Teaching Industry Relevant and Application Oriented Skills in Automation and Control by Developing State-of-the-Art Integrated Robotic Workcell

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Abstract

There is an increasing demand for automation in the industry due to expensive manual labor and faster manufacturing processes. Therefore, there is a need to educate future engineers in relevant to current industry needs automated systems which generally consist of Programmable Logic Controllers (PLCs), industrial robots, conveyors, pneumatic, various sensors and vision systems. Objective of this project is to develop an integrated work cell using 6-axis FANUC robots, PLCs, Conveyor, Sensors, pneumatics and vision systems for academic curriculum bridging the gap between industry and educational institution by teaching rapidly emerging technologies. The developed system provide the students with an opportunity to develop real time scenarios in material handling applications similar pick and place parts moving on a conveyor using sensors and vision systems, end-effector tools, hand shaking of two 6-axis robots and controlled by PLC. Training engineering professionals and testing them on different applications using a single work cell will help them to develop a holistic approach towards solving real time solutions in the automation industry. Presented in this paper work provides a detailed, state-of-the-art laboratory setup that can be replicated by the other educational institutions demanding to expand in the field of industrial automation and controls.

Keywords

Robotics, Control, PLC, and Robotic Education

Robotic Workcell Introduction

There has been a tremendous amount of growth in the worldwide sales of industrial robots. A recent article published by International Federation of Robotics [1] apprises that a new record sale of 248,000 units was set in 2015 which had an increment of 12% compared to 2014. Statistics claim that by 2018, 2.3 million units will be installed in factories around the globe. Industrial Automation is currently making a huge impact on the global economy. With the rapid growth in the industrial automation sector, there is an increasing demand for trained robot engineers in the market. Adam Stienecker (2008) stated [2], “Today, industry is much less in need of robot designers and much more in need of experts in the application of robots and the design of the systems that work with the robots such as end-of-arm-tooling and vision systems”. He rightly highlights that the industry needs more system designers who have the knowledge to interface multiple robots with vision systems, experience with PLC and are aware of different hardware used alongside robots.

Imparting education to students using such laboratories and providing them the confidence to tackle different applications or troubleshooting systems has been the driving force in developing a robotic workcell for the robotics vision course at Michigan Technological University. The main objective of creating such a workcell is to give the students a closer view and a real-time experience of the industrial setting and its applications. Developing an industry-like integrated system to be used for academic curriculum greatly enhances the students' knowledge in subject matter, improves comprehension process, and provides them with a great exposure to the industrial environment. The paper discusses in great detail all the components, equipment, and wiring diagrams of the workcell such that anybody could replicate the workcell at their respective institutions.

Existing Robotic Workcells

Companies such as ABB [3], FANUC America [4] and KUKA Robotics [5] have designed educational robotic carts for hands on learning of certificate based robotic courses. High schools and universities tie up with such robot manufacturers to setup an industrial automation laboratory at their institutions. Most of these robots are mounted on a single cart and are built with certain limitations that restrict the robot from being used for a variety of applications. Adam Stienecker (2008) developed a workcell laboratory at the Ohio Northern University by procuring individual robots from KUKA Robotics and setting up an integrated system with CNC machine, conveyor and sensors [6]. Dr. Arif Sirinterlikci's (2015) team at Robert Morris University developed a vison based sorting laboratory which consists of the FANUC robot's vision system, a bowl feeder, linear actuator and proximity sensors. The workcell was primarily created as a future learning module for the robotics and automation course (ENGR 4700). William Ferry and Andrew Otieno (2004) have designed and developed a low cost bottle capping automation system [7] consisting of PLC, vision system and multiple DENSO robots with the purpose of teaching automation integration of different hardware at Northern Illinois University.

Developed Integrated Robotic Workcell at Michigan Tech

The industrial automation laboratory at Michigan technological university has four FANUC training carts, each comprising of a FANUC LR Mate 200iC robot, R-30iA Mate Controller, Sony XC-56 camera, air supply and a computer. These robots have an option for interchangeable end-effectors such as suction cups and 2-finger parallel grippers, which provides flexibility in developing a variety of application scenarios for the laboratory exercises. Approach of integrating three FANUC robots with a conveyor, programmable logic controller (PLC), safety guards, through beam sensors and vision systems in a single integrated robotic workcell is outlined in this paper. Figure 1 depicts the overall layout of the integrated robotic workcell.

Conveyor System

The conveyor system, shown in #3 of Figure 1, design was selected based on the various functionalities that would be required to develop the industrial scenarios for the lab exercises of the robotic vision course. The system conveys various products such as Jenga blocks, markers, empty cups and pills. The conveyor [8] can either be run at four different speeds in forward direction or at one constant speed in forward and reverse directions. The variable frequency drive (VFD) mounted on the control panel provides an option for setting up the multiple speeds. The specifications of the conveyor and its parts are shown in detail in Table 1.

S No.	Specifications	Description

1	CONVEYOR	Manufactured by Mini Mover Conveyors, LITE series model Width – 10”, Length – 84”, Speed 3-43 feet/min
2	Conveyor frame	Hard black anodized aluminum frame with integral .70" high side guides
3	Belt	Black, PVC (polyvinyl chloride, low friction cover)
5	Geared-Motor	Manufactured by Oriental Motor Co. Ltd., Brushless DC Motor, Model No. BLM460SP-GFV2, Single phase 100-120 V, Output Power - 60 W
6	Variable Frequency Drive	Manufactured by Oriental Motor Co. Ltd., 115/60 VAC input variable speed Digital Display, Model No. BMUD60-A2

Table 1. Detailed Specifications of the conveyor

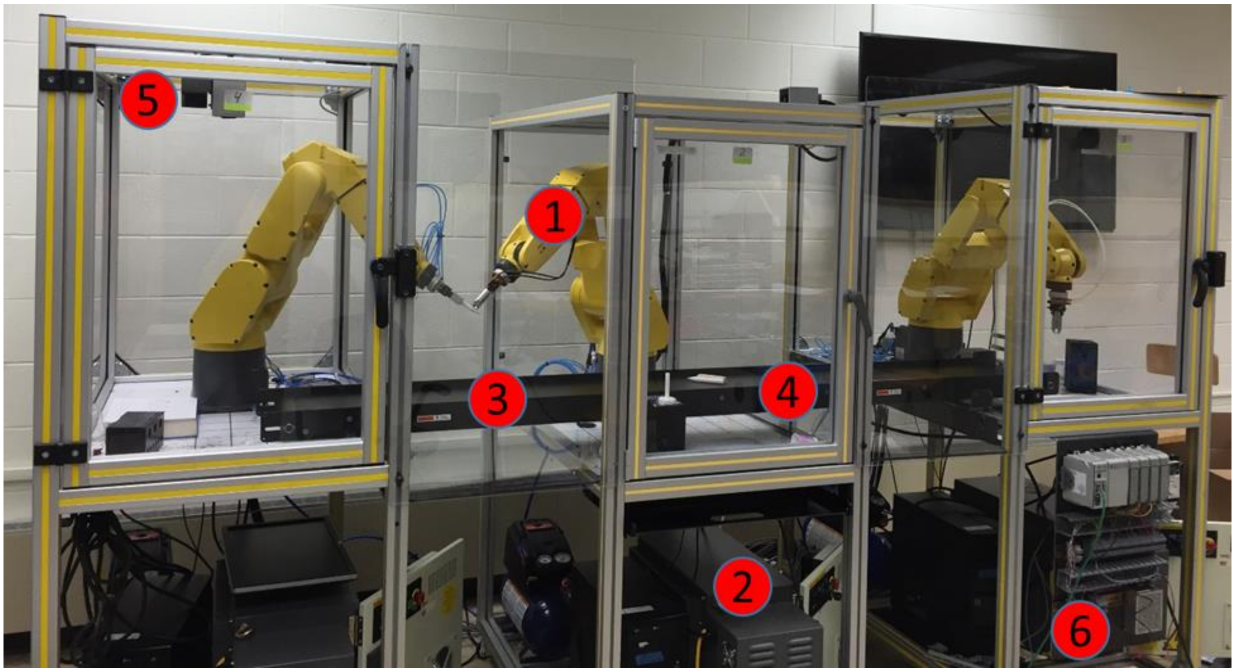

Figure 1. The work cell consisting of 1) Robot 2) Robot Controller 3) Conveyor 4) Sensors 5) Vision system 6) Control Panel

Vision system and sensors

The vision system, shown in Figures 2, consists of a camera, 2D iR-Vision package installed on the FANUC controller and a spot light. Nearly any robot currently used in industry is equipped with a vision system. Vision systems are being used increasingly with robot automation to perform common and sometimes complex industrial tasks, such as: part identification, part location, part orientation, part inspection and tracking. The vision system provides the robot “eyes” needed to perform complex manufacturing tasks. Vision systems are being increasingly used in the automation industry to achieve high accuracy and speeds for various operations in manufacturing and assembly lines. The specifications of the installed camera and light are shown in the Table 2. Sensors are an integral part of automation system that help to detect objects and create logical operation in the system. Currently, photoelectric through beam sensor, shown in Figure 3, that consist of an emitter (emits IR light) and a receiver have been installed on the conveyor. The sensors detect an object when the beam emitted by the emitter is obstructed and not received at the receiver's end. These sensors were chosen to detect the presence of marker in one of the laboratory exercises discussed in the paper. These sensors are mounted on the steel brackets and can be adjusted to suit the height of different objects. The sensors have the specifications as shown in Table 3.

Figure 3. 1) XC-56 Sony Camera 2) LED spot light

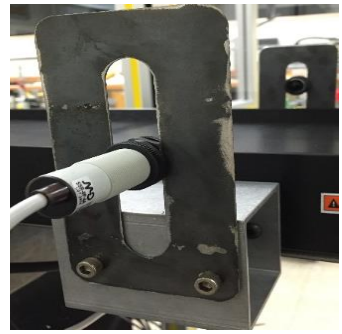

Figure 2. Through beam sensor mounted on brackets

Serial No.	Parts	Description
1	Camera	Model No. - XC-56, manufactured by Sony, Black & white CCD camera, 659 X 494 pixel array running at 30 frames/sec, VGA resolution
2	Spot Light	Model No. - LEDWS50L20-XQ High intensity LED White spot light, 3 LED's

Table 2. Specifications of the vision system

Serial No.	Parts	Description
1	Photoelectric switch receiver	Model No. SSR-0P-4A, manufactured by Automation Direct,
2	Photoelectric switch emitter	Model No. SSE-00-4A, manufactured by Automation Direct

Table 3. Specifications of sensor

Control Panel and PLC Setup

The control panel, shown in Figure 4, consists of the Allen Bradley PLC (Model No. 1769-L32E) with one input (Model No.1769-IQ16) and 3 output (Model No.1769-OB16) modules, conveyor VFD and Omron SMPS (Switch mode power supply, Output - 24V, 1.1 A). The PLC is used to control the conditional and sequential operation of the entire workcell in production mode. The PLC interacts with all the components of the system such as sensors, conveyor system and the robot controllers. It also acts as the master controller of the system by sending digital I/O signals to the robot controllers for them to start executing their individual programs.

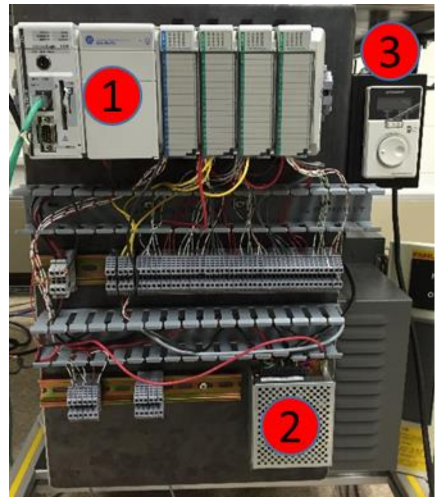

Figure 4. 1) Programmable Logic Controller, 1769-L32E 2) Switch Mode Power Supply, S82J-0224 3) Variable Frequency Drive, BMUD60-A2

The PLC is connected to a computer with the Ethernet cable using the TCP/IP protocol and the PLC programming is done on RSLOGIX5000 software installed on the computer. The panel in mounted on the cart of the FANUC robot and is enclosed safely with Plexiglas guarding. The PLC is powered by the SMPS and assigned an IP address for communication using Ethernet.

Using the digital I/O (input/output) method of communication, the user can send signals from the PLC to run a program on the robot controller. The PLC consists of digital output modules that send on/off signals as outputs and these are received as input signals by the input module of the robot controller. To achieve this functionality following are the steps involved:

1) Configuring and wiring the devices
2) Mapping the I/O on the controller to the connections
3) Sending the signal from PLC using ladder logic program

Configuring and wiring the controller devices

The variable frequency drive (VFD) is used to start and stop the conveyor system. The VFD of the conveyor motor is connected, as shown in Figure 5, to the PLC and using the digital I/O signals the conveyor can be run in reverse or forward direction from the PLC. Since the SMPS provides a 24 V output, the pins shown in Table 4 are wired to the system. The PLC acts as a peripheral device as shown in Figure 6, to the robot controller, and the connections between the PLC and the controller are made at the connection conversion board (appendix) using a 50 pin Honda Tsushin Kogyo MR-50RFD connector shown in Figure 7.

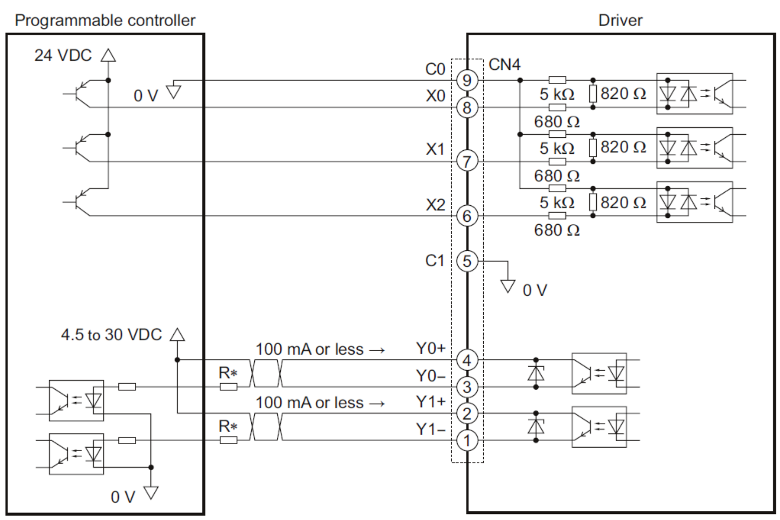

Figure 5. Connection from PLC to the VFD using source logic

Pin No.	VFD Terminal	Function	Description
9	C0	In-COM0	Input Signal common (0 V external power supply)
8	X0	FWD	The motor rotates in forward direction when this signal is turned on
7	X1	REV	The motor rotates in reverse direction when this signal is turned on
6	X2	M0	The two speeds can be selected using this signal
5	C1	IN-COM1	Input Signal common (0 V external power supply)

Table 1. Details of the VFD terminals connected to PLC with description of its functionality

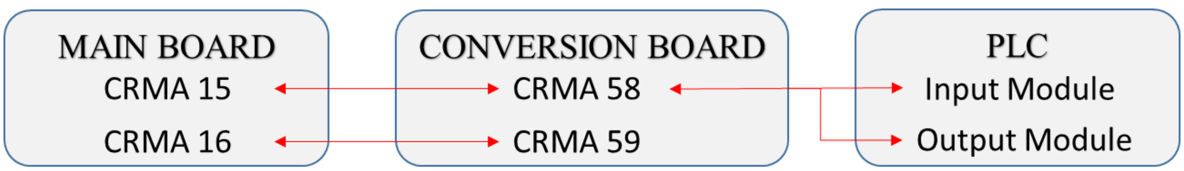

Figure 6. Wiring Connections between the PLC and Robot Controller

The connector conversion board is installed on the controller. It allows the connection between peripheral device and the Main board I/O ports which are CRMA15 and CRMA16 (Figure 6). Each digital I/O of the PLC module is connected to the CRMA58 I/O port on the controller using the Honda pin connector (Figure 8.). The pin numbers represent the physical Digital inputs and outputs of the robot's I/O module. FANUC controller has an already defined I/O section called User Operator Panel I/O. These UI (user input) and UO (user output) signals are being used to communicate with the PLC. The functions of these I/O's has already been configured by FANUC and assigned to dedicated UI and UO numbers (Table 5). The function of each individual command has been explained in the FANUC Robotics System R-30iA Controller's HandlingTool setup and operations manual. Each of these I/O's is mapped to the digital I/O's of the robot controller.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	19	20	21	22	23	24	25	26	27	28	29	30	31	32			
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Where, Pin no. 1-16 represent DI101-DI116 (Digital inputs)

Pin no. 17-20, 29-30 represent 0 V (Ground)

Pin no. 22-25 represent DI117-DI120 (Digital inputs)

Figure 7. 50 pin Honda Tsushin Kogyo MR-50RFD connector with detailed pin assignments

UOP Input Signals	Process I/O UOP UI (User Input)	UOP Output Signals	Process I/O UOP UO (User Input)
IMSTP	UI 1	CMDENBL	UO 1
HOLD	UI 2	SYSRDY	UO 2
SFSPD	UI 3	PROGRUN	UO 3
FAULT RESET	UI 5	PAUSED	UO 4
HOME	UI 7	HELD	UO 5
ENBL	UI 8	FAULT	UO 6
PNS1	UI 9	ATPERCH	UO 7
PNS2	UI 10	TPENBL	UO 8
PNS3	UI 11	BATALM	UO 9
PNS4	UI 12	BUSY	UO 10
PNS5	UI 13	SNO1	UO 11
PNS6	UI 14	SNO2	UO 12
PNS7	UI 15	SNO3	UO 13
PNS8	UI 16	SNO4	UO 14
PNSTROBE	UI 17	SNACK	UO 19
PROD_START	UI 18	RESERVED	UO 20

Table 2. UOP inputs and outputs to individual commands

Mapping the I/O on the teach pendant controller to the connections

Since the physical connections have been established, the software needs the details of the pins that have been connected to the PLC. This is called mapping the I/O's and is shown in Figure 8. To map the individual I/O's, the following steps on the teach pendant are performed:

- Press MENU. Select I/O and select the TYPE, UOP.
- Press F4 for switching between Inputs and Outputs.
- Press F3, CONFIGURE to see a screen similar to Table 4.

In the Range column the UI range that is being used is entered. Rack and Slot refer to the position of the I/O module on the controller. Start refers to the Pin no. of the 50 pin Honda connector that is being assigned to the respective UI or UO. Status indicates the current state of the I/O and will display any of these three options: Assigned, Unassigned and Pending. If there is any I/O with the status pending, then restarting the controller will automatically set the status to assigned.

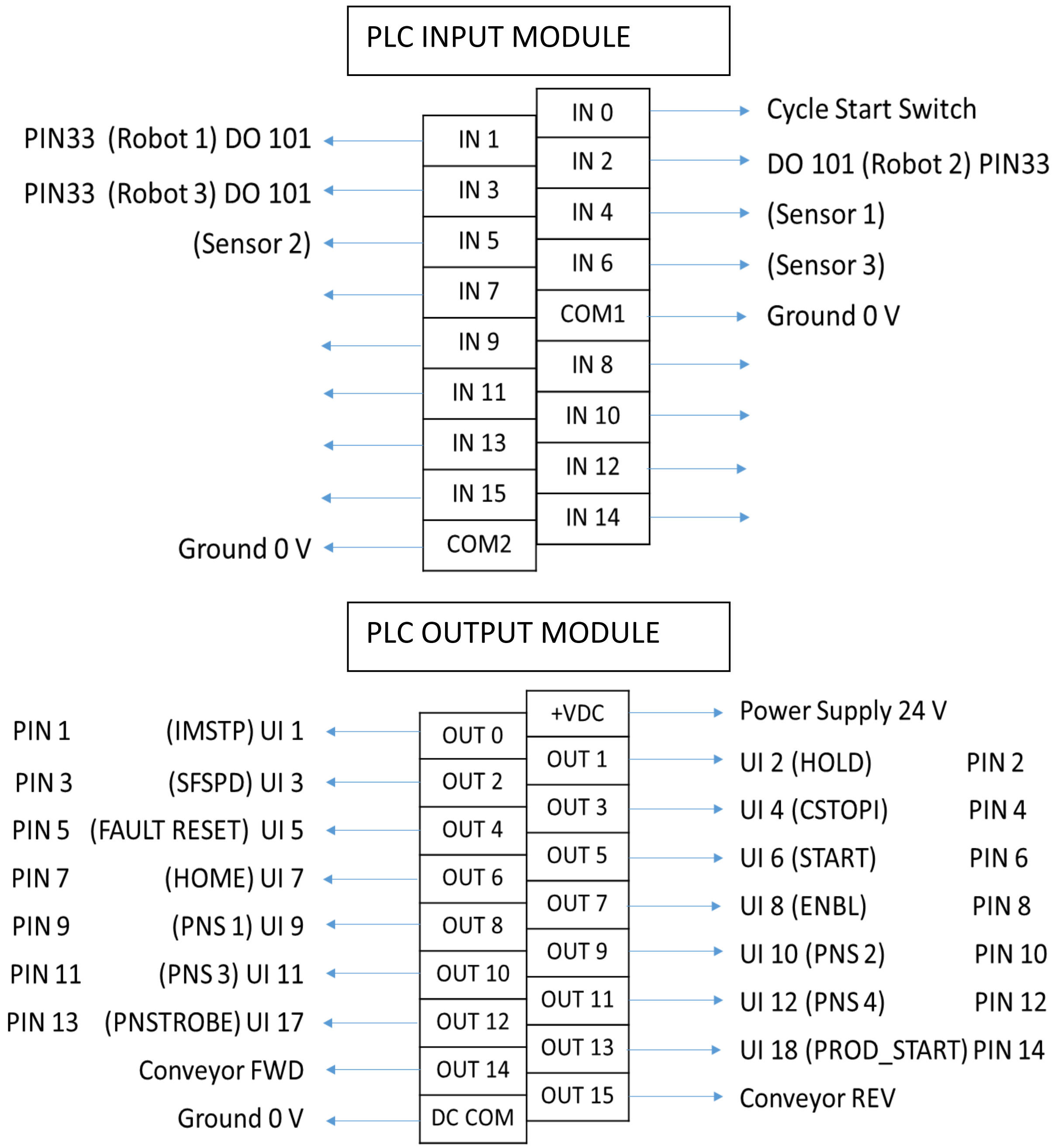

Figure 8. PLC I/O to UI/UO connections

After mapping the UOP I/O's, the system controller is configured so that the signals sent from the PLC to control the operation of the robot. To configure it, Press MENU. Select SYSTEM and select the TYPE, CONFIG. A list of options is displayed and change the following as shown.

1)	Enable UI signals:	TRUE
2)	START for CONTINUE only:	TRUE

3) CSTOPI for ABORT: TRUE
4) Abort all programs by CSTOPI: TRUE
5) PROD_START depend on PNSTROBE: TRUE
6) Detect FAULT_RESET signal: FALL
7) Remote/Local Setup: Remote

#	RANGE	RACK	SLOT	START	STATUS
1	UI [1— 1]	48	1	1	ASSIGNED
2	UI [2— 2]	48	1	2	ASSIGNED
3	UI [3— 3]	48	1	3	ASSIGNED
4	UI [4— 4]	48	1	4	ASSIGNED
5	UI [5— 5]	48	1	5	ASSIGNED
6	UI [6— 6]	48	1	6	ASSIGNED
7	UI [7— 7]	48	1	7	ASSIGNED
8	UI [8— 8]	48	1	8	ASSIGNED
9	UI [9— 12]	48	1	9	ASSIGNED
10	UI [17— 17]	48	1	13	ASSIGNED
11	UI [18— 18]	48	1	14	ASSIGNED
12	UI [13— 16]	0	0	0	UNASSIGNED

Table 3. Details of the UI's assigned

The PLC ladder logic program initializes the basic signals that are required to run the robot program. Firstly, Immediate stop, Hold and Safety speed signals are turned on and activated for production. The fault is reset and the robot is enabled. The program on the robot is saved with the name PNSxxxx and the signals from sent from PLC are read as binary inputs by the robot controller. For example, to execute program PNS0011 the signals sent by PLC are PNS1 (20), PNS2 (21) and PNS4 (23). After the program number is read by the controller. The Program number select strobe signal (PNSTROBE) selects the program on the robot. Production start signal executes the program in production mode.

Application Scenarios of Lab Exercises.

Using the above setup to run the robots using PLC, a number of applications can be developed to perform tasks such as packaging, manufacturing and assembly of parts. Using the above system, students can create their own and innovative projects for the Robotics Vision course. To provide hands on experience to the students and explain the working of the integrated system, different lab exercises have been implemented as a part of the course and are discussed next.

Jenga Blocks Production and Palletizing

This exercise lets students relate to the various palletizing applications that are used throughout the industry. There are a few wooden blocks placed on the conveyor in a random orientation as shown in Figure 10.

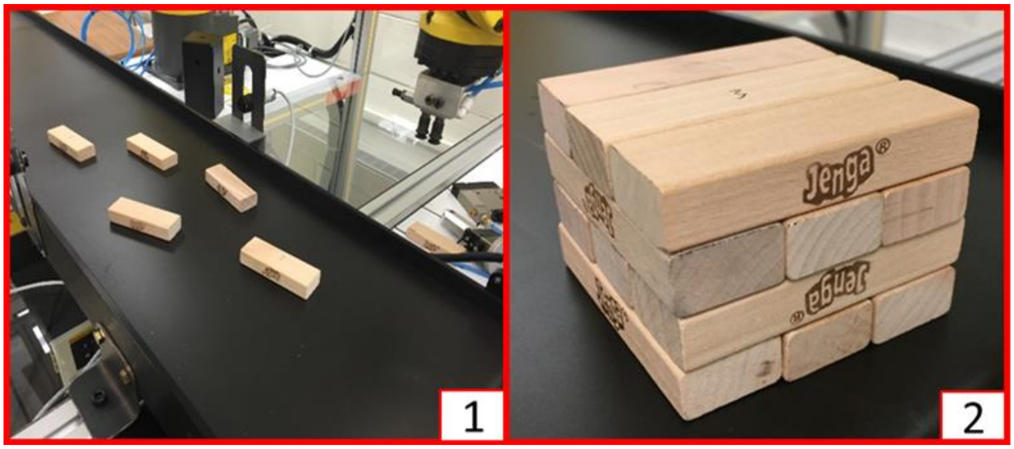

Figure 9. 1) Randomly placed Jenga blocks travelling on conveyor 2) Final Pallet formed by the robot

The robot's vision system has to detect the blocks moving on the conveyor, stop the conveyor and, using the vacuum cup end-of-arm-tooling, pick up the blocks and form the final pallet. This is done using the palletizing option provided on the FANUC controller where number of rows, columns and layers of the pallet are defined along with the robot's approach and retreat points from the pallet. The second task is to teach the image of the block to the iR-Vision system's camera which is mounted exactly above the conveyor. The camera's search window is defined on the conveyor closer to the robot for easy approach. After the vision process is defined by the students, a program is written to integrate the vision with the palletizing program.

Having completed this exercise, students learn to create shorter programs on the teach pendant for palletizing applications. They also learn the procedure of the iR-Vision system that involves camera calibration, teaching geometric pattern to the camera and programming the vision instructions.

Marker pen color sorting and assembly

The main objective of this exercise, demonstrated in Figure 11, is to train the students the ability of the robotic vision system to differentiate between color and understand the importance of lighting conditions for the vision system. It also gives an insight to the students about the working of multiple robots controlled safely with the PLC. Three teams work on three different robots to program individual tasks.

The color of the markers, blue, red and pink are chosen in the increasing order of contrast. The belt being black in color makes it difficult for the robot to detect the dark colors such as blue. The students have to adjust the environment lighting and create enough brightness for the camera to detect the blue contrast. The caps are placed in the search region of robot 3 and the open markers are placed in the region of robot 2. The robot 2's vision system detects the markers position and orientation in ascending order of contrast (blue, red and pink).

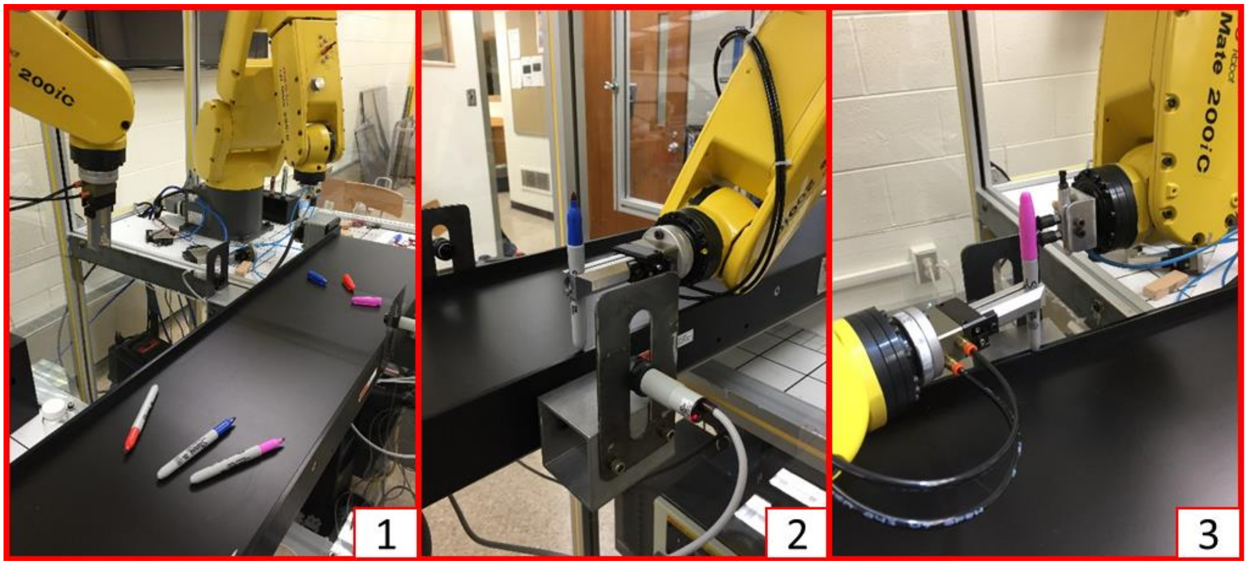

Figure 10. 1) Inital setup with open markers and caps 2) Robot 2 picks the open marker and places it for assembly 3) Robot 3 assembles the cap on the marker

The robot 2 picks up the marker and places it on the flat surface for assembly. The through beam sensor confirms the presence of the marker and the robot 3's vision system finds the blue cap. The robot 3 picks up the cap from the conveyor and places it on the marker. The robot 3 tightens the cap, as shown in Figure 12, and sends signal to the PLC that it has completed its task. Now, the robot 2 places the blue marker on the conveyor. After the above process is completed for all the three markers, the conveyors start to move and brings the markers in the search region of robot 1. The robot 1 detects the markers and places them on the tray.

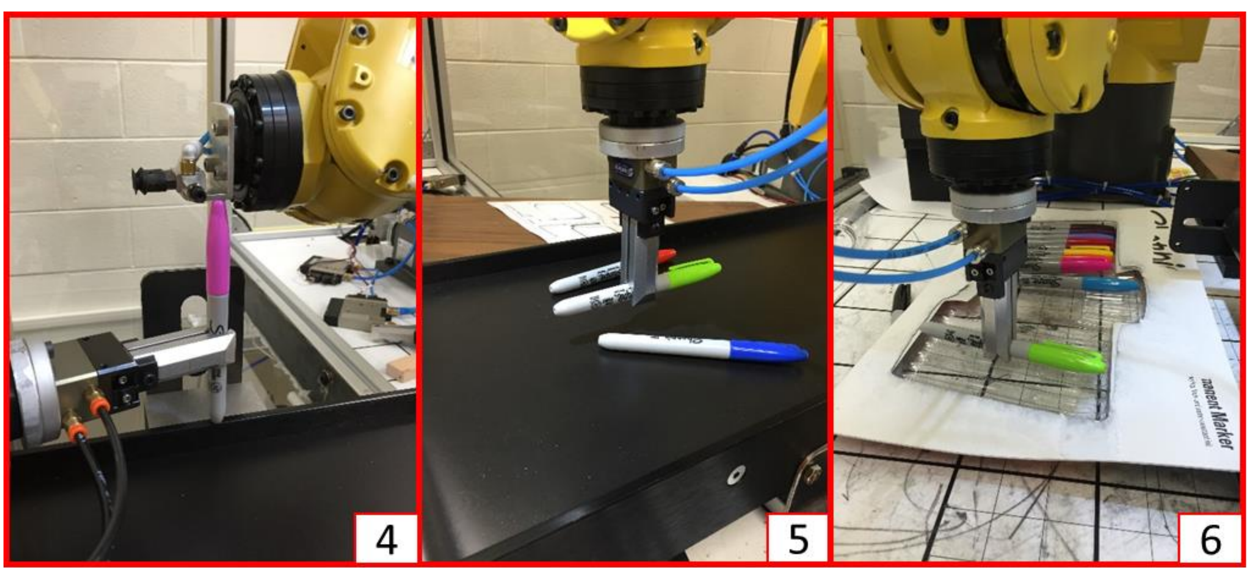

Figure 11. 4) Robot 3 tightens the cap by pressing it on the marker 5) Robot 1 picks the assembled marker 6) Robot 1 places the assembled marker on the tray

Combining three of these robotic carts into a single robotic work cell was developed with an aim to enhance the laboratory usage of these robots along with providing hands-on experience to students. The course will aim to have many such lab exercises in future.

Conclusion and Future Work

The modifications and development done to the existing education carts provided by FANUC will provide a greater learning experience for the Robotics Vision course that is being introduced in the spring semester of 2017. The main objective of creating the robotic workcell is to give students a maximum exposure to the industrial scenarios that would assist them in their future. Automation system integrators often design the manufacturing or assembly lines with multiple robots and other hardware systems. The workcell's design has been inspired from observing the current automation lines in different industries such as food and packaging, medical, logistics and assembly lines. The workcell is an integrated system of three robotic arms, a bi-directional conveyor, sensors and vision systems. A PLC acts as the master controller and sends signals to the robot controllers to run the complete system in production. Ladder logic programs have been created for teaching laboratory exercises that involve different applications such as palletizing using vision, assembly of parts, color based sorting of pills and identification of parts for acceptance or rejection.

The workcell design has also opened the doors for students to come up with innovative ideas for their projects which is a part of the course requirement. Students will now be able to achieve control over operation of multiple robots and demonstrate their abilities in building a complete integrated system. Having learnt the process of integrating an automation system, students will be able to troubleshoot and work on different applications in the industry.

In the future, the workcell can be equipped with capabilities to execute advanced vision based applications like 3D Bin picking and visual tracking. 3D bin picking is being widely used in the industry to pick up parts from a bin and place it in the required orientation. Also, by procuring the visual tracking option for the FANUC controller [9], picking up objects while the conveyor is running would be one of the various possible applications. The industry demands highly efficient production cycle times of the automation systems and future laboratory exercises would be modified to teach the optimum path of operation for robots and vision. Also, since lighting is the most important aspect of vision, lab exercises involving the usage of different colored lights for different objects would be implemented.

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