programmed using a different user frames such that the inspection criteria can be easily changed and implemented. Figure 1 represent a MOTOMAN HP3C robot mounted with Cognex[5] camera and pneumatic gripper.

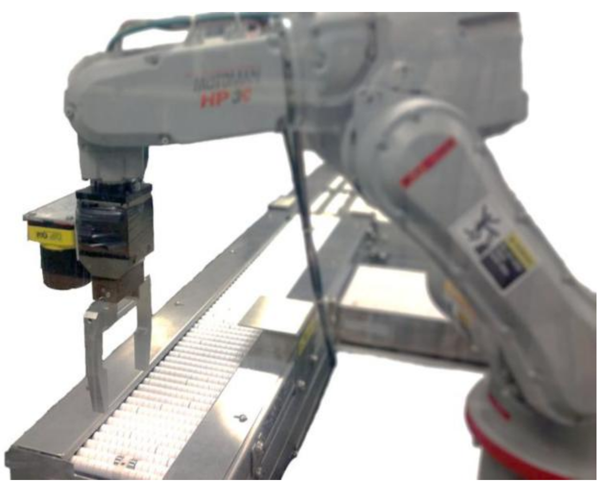

Figure 1: MOTOMAN HP3C robot mounted with Cognex[5] camera and pneumatic gripper

Each of these user frames should assign the position variables which mean the X, Y, Z co-ordination of a fixed location of the system. A Cognex[5] camera has been trained to recognize a defect of a part and send the right digital pulse to the robot for separating the defective part from the main product line to reject conveyor. Here the communication protocol among PLC, Cognex[5] camera and robot are important because together they determine the defect and separate the unacceptable parts. This research will encompass study involving component sizing required for the retrofit of the existing error-prone inspection system. Both electrical and mechanical aspects will be covered in this paper, with emphasis on the robot programming, vision system training, PLC programming and other electrical aspect. Sizing components and overall system setup will be dictated by a proper understanding of the process and its requirements. The electrical scope of the project will cover frame by frame MOTOMAN industrial robot programming, Allen-Bradley® MicroLogix PLC ladder logic programming, training Cognex[5] camera vison system for pattern recognition, and organizing sensors and electrical system to work in synchronism for accurate inspection and separation of defective parts. This research will emphasize on the ease of adoptability and automated calibration of the inspection system as the defect location, defect type, part type vary. The mechanical scope of the project will cover End of the arm tool design, Robot cell design, robot base design, and modification of the secondary conveyor stands. This arrangement will represent an intelligent inspection and sorting setup used in the industrial application. This inspection system can modified rapidly to fit any unique characteristics that is required to be inspected for the product at hand. These inspection characteristics determine the ultimate quality of the manufactured products. The products which do not meet the required quality will be diverted to a reject lane for further inspection and recycling. The robot and PLC programming structure must be modular to provide scopes for future extensions and improvements.

Problem Description:

This inspection system is designed to inspect a small foreign object anywhere on a 4 inch by 3 inch part as per the trained Cognex[5] camera vision system. Before the inspection, the part is picked up by the robot from a specific location on the conveyor system and is placed on a backlighted table in order to achieve the higher accuracy of the inspection process. If the part passes the inspection process it continues on the conveyor. However, if the inspection fails as per the trained criteria the part is separated to the reject conveyor for further processing. The Cognex[5] camera is mounted on the robot arm and back lighted table is used to achieve the speed and accuracy of the inspection process. The camera is faced straight towards the top face of the product, a top view of inspecting part. Any change in the inspection criteria, change in the part type or change in part size can be adopted promptly in to inspection process for modular programming techniques. The camera is programmed based on the inspection criteria of the product. The inspection criteria can vary widely. Any mismatch with the pre-saved inspection pattern, the camera will detect it that is difficult to detect at high speed by naked eye. Based on the unique criteria of the product, parameter values of certain unique criteria will be extracted at the point of view of the inspection tool. Then the camera will compare with pre-saved formats and identify the product based on the comparison.

Criteria for Accepted Product

For the target setup we assume the criteria for an accepted product is “empty / blank holes”. Figure 2 shows a sample accepted product. This is analogous to a clean end product.

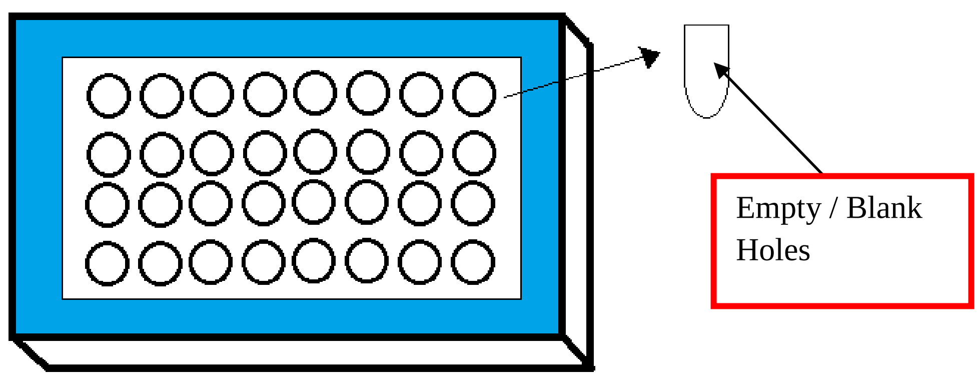

Figure 2: Criteria for accepted product

If the camera does not see any objects in the holes, the products will be detected as accepted. Only the red-marked region as shown in Figure 3 on the products will be inspected for the inspection.

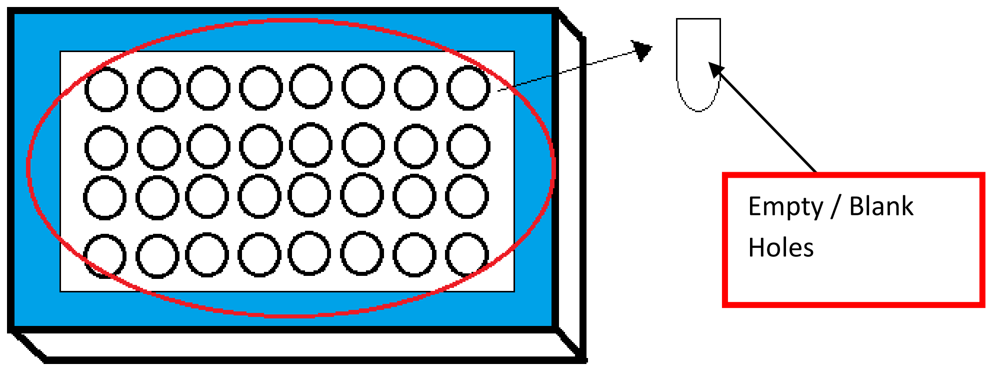

Figure 3: Region to inspect

Criteria for Rejected Product

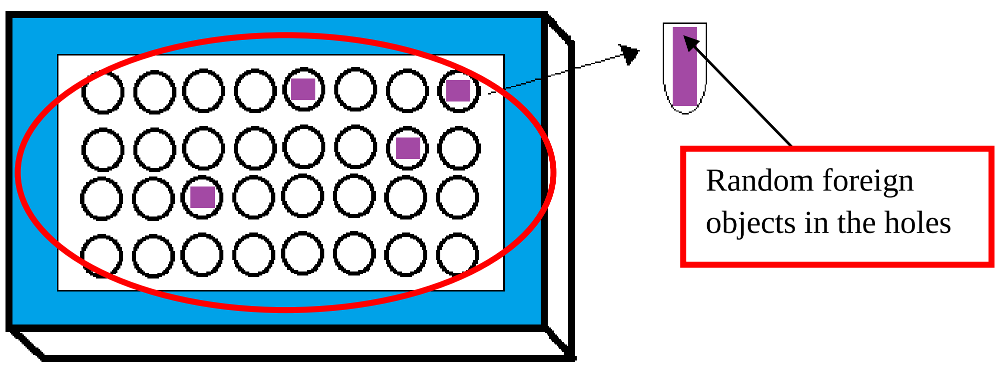

Figure 4: Sample rejected product

For our test setup we assume that the criteria for a rejected product are random foreign objects in holes of the containers. This object can be any random non-transparent visible object in the point of view of the camera. Any presence of any visible unknown object for example, pieces of nuts, screws will trigger a rejected result for the camera.

Process Description

Under existing setup, a conveyor line is use to bring the product to the camera inspection area. Then the robot will pick it up and place it to the inspection table for inspection. The back light in the inspection table turn on for the camera to inspect properly. If the product is accepted then it will bring back to the main conveyor. In case of rejected product, the robot will take it and place in the secondary conveyor and then diverted to a certain direction. The process flow of the retrofitted setup is shown in Figure 5.

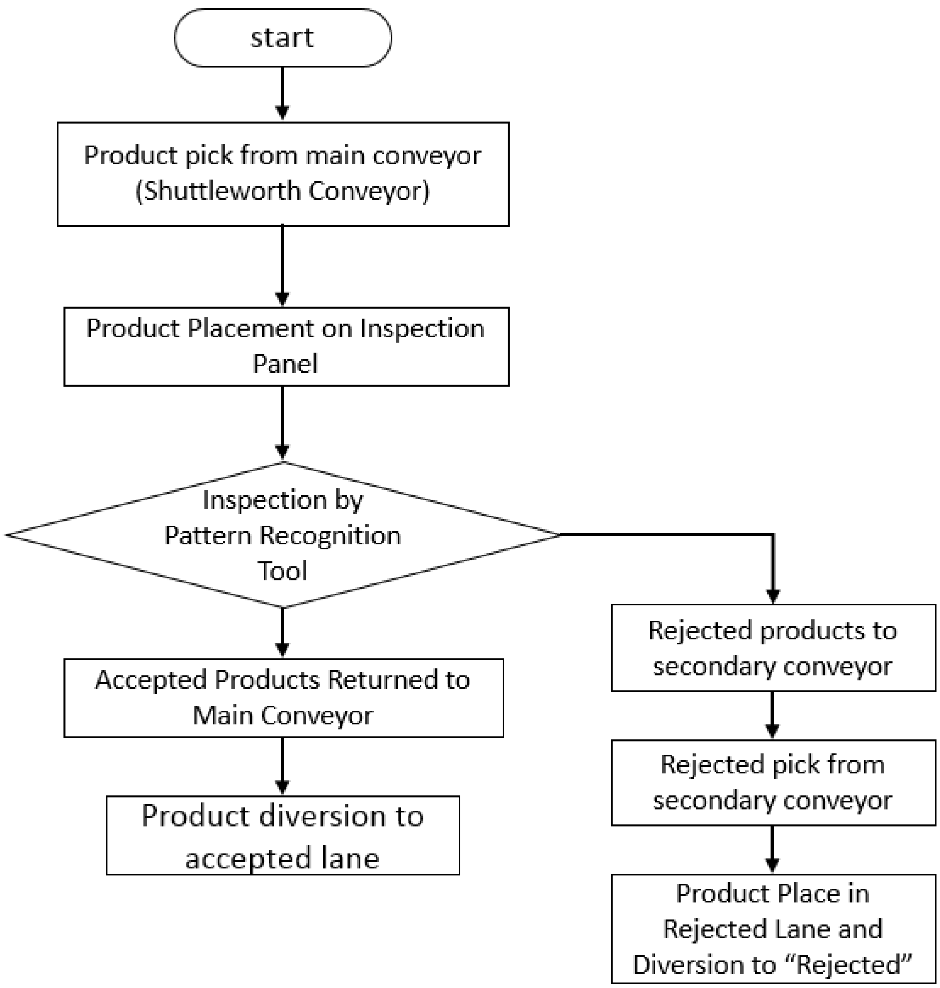

Figure 5: Process flow of the retrofitted setup

In the proposed inspection system, PLC acts as the master control center. It controls and communicates with the HMI, Camera, the Conveyor and the pneumatic gripper. PLC controls the overall process by calling certain functions of the slave components (e.g. robot, camera, actuator) when required by the process. The slave components complete their function and inform the PLC of its completion. After this process, PLC cross-checks the feedback by utilizing photo-eyes, deployed at different portions of the setup. For synchronization of the process flow, different components from different manufacturers and different vendors are communicating over 24VDC discrete data.

System Set Up

Figure 6: shows the suggested retrofit setup.

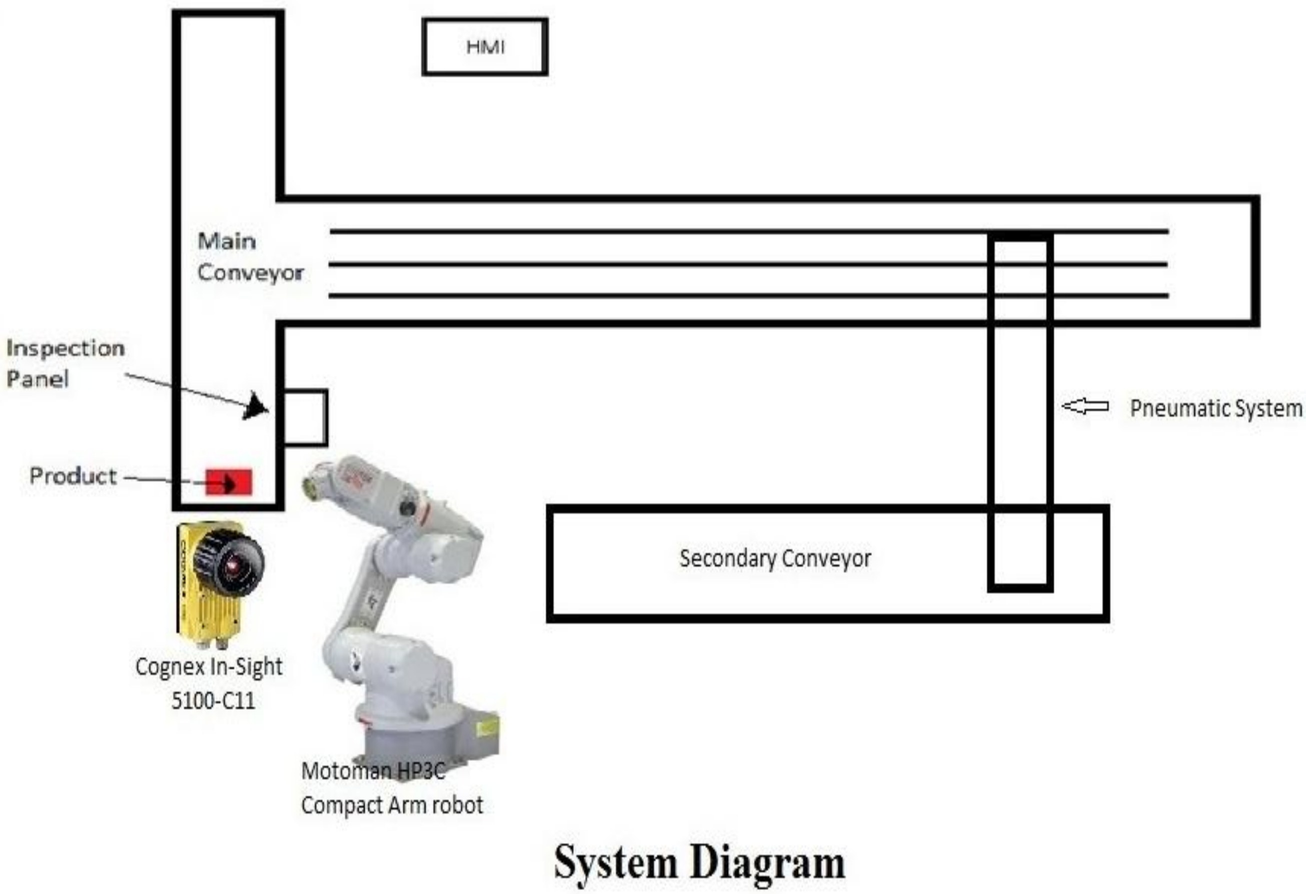

Figure 6: suggested retrofit machine setup.

System Hardware

Conveyor: A mechanical apparatus consisting of a continuous moving belt that transports materials or packages from one place to another. In this setup Shuttleworth conveyor system is used.

HMI: Schneider Magellis Compact iPCHMI . Human Machine Interface is the part of the machine that handles the Human-machine interaction.

Industrial Robot: Motoman HP3C (produced by Yaskawa) a six axes programmable industrial robot is used.

Robot Cell Guarding: A fixed barrier across the robot is used to separate the robot working area for safety purpose.

Machine Vision System: A Cognex[5] In-Sight 5100-C11 Camera vision system is a combination of lighting, lenses, digital signal processing for detecting patterns and providing feedback to the control system.

PLC: MicroLogix™ 1100 is the product of the Allen-Bradley® Company, Rockwell Automation installed here for controlling the system. Another brand of "PLC" we used for the secondary conveyor is ElauPacDrive C-400 .

Pneumatic Gripper: A pneumatic gripper (MHL2-20D1 from SMC) helps to grip the rejected product on the Secondary conveyor placed by Motoman HP3C Robot.

Pneumatic Guide Cylinder: A Pneumatic guide cylinder (MGPM25R-50 from SMC) is being implemented to lift up the rejected product after gripping to a certain height at the secondary conveyor and to bring down from that specific height when the product reaches at the rejected lane of the shuttleworth conveyor.

Pneumatic Actuator: The pneumatic actuator (Numatics Rodless Cylinder, S1011250036AOO) serves the sorting application by transporting the rejected product along with the gripper and guide cylinder from the secondary conveyor to the rejected lane of the Shuttleworth conveyor.

System Software

Each of the hardware has individual software. Following are the main routines of the coding. More details on coding can be found reference [1].

Deployed Robot Program for Motoman:

Master Job: STL-CG_N

LINE 0000: NOP

LINE 0001: ‘HOME POSITION AT ROBOT FRAME

LINE 0002: MOVJ P000 VJ=30.00 PL=0 //HOMING

LINE 0003: CALL JOB:GRPOP

LINE 0004: ‘POUNCE POSITION AT PE113

LINE 0005: SFTON P002 UF#(1) “P002 IS +80 ON +Z AXIS

LINE 0006: MOVJ P001 VJ=30.00 PL=0 //POUNCE AT PE113

LINE 0007: SFTOF

LINE 0008: *MAINLOOP

LINE 0009: ‘INITIALIZATION:

LINE 0010: SET S001 “P_F_DECISION_PENDING”

LINE 0011: ‘I:2/9: PART PUT ON LIGHT PANEL

LINE 0012: DOUT OT#(4) OFF

LINE 0013: ‘I:2/8 PART RETURNED TO PE113

LINE 0014: DOUT OT#(5) OFF

LINE 0015: ‘PART NOT RETURNED TO CONVEYOR

LINE 0016: DOUT OT#(6) OFF

LINE 0017: ‘PE113_PART READY FOR PICK

LINE 0018: WAIT IN#(4)=ON

LINE 0019: ‘DELAY FOR PRODUCT TO SETTLE DOWN

LINE 0020: TIMER T=0.10

LINE 0021: ‘PICK POSITION AT PE113

LINE 0022: MOVL P001 V=100.00 PL=0 //PICK AT PE113

LINE 0023: CALL JOB:GRPCL

LINE 0024: ‘POUNCE POSITION AT PE113

LINE 0025: SFTON P002 UF#(1) “P002 IS +80 ON +Z AXIS

LINE 0026: MOVL P001 V=300.00 PL=0 //LEAVING FROM PE113

LINE 0027: SFTOF

LINE 0028: ‘POUNCE POSITION AT LIGHT PANEL

LINE 0029: SFTON P007 UF#(2) “P007 IS +80 ON +Z AXIS

LINE 0030: MOVJ P006 VJ=30.00 PL=0 //ARRIVE AT LIGHT PANEL

LINE 0031: SFTOF

LINE 0032: ‘PICK POSITION AT LIGHT PANEL

LINE 0033: MOVL P006 V=100.0 PL=0 //DROP AT LIGHT PANEL

LINE 0034: CALL JOB:GRPOP

LINE 0035: ‘CGX VIEW POSTN AT LIGHT PANEL

LINE 0036: MOVL P008 V=500 PL=0 //CGX VIEW AT LIGHT PANEL

LINE 0037: ‘I:2/9: PART PUT ON LIGHT PANEL

LINE 0038: DOUT OT#(4) ON

[NOW THE PART FALLS UNDER CGX-VIEW POSITION AND THE COGNEX 5100-C11 CAMERA TAKES A PASS/FAIL DECISION AND SENDS IT TO PLC. PLC SENDS THE DECISIONS TO ROBOT FOR CALLING APPROPRIATE SUBROUTINE. ROBOT WAITS FOR PLC SIGNAL FOR THE SUBROUTINE, AFTER 1.5 SECONDS OF REACHING “CGX VIEW AT LIGHT PANEL”.]

LINE 0039: ‘ACCEPT/ REJECT DECISN FRM CGX-PLC

LINE 0040: TIMER T=1.50

LINE 0041: ‘O:4/13. SORT CONVEYOR

LINE 0042: CALL JOB:SORT_CNV IF IN#(5)=ON

LINE 0043: JUMP *MAINLOOP IF S001=”FAIL”

LINE 0044: ‘O:4:14. RETURN TO PE113.

LINE 0045: CALL JOB:RET_113 IF IN#(6)=ON

LINE 0046: JUMP *MAINLOOP IF S001="PASS"

LINE 0047: END

Deployed Camera Configuration Program for Cognex[5] (In-Sight Explorer 4.7.3)

Figure 7 show how Cognex[5] camera is taught for fault detection by In-Sight Explorer 4.7.3.

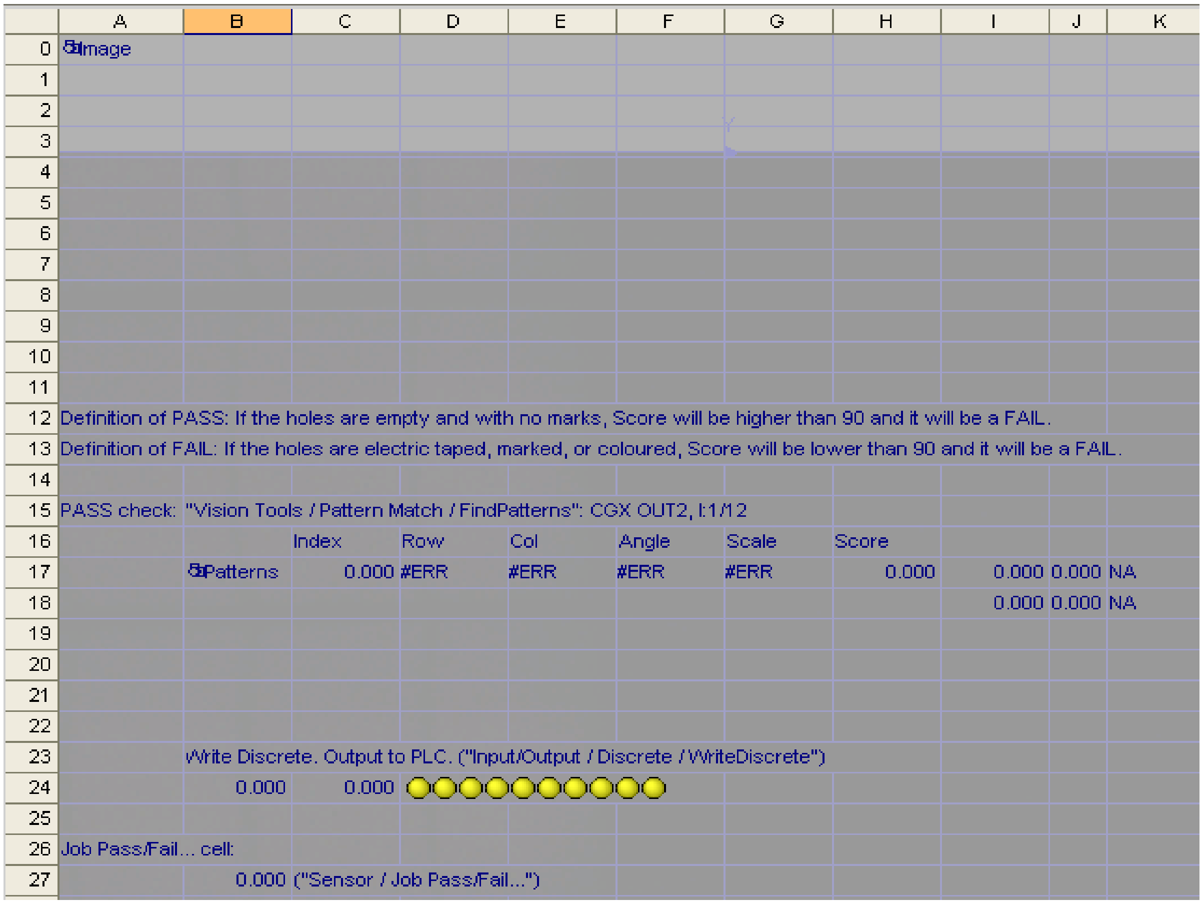

Figure 7: Cognex[5] camera teaching for fault detection

ElauPacDrive C-400 servo program for Secondary Conveyor

Figure 8 shows how the secondary conveyor is programmed by using Automation toolkit EPAS-4

```
PROGRAM EndlessFeedExample
VAR
     iFB_EndlessFeed: EndlessFeed3;
     iFB_EndlessFeed2:     EndlessFeed3;
     xStart:               BOOL;
     xStart2:              BOOL;
     ControllerEnableSignal: BOOL;
     MotionStartSignal: BOOL;
     xActive1:             BOOL;
     xMotionActive1:       BOOL;
     diResult1:            DINT;
     sResultText1:         STRING[40];
     lrPosition1:        LREAL;

     xActive2:             BOOL;
     xMotionActive2:       BOOL;
     diResult2:            DINT;
     sResultText2:         STRING[40];
     lrPosition2:        LREAL;








     Reverse: BOOL;
     Velocity: BOOL;
     Vel: DINT;
     Ready_to_Run: BOOL;
     toggle: BOOL;
END_VAR
```

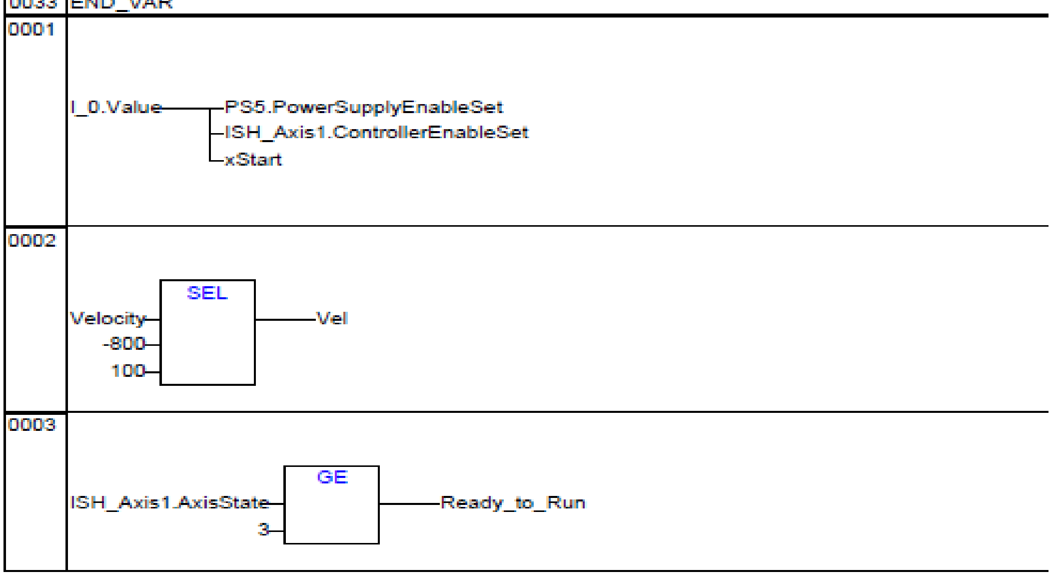

Figure 8: ElauPacDrive C-400 servo program for Secondary Conveyor

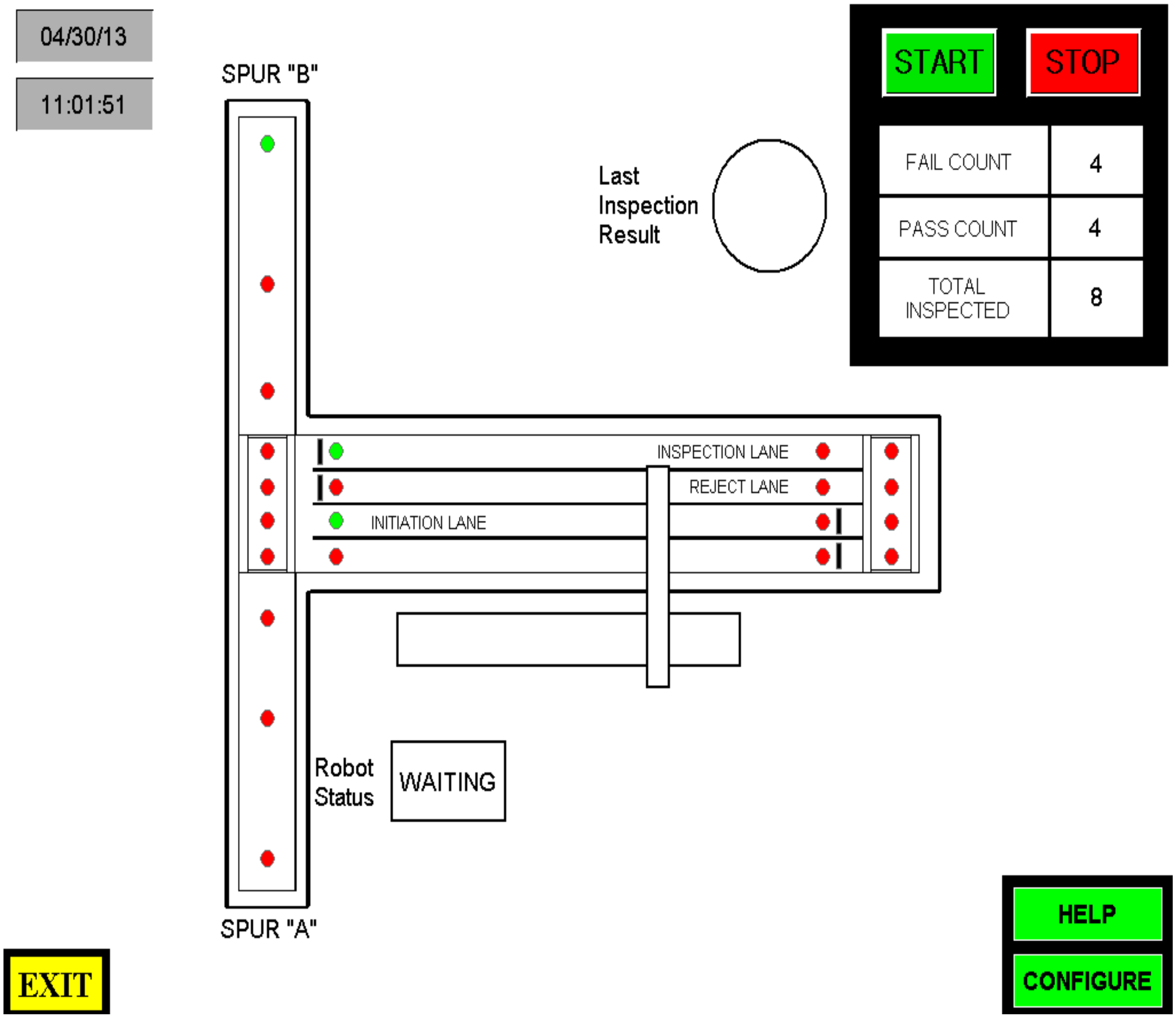

Figure 9: Human Machine Interface (HMI) program screen on Schneider ViJeo Designer software

Inspection Results

In this inspection system, the Cognex[5] camera vision system has been trained for continuous triggering for inspecting and sorting. The advantage of continuous triggering is more realized when the system throughput requirement is very fast. Although the maximum rate of capture depends on the job, the camera is capable of acquisition of 60 full frames per second. If the camera does not need to be triggered for inspection, that also saves one discrete output pin of the PLC rack, which can be used for other purposes when required. Figure 10 shows the pattern it looks for, for an Accepted product.

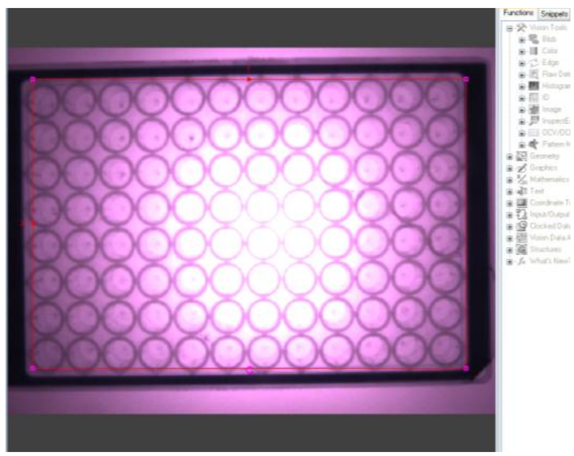

Figure 10: Find Region using Find Patterns command

It shows a sample inspection result at camera point of view. Due to back lighting, the border color of the product becomes irrelevant for the inspection. Figure 11 is a blue bordered product without any objects in its container holes. An accepted result was triggered as a result of this inspection.

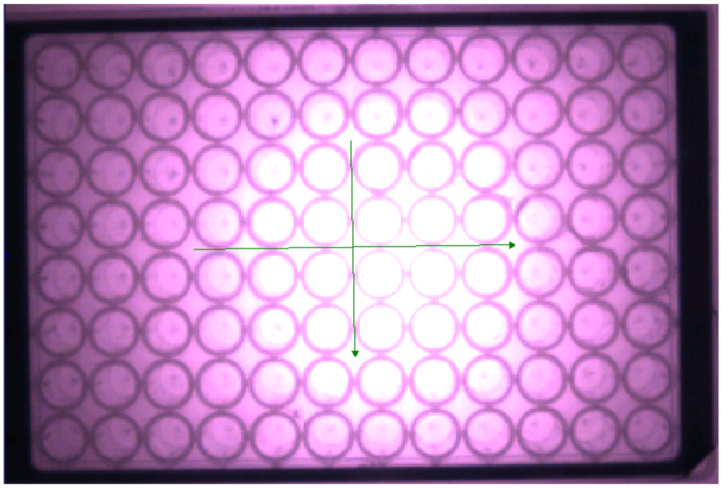

Figure 11: Snapshot of good product from camera view

Figure 12 shows samples of a few rejected products.

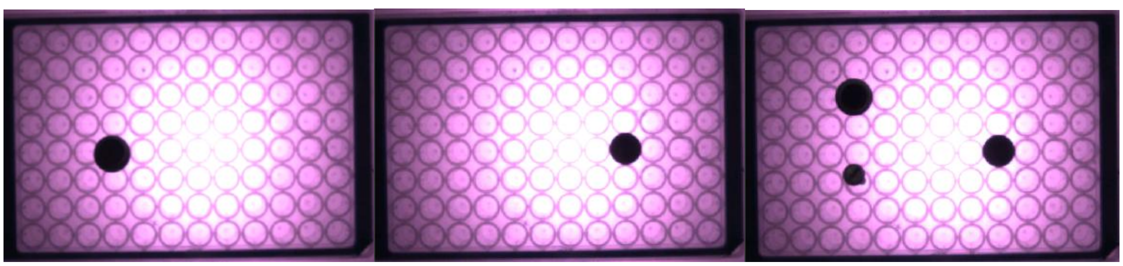

Figure 12: Snapshots of bad products from camera view

To ensure that the trained inspection of Cognex[5] machine vision system is working accurately, an experiment is performed for testing. In the experiment, 100 products are passed through the inspection stage. To make sure that the success rate is 100%, the good and the defected products are visually cross-checked by the operator. For discrepancy occurs in the results, the camera program was perfected by tweaking the snapshot pattern. The diverter section, consisting of the Motoman HP3C Compact Robot, Cognex[5] In-Sight 5100-C11 inspection tool, the secondary conveyor and the pneumatics rodless actuator, takes 20 seconds to complete an accept or reject cycle on average. Overall diversion speed of the intelligent sorting system is 3 products per minute.

Discussion and Analysis

As this is a demonstration project for the Nick and Nancy Mechatronics Laboratory, the inspection stage was a simulation of a real industry application. The target is to judge the end product based on its quality. If the quality of the end product does not meet the required pre-defined standard, it had to be identified as a bad or rejected product. The products meeting the quality requirement had to be identified as a good or accepted product. After identification, the bad products had been separated from the good products. For the demonstration, a mixture of good and bad products was placed in the in-feed lane. All the products in the in-feed lane were sent to the inspection zone of the setup. To simulate accept or reject, it was assumed that if the inspection tool find and detect foreign objects in the container holes of a product, the product will be inspected as a rejected product. A product with blank container holes was assumed to be a clean product. The dirt can be simulated by placing any non-transparent object. Small piece(s) of nut(s) or screw(s) are good candidates to simulate dirt. The rejected products will be placed in a separate lane and will be diverted to the rejected accumulation section of the main conveyor. The good products will be placed in the accepted lane. The accepted lane of the conveyor will be programmed to loop the process and keep sending the accepted products to the inspection zone. This is advantageous for the demonstration application. The operator can, at any point of time, pick a bad product from the rejected accumulation zone and mix it with the accepted products in the accepted lane. Thus the bad product will go through the inspection stage again, allowing the demonstration of separating them to be performed again. The outcome of this project is a demo setup to demonstrate an accurate inspection and sorting mechanism appropriate for a packaging line. However this is a laboratory setup in contrast to the real environment.

Conclusion

The primary intention of this project was to eliminate the requirement of human labor for the function of quality inspection, pick-and-place. This project was conducted as a laboratory setup at Nick and Nancy Mechatronics Laboratory, Purdue University Calumet. Components that available in the laboratory inventory were scavenged for the project. The pick and place stage could have been designed using a more sized SCARA robot instead of an articulated arm robot. But the project has been conducted using the articulated arm robot as that was available for testing. A Keyence GL-R Series Robot Cell Safety Light Curtain will be a possible future improvement for this solution.

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