A CAPSTONE EXPERIENCE IN MANUFACTURING AUTOMATION THROUGH INTEGRATION OF ROBOTICS, MACHINE VISION AND PROGRAMMABLE CONTROLLERS

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Abstract

Capstone projects form a basis for the culmination of Engineering and Engineering Technology programs. In many engineering programs capstone projects require students to demonstrate integration of various skills they have learned in their respective disciplines. While many projects are sought from industry, some are offered from within departments. This paper describes a capstone project based on implementing an automated bottle capping and sorting system. The system comprises of three robots, a camera which will be integrated through a programmable logic controller, and a conveyor. The first robot is used to load the empty bottles into a special pallet that sits on the conveyor. Upon completion of the loading cycle, the palette is released by a pneumatic actuator and moves across a camera which captures the image of the bottle. The bottles have two different markers used to select a black or white cap. A second robot picks up the caps and installs them onto the bottles. A third robot unloads them and places the bottles in any one of two bins depending on the cap installed. I/O handshaking between the robots and the vision system is controlled by the programmable controller. Through this project, students will have a better understanding of implementation of automated systems and will be better trained to join the workforce.

Introduction

The changing face of the manufacturing sector in the United States has caused educators to start thinking critically about how to train the next generation engineers and technologists. Educators need to provide training that mirrors this environment which students seek to enter. A well rounded engineer is key to today's manufacturing workforce and this implies diverse knowledge in various fields of automation. These fields include areas of machine vision, programmable controllers, robotics, supervisory

control and data acquisition. Most importantly, the engineer must be familiar with methods of integrating all these components in an effective way to allow automated processes to function efficiently. Manufacturing education curricula therefore ought to be geared towards producing an engineer with all these skills.
Although there is evidence that in the past 10 years the level of manufacturing in the US has declined slightly, partly due to lower labor costs in international markets and the shift in the early 90's to the information technology sector, innovation, especially in niche areas such as automation, will help the nation stay ahead of the rest of the world. The demand for qualified engineers and technologists continues to increase in the US despite the fact that the rate of graduation of students in these areas declined from 1990 to 1999 and then picked up again[1]. According to the Bureau of Labor Statistics, the projected demand for skilled technicians is expected to increase by between 9 and 17% by the year 2014[2], yet the trend of graduation of students in these fields are not likely to cope with this demand. It is very important, especially in this era of economic hardship, that academic institutions of higher learning address these problems and seek ways by which there can be cost effective ways of offering programs that would otherwise be very expensive to offer. As stated earlier, one way is to be able to introduce engineering and technology curriculum and then broaden the skills of the next generation engineers.

In an effort to improve its curriculum, the Technology Department at Northern Illinois University developed a low cost automated cell that has been used for instruction in the automation classes[3]. However, due to the partial functionality of the cell, its use as an effective laboratory asset has been greatly inhibited. To complete the automated cell and have it fully integrated, more resources were needed. This paper describes the finalization of the automated assembly cell through a capstone student design project.

Capstone Design Project

i) The existing setup.

The existing automated cell is built around a carousel type conveyor with two 6-axis, and two 4-axis DENSO™ robots. It involves an automated bottle capping assembly cell in which the capping process is done by a 4-axis robot. The proposed activity involves loading the bottles from a holding rack shown in figure 1 below into a pallet. The pallet is originally held in place by a pneumatic stop as the conveyor is continuously rotating. Upon completion of the bottle loading operation the stop is released to allow the bottle to travel past a camera. A proximity sensor triggers the camera to capture an image of the bottle. The bottles are labeled with either a "O" or a "+" sign (figure 2) and depending of which sign it has, it receives either a black or white cap. The bottles are then stored in different bins according to the color of the caps. Figure 3 shows some details of the current setup.

The installed programmable controller (PLC) was a 14-point DL 05 from Automationdirect™. Because of the limited number of inputs and outputs (I/O) in the existing PLC that is meant to provide I/O "handshakes", each of the described processes can be carried out independently. There is no full integration and automation of the processes to provide an effective way of allowing the different devices to communicate with each other. In addition to this, the I/O current rating on the robot outputs is very low (in the region of 70mA maximum). The fact that the DL 05 maximum current output rating is 2A provides more challenges as to implementing effective relaying techniques. This called for a total redesigning of the project as well as a need to change some of the existing devices, such as the PLC and the relays used to isolate robot power from PLC power. The following section describes the redesign and what the current status of the project is.

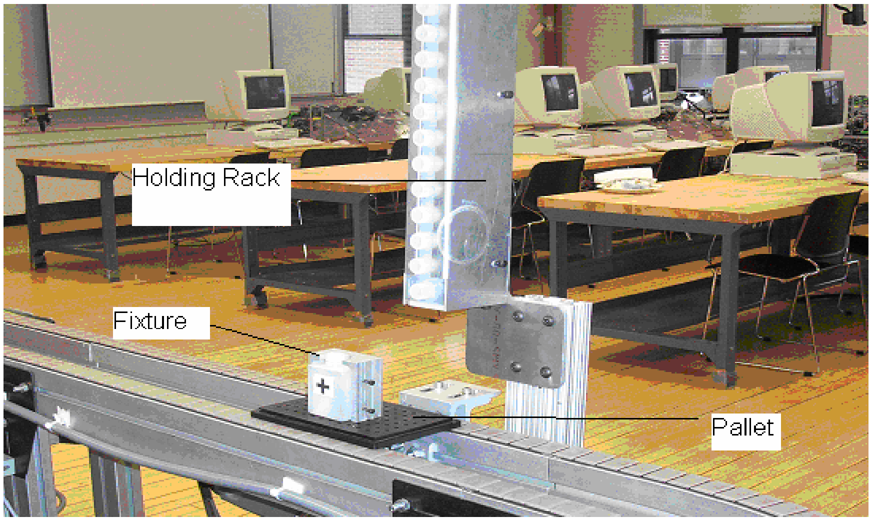

Figure 1. Existing bottle racks

Figure 2. Un-capped bottles

Figure 2. Existing capping process with details of the cap rack

ii) Proposed changes and modifications to the project

The first proposed change was the redesign of the bottle holding rack. The previous design was gravity fed onto the bottom from a single stack. The new design incorporates a pneumatically operated ejector that draws the bottle out farther, allowing for easier pick up by the 6-axis robot. This re-designed system is shown in figure 4 below.

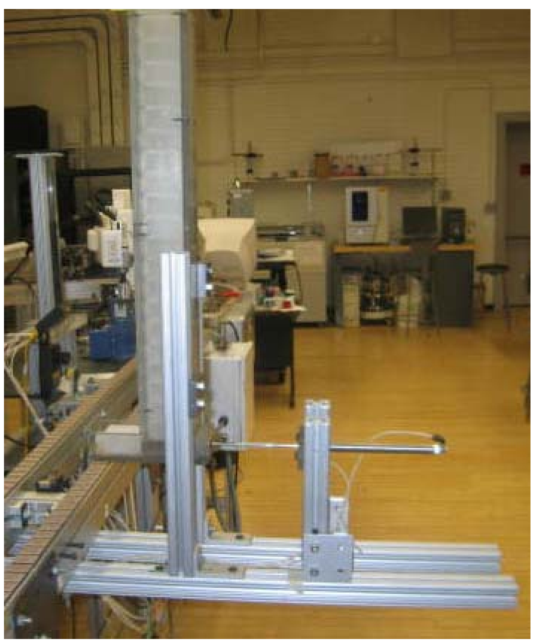

Figure 4. The re-designed bottle feeding rack.

The second change was to re-evaluate how many I/Os the system required to operate fully autonomous. Because additional I/Os were required, an expansion unit was added to the existing

DL05, increasing the total number of I/Os from 14 to 21 (14 inputs and 7 outputs). The table below summarizes the I/O assignments.

Table 1. I/o Assignment for the PLC

Inputs		**Outputs**	
0	Prox sensor – load station	0	Solenoid valve - Load station
1	Prox sensor – capping station	1	Solenoid valve – cap station
2	Prox sensor – Unload station	2	Solenoid valve – unload station
3	Prox sensor – Pallet cleared	3	Solenoid valve – black cap load
4	Switch – Emergency stop	4	Solenoid valve – white cap load
5	Push button – cycle start	5	Robot – I/O handshake
6	Push button – cycle stop	6	Robot – I/O handshake
7	Push button – robot calibration		
8	Camera input – black cap		
9	Robot – I/O handshake		
10	Robot – I/O handshake		

To implement the operation, a DVT camera (Legend Series 500 SmartImage™ Sensor) is used to capture an image of the bottle after the loading cycle has been complete. An extra proximity sensor located below the camera is used to trigger the image capture. This is shown in figure 5 below. The purpose of this process is to detect whether the bottle will need a black, or a white cap.

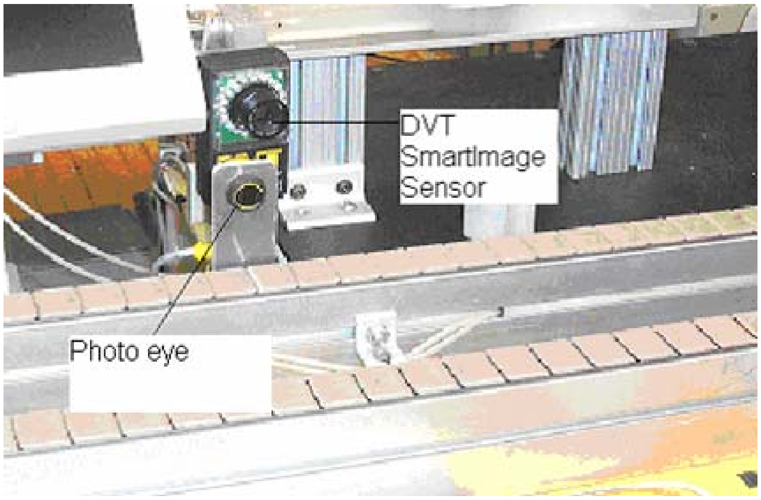

Figure 5. Camera set-up

Determination of which color cap to install on the bottle is done through programming of the camera. A suite of in-built image processing functions of the system known as Framework™ software are utilized to accomplish this. For the bottles, a linear edge detection tool is used to determine the number of edges on the label. This feature is known as EdgeCount and it is a tool that counts the total number of times the “sensor” path crosses edges in an image. An edge is defined as a transition point between dark and bright pixels. The “O” has four edges while the

"+" only has two edges, if the EdgeCount is drawn horizontally across the image. When the vision system finds four edges (ring), a "pass" result is sent to the PLC via an I/O breakout board and this signal activates a cylinder to eject a white cap. If the two edges are found, a "fail" result is sent to a different PLC input via the same I/O board to activate the cylinder that ejects a black cap. The implementation of an EdgeCount tool is shown in figure 6 and the cap ejection is shown in figure 7.

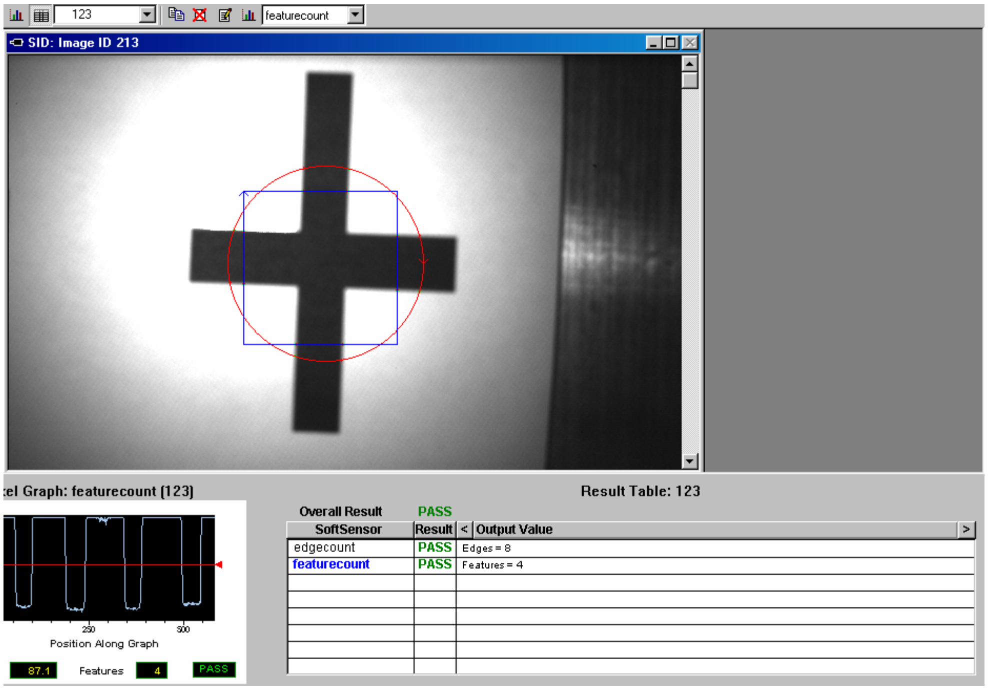

Figure 6. Edge detection tools

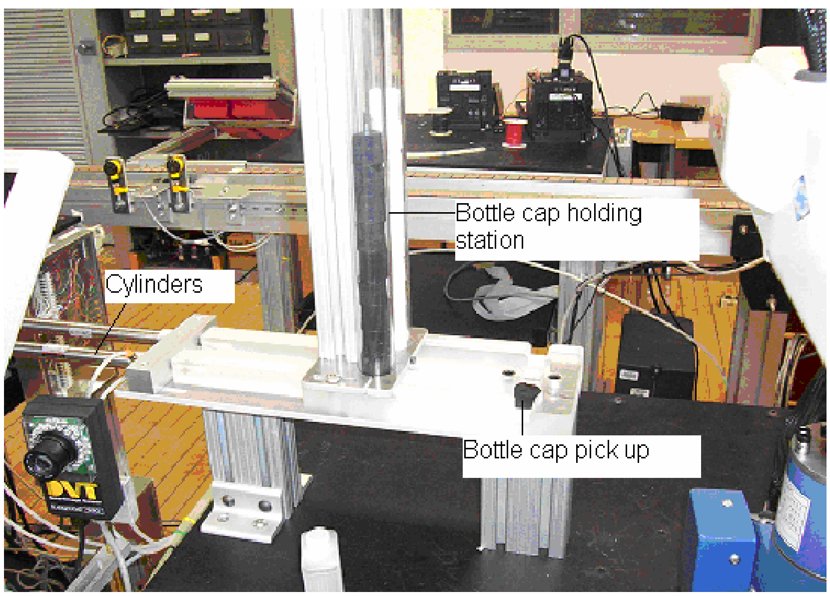

Figure 7. The cap holding and ejection station.

As the camera sends out a signal to the PLC to eject the correct cap, the same signal is sent to the robot I/O system. A proximity sensor is located just before the capping station which activates the pallet stop when the bottle arrives. This signal is used as an input into the robot as well (via relay) to commence the cap gripping and installation cycle. Within the robots main program, two subprograms are written to install the two different types of caps. The “pass” signal from the camera is sent into one of the robot’s input ports while the “fail” is sent to another one. When the proximity sensor signal is high and the capping cycle starts, the specific subprograms to be run are controlled by which of the two robot input ports is high; thus enabling the robot to select the correct pick location for a cap.

When the capping is complete, the robot controller sends an output signal through an output port to the PLC (through relay) as “handshake” for the cycle completion process. This signal is used to release the pallet stop and allow the bottle to proceed to the shelving station. The bottles have to be loaded into separate bins (black or white caps). To achieve this, the second six axis robot is used. Implementation of the program for storing the bins is done in a slightly different way from the capping process. A proximity sensor is used to activate a pallet stop to allow the robot to pick up the bottles and then place them into their respective bins. This signal is also used to start the “pick and place” cycle for storage process. However, to enable the robot to place the different bottles in their respective bins, the “pass” or “fail” signals from the camera, which were also sent to the PLC are used to control a shift register in the PLC. The PLC will either shift a “1” or a “0” depending whether the signal from the camera is a “pass” or a “fail” respectively. The status bits in the shift register are used to control a specific output which sends a high or low signal to one of the six-axis robot’s input ports. If this port is high, the robot will place the bottle in a location designated by position variable P1 that corresponds to the bin bottles marked with a “O”. Otherwise, if the port is low, then the robot will place the bottle in a location designated by position variable P2 which corresponds to the location of the bin for bottles marked with a “+”.

Conclusions

Manufacturing automation consists of different components, specifically robotics, machine vision, programmable controllers, sensors and actuators, in this particular project. Each component can be used as “stand-alone” systems to implement an activity. Each of these can be taught in a classroom environment with laboratory activities to enhance students’ skills in the specific area. However it is not easy to teach students to implement an integrated system that utilizes the different components to automate a process in a systematic manner. The purpose of a capstone project in manufacturing automation is to allow students to utilize skills learned in the different areas of automation to implement an integrated system. This project offers an opportunity for students to design and implement an automated system. The system, once completed, will be used as an instructional laboratory facility for the manufacturing automation course and student demos.

Bibliography

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Biographical Information

Andrew Otieno is an associate professor in the Department of Technology at NIU. He has done extensive research in experimental and theoretical analysis of metal machining problems. His research and teaching interests include machine vision, manufacturing processes, finite element analysis, and manufacturing automation.

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Richard Velasco is a graduate student in the Department of Technology. He graduated in May 2006 and has since worked as a graduate assistant in the areas of manufacturing automation, metrology and electronics. He has extensive experience in programmable controllers (PLC) and has also worked as a laboratory teaching assistant for the PLC classes in the department.