AC 2009-1176: A PORTABLE WORKCELL DESIGN FOR THE ROBOTICS INDUSTRY

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A Portable Workcell Design for Robotics Industry

Abstract

This paper presents how a senior capstone project can be utilized to build partnerships between the academia and several companies representing key industries in modern robotics technology. The project can be described as designing a portable robotic workcell for industry to showcase state-of-the-art equipment and technologies in robotics. The industrial sponsor for this project is Applied Manufacturing Technologies (AMT) located in Orion, Michigan. AMT plans to use the workcell for demonstrating current robotics technology in tradeshows, industrial open houses and/or robotics conferences. In addition, the workcell is to be used as a platform to provide training to engineers working in robotics industry on robot programming, machine vision and systems integration. The small size, flexible design and durability make the workcell appealing to many other applications in robotics engineering.

An engineering senior project design team composed of one computer engineer, two electrical engineers and two manufacturing engineering technologists at Lake Superior State University has worked on this project as their capstone design requirement through the 2007-2008 academic year. Lake Superior State University offers ABET accredited programs in computer, electrical and mechanical engineering as well as in manufacturing engineering technology. Robotics and automation is a degree option in all majors. The capstone senior design project is an integral part of all the degree programs and provides a real-life experience for the engineering senior students. The two-semester course has been an important tool to introduce students to soft skills such as project management, communications, engineering economics, and engineering ethics.

The paper illustrates how a capstone design project can be used to build partnerships in robotics technology. An educational partnership between Lake Superior State University and Applied Manufacturing Technologies has quickly expanded to include many other partners such as Bosch Rexroth and Siemens. The paper discusses the technology used in designing the portable robotic workcell as well as the capstone design course in detail.

Introduction

In the past few decades, robotics technology has seen rapid improvement in response to a growing demand for automated system design. As advanced camera technologies continue to emerge, vision based robotic automation remains to be one of the most popular fields in research, development and training.

It is evident from the literature that vision based automated systems play an important role in manufacturing industry. A flexible vision guided robotics system developed in Sweden provides a good example[1]. The modular design, ease-of-use and small size of the system makes it suitable for automating production lines with smaller batches or production where new parts continuously must be added to the line.

Applications on an industrial robotic workcell with visual servo also pose challenging research problems. An experimental setup is introduced in [2] for the development of advanced sensorbased control algorithms. The workcell is composed of two industrial robot manipulators, a vision system and a belt conveyor. A software platform is developed for the system to run experiments that use image processing and visual tracking algorithms.

A machine vision system used in inspection processes is discussed in [3]. The system was designed within the scope of a capstone project and integrated a conveyor, a camera, a robot, a programmable logic controller (PLC), and a pneumatic actuator. The inspection system identifies parts on a production line and either accepts or rejects the part based on a number of features obtained from the camera image.

As illustrated by these examples, vision-based robotic workcells, in one form or another, have been the focus of research, development and engineering education[5-8].

This paper introduces a capstone design project completed by senior engineering students at Lake Superior State University. The project can be described as development of a portable robotic workcell that integrates a robotic manipulator, a conveyor and a vision system. The key features of the workcell are its portability, modular design, and relatively low cost. The final design showcases a number of emerging technologies, equipment and processes in industrial robotics. The modular design of the workcell provides a flexible platform for training purposes as well. The project was proposed and sponsored by Applied Manufacturing Technologies, Inc.

From an educational perspective, this project has become an excellent tool to reinforce design from a systems engineering point of view. The project required a complete mechanical design, systems integration, software design as well as an electrical systems design.

Below, a detailed description of the project, key robotics technologies employed in the development of the workcell and the design process will be presented.

Background

The objective for the project to be discussed is to design and develop a portable robotic workcell to showcase current technology and processes used in production line automation. The project is proposed and sponsored by Applied Manufacturing Technologies, Inc. (AMT) located in Orion, Michigan. Founded in 1989, AMT is a leading supplier of complete consulting and engineering services, offering single-source engineering solutions to the automation and manufacturing industries. The company's service offerings range from design and simulation to programming, installation and support of industrial automation solutions for the automotive, aerospace, building materials, consumer products, food, heavy equipment, machinery, medical, and truck industries.

AMT plans to use the workcell described above for demonstrating current robotics technology in tradeshows, industrial open houses or robotics conferences. In addition, the workcell is going to be used as a platform to provide training to engineers working in robotics industry on robot programming, machine vision and systems integration. The small size, flexible design and low cost of the the workcell makes it appealing to many other applications in robotics engineering. The completed workcell is shown in Figure 1.

Figure 1: Portable robotic workcell integrating a robot manipulator with vision and conveyor systems.

An engineering senior project design team composed of one computer engineer, two electrical engineers and two manufacturing engineering technologists at Lake Superior State University (LSSU) has worked on this project during the academic year 2007-2008. Y University located in Michigan, offers ABET accredited programs in computer, electrical and mechanical engineering as well as in manufacturing engineering technology. Robotics and automation is a degree option in all majors. The capstone senior design project is an integral part of all the degree programs and provides a real-life experience for the engineering senior students. The two-semester course sequence (EGNR 491-495 Senior Design Project I-II) has been an important tool to introduce students to soft skills such as project management, communications, engineering economics, and engineering ethics.

This project clearly illustrates how a design project can be used to build partnerships in robotics technology. An educational partnership between Lake Superior State University and Applied Manufacturing Technologies has quickly expanded to include many other partners such as Bosch Rexroth and Siemens.

EGNR 491-495

Senior design project courses at LSSU (EGNR 491-495) are aimed at providing students with the skills for successful completion of their senior project, future projects in industry, and future projects in graduate school. The students will also develop effective design/project teams. Specific objectives for the course are the following:

Upon successful completion of this course, students will be able to:
1. Deliver an effective professional oral presentation.
2. Write memos, letters, and project plans in a clear, concise and professional manner.
3. Explain the principles and issues of ethical behavior in engineering and professional fields.
4. Explain the use of responsibility charts and timelines in project planning.
5. Complete effective performance evaluations of team members.
6. Identify concepts, technologies, or components and select between them to meet design and cost criteria.
7. Demonstrate that they are effective team members.
8. Incorporate safety standards and procedures in all senior project activities.
9. Conduct an effective design review with supporting technical analysis, options, and information.

Lecture topics include technical writing practices, team building, project management, responsibility charts and timelines, design review, safety and a 2-week module on engineering ethics.

Workcell Description

In this section, a complete description of the robotic workcell designed and built within the scope of EGNR491-495 will be discussed.

Functionality

The system through its camera recognizes a variety of medicine boxes (products) randomly circulating on the conveyor belt. There are two modes of operation. In the automatic mode, the system completes one of the preprogrammed orders that is stored within the human-machine interface (HMI) unit. An order contains the quantity and type information for the products in the order. For example, 1: *Box A*, 1: *Box B*, 3: *Box C* make up an order. In the manual mode, HMI waits for a user-input. User can specify the order through an interactive menu system programmed in the HMI.

The system will complete an order by inspecting the products circulating on the conveyor belt while robot arm and its camera are stationary at a pre-specified inspection point. When a product in the order is recognized, the robot arm moves to a calculated pick-up point, grabs the product using its pneumatic end-effector and places it on the output shelf of the workcell. Once the order is complete, the robot arm moves the products that are on the output shelf back onto the conveyor belt and starts inspecting to complete the next order in the queue.

Design Specifications

Table 1 provides a list of the design specifications that outlined the scope of the project. The key specifications are the duration for which the system is capable of continuous operation, accuracy in product recognition, accuracy in acquiring a product, portability, user-friendliness and interactive operation and the size of the workcell. Students had to make design decisions based on these specifications. For example, there is a design tradeoff between the product recognition accuracy and the processing time and complexity of the algorithm run on the DVT camera system. A similar tradeoff exists between the accuracy for acquiring the product and the speed the robot and the conveyor belt run.

Length of Operation	10 hrs continuously (max 1hr downtime)
Accuracy	95% (product recognition) 95% (acquiring the product)
Portability	movable by a forklift
Interactive	accepts user-input as orders
Products	Medicine boxes
Size	4'10" by 6'10" (max)

Table 1: Workcell Design Specifications

System Components

1. *Robot Arm:* The workcell is equipped with a Staubli RX60 industrial robotic arm. It is the main actuator for the system with its 6 degrees-of-freedom, 665 mm of range and a nominal load capacity of 2.5 kg.
2. *Camera:* A DVT Legend 520 camera is mounted on the robot end-effector, next to the pneumatic gripper. This provides the system with the flexibility of acquiring images from any point within the reach of the robot. The camera is equipped with its image processing tool. The system is capable of recognizing a product with a very high accuracy by using a simple inspection algorithm based on blob analysis.
3. *Motion Logic Controller (MLC):* One of the key components of the workcell is the Bosch Rexroth's controller-based motion control system, IndraMotion MLC. It has a x86 compatible CPU, 32MB user memory, 64kB RAM and a CompactFlash Card as removable memory. The IndraMotion MLC also has 1x Ethernet connection, 1x serial RS232 interface, 1x SERCOS interface as communication interfaces that can be used both for the standard drive interface, and for HMI and vision system integration. 8 digital inputs and 8 digital outputs with a possibility of expansion up to 63 I/O modules provide flexibility in terms of adding more functionality to the system.

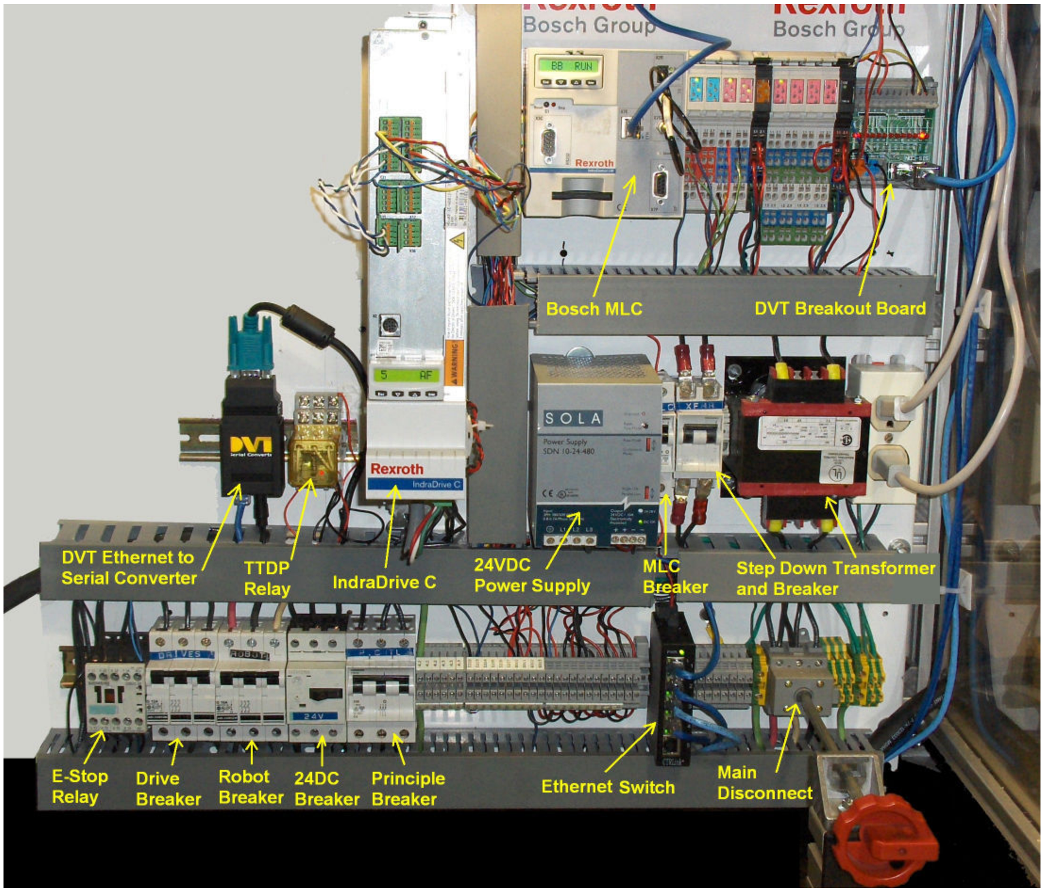

Figure 2: Control panel for the system with major components identified.

4. *Human Machine Interface (HMI):* The system has user interaction capability through a Bosch VEP40 human-machine interface (HMI). HMI has a 12.1 TFT display with 800x600 pixels resolution. The specific model that was used in the system has a 600 MHz Celeron processor with 256MB RAM. HMI also had 1x RS232, 2x USB, 1x Ethernet ports for interfacing.
5. *Electrical and Pneumatic System:* The electrical control panel including the MLC is shown in Figure 2. The entire system runs on 480VAC three-phase with a 15 A circuit breaker. System also requires a minimum of 60 psi working pressure.
6. *Communications:* A number of design selections has been made throughout the development of the workcell based on the capabilities of each subsystem. The following summarizes the communications within the system:
   - MLC is connected to the HMI via the Ethernet port.
   - MLC is also connected to the robot and camera via discrete inputs and outputs. Discrete I/O signals are utilized for system ready signals, e-stops, and order complete signals. For example, MLC communicates the types of the products in a specific order through discrete signals.
   - The robot arm is connected to the camera via the serial port.

- There are discrete I/O connections between the robot and the MLC, the conveyor belt motor, and proximity sensors. They provide the communication within the system for diagnosis purposes.
- The camera communicates to the robot through its Ethernet port via an Ethernet to serial converter.
- There are discrete I/O connections between the camera and MLC to exchange product information.

7. *Programming*: The robotic arm is programmed to receive inputs from the workcell and perform the necessary pick and place actions. The following describes the flow of the program.
    1. *Initialization:* All output signals are turned-off and key variables are initialized.
    2. *System Start-up:* The conveyor system is turned on by the robot and the robot is ready to process an order.
    3. *Inspection:* Robot is moved to inspection point and waits for the TRUE signal from the camera signifying that the product in the order is detected. The camera also communicates the necessary information for the robot to calculate the pick position and orientation.
    4. *Acquiring the product:* The product recognized by the camera as one of the products in the order (manual or automatic) is acquired from the moving conveyor belt and it is placed on the output shelf of the workcell.
    5. *Repeat:* Steps 3 and 4 are repeated until the order has been completed.
    6. *System reset*: Once the order is complete, the robot will depalletize the output shelf by picking the products one-by-one and placing them back on the conveyor belt. At this step, the system looks for empty spaces on the conveyor belt using proximity sensors before a product is returned back onto the belt. The process returns to step 3 to complete another order.
    7. *Shutdown:* The system operation stops if the shutdown procedure is completed or an emergency stop is triggered.

The HMI and the MLC provide the user interface and play important roles in system integration. A sample screenshot of the HMI program is shown in Figure 3. The HMI and MLC program flow is described below.

1. *User input:* The system accepts the user input through the HMI. A menu-driven, user-friendly program is used for this purpose. If there is no manual order present in the queue, the system starts executing one of the preprogrammed automatic orders.
2. *Order processing:* Once the order is validated for consistency and accepted by the MLC, the control of the flow is passed on to the robot. And, the robot completes the order based on sensory inputs from the camera and the rest of the system. The MLC continues to communicate with the camera, robot and HMI. The user can add orders to the queue thorough the HMI while the current order is in progress.
3. *Order completion:* Once the order is complete the MLC instructs the robot to start the depalletization.

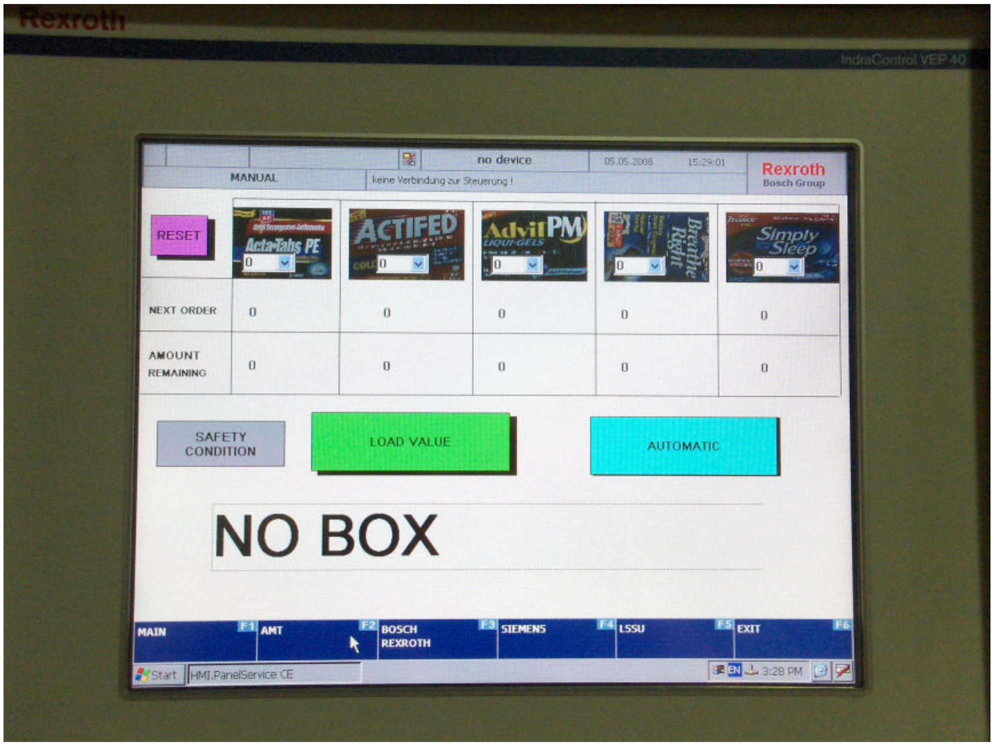

Figure 3: Sample HMI screenshot: Users can enter manual orders on this screen by selecting the product type and quantity.

Outcomes and Observations

As described earlier, a capstone design project can serve as a platform for building partnerships between academia and several companies representing key industries in modern robotics technology. An educational partnership between LSSU and AMT has quickly expanded to include many other partners such as Bosch Rexroth and Siemens. Bosch Rexroth provided the state-of-the-art motion logic controller and its drive systems, Indraworks software for programming the MLC, human-machine interface, the pneumatic end-effector, and all the aluminum extrusions used in the mechanical design. Siemens provided the DVT camera and its peripherals.

The rest of this section is devoted to a discussion of the outcomes and some observations made during the project.

1. *System Performance:* Table 1 summarizes the design specifications used throughout the project. Upon completion, performance tests were run on the workcell. The system was operated for 10 hours continuously to execute various manual and automatic orders. And this test was repeated twice. The following is a summary of the test results.
    - The system recognized the products in the order with an accuracy of 95.4%.
    - The system picked and placed a product correctly with an accuracy of 99.3%.
    - The system completed the order with a 100% accuracy.

- The total downtime over the 10 hour period was 9 minutes. The system went down typically due to a product jam on the conveyor belt or for adjustments to the system to compensate for changes in the ambient light.
- The system did not have any mechanical or electrical problems.

2. The workcell was designed and built to comply with ANSI/RIA R15.06-1999 safety requirements.
3. The dimensions of the workcell are 79 × 42 ×76 in. It weighs approximately 1600 lb.
4. Given its size and weight, ease-of-use, and relatively simple setup procedures, the workcell can be transported to open houses, trade shows, and expositions to illustrate robotics technologies and capabilities.
5. The flexible structure of the workcell makes it an appealing training tool for robotics engineers and technologists. The system can be used to provide training on basic robotics programming, advanced vision algorithms, real-time programming and systems integration.
6. Several new features can be incorporated into the workcell. For example, the system can search for the products dynamically. This is possible since the camera is mounted at the robot end-effector and does not have to be stationary while inspecting the conveyor belt. This will require more computational power but will be a more intelligent and effective approach.
7. The project fit quite well with the multidisciplinary team of students. Manufacturing Engineering Technology students provided expertise on mechanical system design, and implementation which included manufacturing the parts used in the workcell, conveyor belt design as well as robot programming. Electrical engineering students were heavily involved with electrical system design, systems integration and communications. Computer engineering student was the lead person on overall software design and robot programming.
8. Capstone design projects can effectively be used to build robotics technology partnerships.

Conclusion

In this paper, we discussed the design and development of a portable robotic workcell within the scope of a capstone design project. The system employed many components including an industrial robot arm for manipulation, a vision system for identification, a conveyor system representing a production line, a human-machine interface for user interaction and a motion logic controller for system integration. We also illustrated how a capstone design project can effectively be used to build partnerships between academia and industry.

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