Teaching Critical Skills in Robotics Automation: iR-Vision 2D Course in Robotic Vision Systems Development and Implementation

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Abstract

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. The benefits of robotics equipped with the vision systems, however, depend on workers with up-to-date knowledge and skills to maintain and use existing robots, enhance future technologies, and educate users. It is critical that education efforts respond to the demand for robotics specialists by creating and offering courses relevant to robotics and automation. The curriculum and software developed by this collaboration of two- and four-year institutions will match industry needs and provide a replicable model for programs around the US.

This paper describes the development of the iR-Vision 2D course in Robotics Vision Systems, as part of NSF sponsored project that aims to introduce a new approach for Industrial Robotics in electrical engineering technology (EET) programs at Michigan Technological University and Bay De Noc Community College. The iR-Vision 2D robotics course is designed as a 4 credit hour course and introduces topics on: safety; basics of optics and image processing; setting up lightning conditions required for the successful vision error proofing and camera calibration; teaching tool, application, and calibration frames; performing 2D calibration and 2D single and multi-view robotic processes. Hands-on training is an integral part of the course and includes various laboratory exercises, with the goal of providing students the opportunity to configure and execute real-life, industry comparable, robotic vision scenarios.

Introduction

Many existing jobs will be automated in the next 20 years, and robotics will be a major driver for global job creation over the next five years. These trends are made clear in a study conducted by the market research firm, Metra Martech, "Positive Impact of Industrial Robots on Employment" [1]. Many repetitive, low-skilled jobs are already being supplanted by technology. However, a number of studies have found that in the aggregate, the robotics industry is creating more jobs than the number of jobs lost to robots. For example, the International Federation of Robotics (IFR) estimates that robotics directly created 4 to 6 million jobs through 2011 worldwide, with the total rising to eight to 10 million if indirect jobs are counted. The IFR projects that 1.9 to 3.5 million jobs related to robotics will be created in the next eight years [2]. The rapid growth of robotics and automation, especially during the last few years, its current positive impact and future projections for impact on the United States economy are very promising. Even by conservative estimates [1], the number of robots used in industry in the United States has almost doubled in recent years. In the manufacturing sector, the recent growth was 41% in just three years - the number of robots per 10,000 workers employed in 2008 was 96 and reached 135 in 2011. The automotive sector in the United States relies heavily on robotics as well - China produces more cars than the US, but the number of robots used in vehicle manufacture in China is estimated at 40,000 compared to 65,000 in US. From 2014 to 2016, robot installations are estimated to increase about 6% a year, resulting in an overall 3-year increase of 18% [1]. Likewise, industrial robot manufacturers are reporting 18-25% growth in orders and revenue year on year. While some jobs will be displaced due to the increased rollout of robots in the manufacturing sector, many will also be created as robot manufactures recruit to meet growing demand. Furthermore, jobs that were previously sent offshore are now being brought back to developed countries due to advances in robotics. For example, Apple now manufactures the Mac Pro in America and has spent approximately $10.5 billion in assembly robotics and machinery [3]. In March 2012, Amazon has acquired Kiva Systems, a warehouse automation robot, and in 2013 deployed 1,382 Kiva robots in three Fulfillment Centers. This initiative has not reduced the number of employees at Amazon; in fact, it added 20,000 full-time employees to its US fulfillment centers alone.

Such rapid growth of robotic automation in all sectors of industry will require an enormous number of technically sound specialists with the skills in industrial robotics and automation to maintain and monitor existing robots, enhance development of future technologies, and educate users on implementation and applications. It is critical, therefore, that educational institutions adequately respond to this high demand for robotics specialists by developing and offering appropriate courses geared towards professional certification in robotics and automation. In addition, certified robotic training centers (CRTCs) will be in high demand by industry representatives and displaced workers who need to retool their skills. In previous publications [4, 5] authors have already reported on the developments of various robotic oriented courses for university and community college enrolled students, as well as industry representatives. In this article, authors focus their attention on iR-Vision 2D Robotics course development and implementation at both Michigan Tech and Bay de noc Community College.

Current Robotics Curriculum at Michigan Tech and Bay de noc Community College

The project described in this paper is devoted to have a significant impact on the curriculum at both institutions - Bay College and Michigan Tech. During this collaborative initiative, a broad spectrum of educational materials is to be developed and made available between institutions for adaptation. Figure 1 depicts the proposed models in robotics curriculum development which will impact three different educational groups: 1) two- and four-year institutions; 2) students from other universities and community colleges, industry representatives, and displaced workers; and 3) K-12 teachers and high school students. There are several courses [4, 5] in robotics automation for two- and four-year degree institutions, as well as industry representatives that have already been developed via this partnership. These courses are: Real-Time Robotics Systems, Handling Tool Operation and Programming, and Robot Operations. Authors have already reported [4, 5] on these developments and therefore the detailed description of these courses has been omitted. Instead, authors will emphasize their attention on new courses in robotic vision. One course Robotic Vision Systems is developing to be introduced to the students of two- and four-year degree institutions, and the other alternative of this course, iR-Vision 2D, is designed to address industry needs with certification. Details of both courses are provided in the following sections after authors will address existing robotic courses, including vision, at the other institutions

Robotic Vision Courses at other Universities

In a recent research publication, a team at Oregon Institute of Technology has proposed to implement a course on vision systems with applications in robotics [6]. The main objective of their proposal is to broaden the interdisciplinary skills of manufacturing and mechanical engineers by providing the students with a software language that has basic functionality and tools that will help them learn the vision systems and implement vision technology in different applications. Northern Illinois University restructured their manufacturing automation course by introducing machine vision in their curriculum [7]. The course covers the basic principles of vision, camera systems, lighting, and image acquisition and digitization. In addition, students perform laboratory activities to have hands on experience in integrating and applying the vision techniques. University of Missouri – Columbia offers the course "Introduction to Mechatronics and Robotic Vision" [8]. The course focuses on: 1) mechatronic systems and their components; 2) the mathematical tools used to model industrial and mobile robots; and 3) vision sensors, their underlying models and the algorithms that allow us to control and interact with robots. The laboratory activities consist of MATLAB, C and/or C++ programming to control industrial and mobile robots using sensory information from cameras and guiding them to perform required tasks. At the end of the semester, the students will develop an entire system and compete in a game comprising of vision-guided robotics. Students at Robert Morrison University developed a vision-based work-cell for a screw sorting application [9]. Based on this work-cell, the team developed hands-on laboratory components for the automation and robotics course that will provide practical experience of setup wiring, robot programming, vision integration and implementation.

iR-Vision 2D Robotics Course Development

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. The new iR-Vision 2D Robotics course is designed as a 4 credit hour course (3 hours of recitation and 3 hours of weekly lab).

The course will introduce topics on:

- Safety, including laser safety;
- Basics of optics and image processing;
- Setting up lightning conditions required for the successful vision error proofing and camera calibration;
- Teaching tool, application, and calibration frames;
- Performing 2D calibration and 2D single and multi-view robotic processes;
- Performing 3D calibration and 3D single view robotic vision processes.

Hands-on training is an integral part of any course developed in the School of Technology at Michigan Tech, and this course is no exception. It includes 12 laboratory exercises, totaling 36 hours, with the goal of providing students the opportunity to configure and execute real-life, industry comparable, robotic vision scenarios. The course has rigorous assessment strategy and culminates in a two-hour certification exam. Students successfully passing the exam receive a *certificate in iR-Vision 2D* issued by the FANUC certified instructors. In addition to the traditional offering, two derivatives (a hybrid and 2-week intense version) of the *Robotics Vision Systems* will be developed and implemented.

iR-Vision 2D Robotics Course for Industry Representatives

While robots play a role in all STEM fields, robots are key components of most manufacturing industries – from health to automotive sectors. Robotic automation has been embraced as a way to stay globally competitive, and to reduce the reliance on manual labor to perform redundant tasks. If the US doesn't want to outsource, we need to automate. To provide support for the industry, educational institutions need to: 1) develop a training curriculum with industrial certification available to students from institutions where a robotics curriculum is not available; this will make those students more valuable in the job market; 2) provide effective, certified training to industry representatives who need to retool their skills to match rapidly developing technologies, especially in the field of robotics automation; 3) provide displaced workers with the opportunity to enhance, or acquire new, skills in robotics and enter the in-demand robotics job market. Certified curriculum development for all three categories is addressed in this paper.

Certification 1: Handling Tool Operation and Programming (32-hour course): The course [4, 5] is designed to be both practical and progressive. The content offers easily applied guidance to personnel involved in manufacturing with current robotic systems on site, or who may be asked to engage in implementing robotic systems in the near future. The course includes a discussion of scholarly and practical robotic topics ranging from kinematics and programming to practical application areas and economic concerns. Topics include: the development of industrial robotics; an overview of the mechanical design, control, programming, and intelligence; organizational and economic aspects; robotics in operation and various applications. Hands-on experience is an essential part of this course and will occupy 70% of course time. The lab exercises are devoted to practical aspects of programming FANUC Robotics robots. This 32-hour course is designed to be offered partially online. The first 16 hours are devoted to theoretical content delivered online. The remaining 16 hours provide extensive hands-on experience working in the lab manipulating and programming FANUC industrial robots. The course culminates in a certification exam in which the participants will have to demonstrate an understanding of theoretical background as well as the ability to program the robot for a task given by the instructor. Participants successfully passing the exam will receive a certificate issued by a FANUC-certified instructor. Due to the nature of the course, it can be offered on demand and conducted during weekends, students' breaks or in the summer.

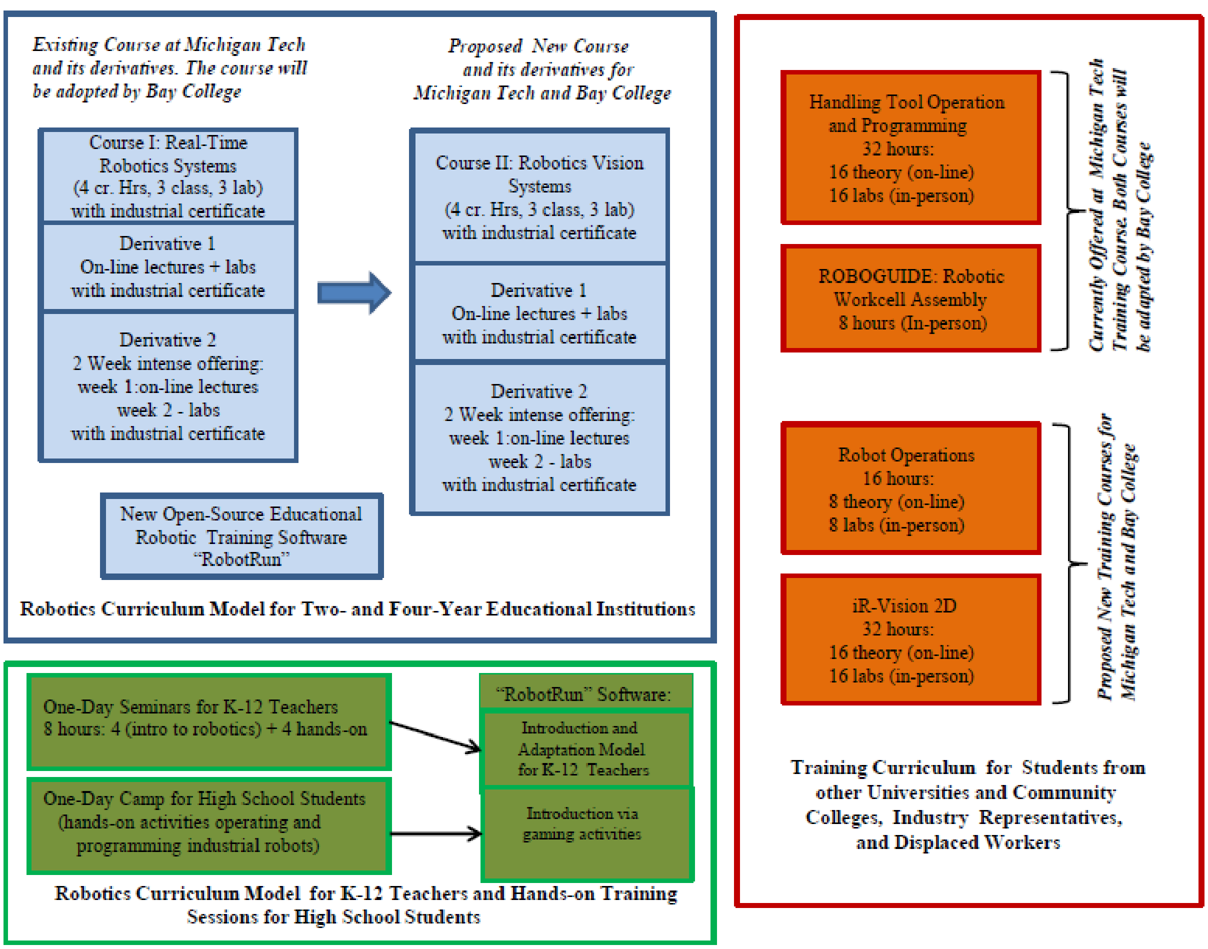

Figure 1: Proposed Robotics Automation Curriculum Development

Certification 2: Roboguide – Robotic Work-cell Assembly (8-hour course): FANUC Roboguide software is widely used in industry; therefore, there is a great need to train workers in this software. The authors have developed [4, 5] an 8-hour training course that provides participants with a foundation for understanding all software features. By the end of the course, students assemble a fully functional virtual robotic work-cell that includes the robot, end-effector, several fixtures and industrial parts that the robot can manipulate. Students program the robot to execute "pick and place" operation, run simulation in step-by-step and production modes, and compile a file that can be further transmitted to the physical FANUC robot for real-time production. This one-day training can be offered on demand and in conjunction with the other existing and under development certification courses.

Certification 3: Robot Operations (16-hour course): There is a great demand in the industrial sector for robot operators that don't necessarily need to have very in-depth programming and theoretical skills. This course [4, 5] is intended for the person who operates or may be required to perform basic maintenance on FANUC robots via the standard application software package. It will teach students how to safely power up, power down, jog the robot to predefined positions, and set up different frames of operation. In addition, it will cover tasks and procedures needed to recover from common program and robot faults, and teach basic programming skills. The course will not address the set-up and operation of specific software features and options nor will it teach in-depth programming skills. These are covered in the 32-hour Handling Toll Operation and Programming course.

Certification 4: iRVision 2D (32-hour course): This new course will teach students how to set up, calibrate, teach, test, and modify iRVision applications using FANUC robots. The course will include detailed discussion of hardware and software setup, establishing the communication link between the robot and teaching computer, teaching single- and multi-view processes, and programming. Safety procedures will be integrated into all exercises. As an integral part of this course, a series of lab exercises are developed to provide hands-on training to reinforce the theory the student has learned. This 32-hour course is designed with a structure similar to the Handling Toll Operation and Programming course: 16 hours of online and 16 hours of hands-on training. The course culminates in a certification exam in which the participants will have to demonstrate an understanding of the theoretical background, as well as, the ability to successfully set up, calibrate, program and utilize the FANUC robot equipped vision system. Participants passing the exam will receive a *certificate in iRVision 2D* issued by a FANUC certified instructor. Similar to the other certification courses, it can be offered on demand and conducted during weekends, students' breaks or in the summer.

Hands-on Training

The industrial automation laboratory at Michigan tech has four FANUC training carts each comprising of a FANUC LR Mate 200iC robot, R-30iA Mate Controller, Sony XC-56 camera, air compressor and a computer. These robots have an option for interchangeable end effector such as suction cups and 2-finger parallel grippers which are used in developing a variety of applications. The iRVision course offered to students at Michigan Tech consists of

12 lab exercises that help them gain hands-on training and experience with the FANUC iRVision 2D system. A scaled down version of the same set of lab exercises are used for the certification program for industry representatives. Following are the topics for the lab exercises:

- Camera And Lighting Concepts
- Camera Setup
- Frames
- 2D calibration
- Error Proofing
- 2D Single-View Process
- 2D Single-View Process: Pill Sorting
- 2D Single-View Process: Chips Sorting & Palletizing
- 2D Single-View Process: Battery Picking, orienting & Placing

The first few exercises begin with introducing the students to all the hardware and software components of the setup consisting of the camera, lights, Robot controller and iRVision software. Significant attention is given explaining the wiring and communication between the camera, robot controller and the computer. The above also includes the type of camera, connection ports, and explains the procedure to setup the camera. Setting up the camera allows the user to select the exposure time, type of mounting of the camera and attain different parameters such as image size, aspect ratio etc.. TCP/IP is the protocol used between the controller and the computer to communicate through the software and the hands on activity is designed to provide a stepwise procedure to achieve successful communication. After the communication is established, the user can access the software and learn the functionality of all the options on the graphical user interface of the software. Objects that will be used to be taught and further recognized by the robotic vision system are placed in the camera's field of view. The camera view is obtained via the robotic vision software and respectively displayed on the computer screen. The clarity of images can be improved by varying the contrast and the exposure time of the camera. These exercises help students to understand how the camera perceives images using pixels under different lighting conditions and apply this knowledge in future.

The next stage is to teach students the coordinate systems referred to as frames, related to the robot's and camera's environment. The three frames that affect the motion of the robot are world, user and tool frames. Using the teach pendant, a hand held device used to program and control the motion of the robot, these frames are taught to the robot and used in the procedure for camera calibration. Camera calibration helps in locating the position of the camera with respect to the robot world frame by implementing a calibration grid, a predetermined pattern of black circles drawn in a grid format, and helps determine different parameters such as focal distance, location etc..

After teaching the basics of setting up and calibrating the vision system the process of error proofing is introduced in the next session. "Error Proofing in automation relates to the ability of a system to either prevent an error in a process or detect it before further operations are performed [10].” It is widely used in the industry for various applications and can be performed on manufactured parts in a process, or can be used to monitor critical components of a process. Error Proofing technique identifies the presence/absence or orientation of parts, critical areas on a part, and is an economical way to perform quality checks. [10] “The Error Proofing Process requires no calibration and does not return any part offset that can be used to modify robot movement. It does, however, return a pass or fail dependent on criteria set by the user [10].” The process involves stepwise approach to teach different objects' location, orientation and size to the vision system. It uses the geometric pattern matching tool to teach the pattern of the object and this tool includes features like masking and emphasis area which help in identifying unimportant areas of the image or emphasize on important ones. Image recognition accuracy is expressed by a score threshold and the target object is successfully found if its score is equal to or higher than this threshold value. Based on the PASS and FAIL results of the error proofing process the user can use this data to program the robot.

Upon going through initial laboratory exercises described above, students obtain hands-on training on the basics of robotic vision, and become well accustomed to the vision system process. The next few sessions involve the use of 2-D single-view process with the camera in a fixed mounted position and different practical applications using the vision system are programmed on the robot. One of the exercises is a pill sorting application in which few pills of two different colors (red and white) are placed on a black background (Figure 2) and two empty bottles are placed on the side for collecting them. The main objective of this exercise is to recognize the differently colored pills using the vision system, and pick and place them into their respective bottles. The robot equipped with vacuum cup end-effector uses suction for the pick and place process. This exercise trains the students in differentiating between objects of the same size but different colors and improves their programming skills of using iRVision.

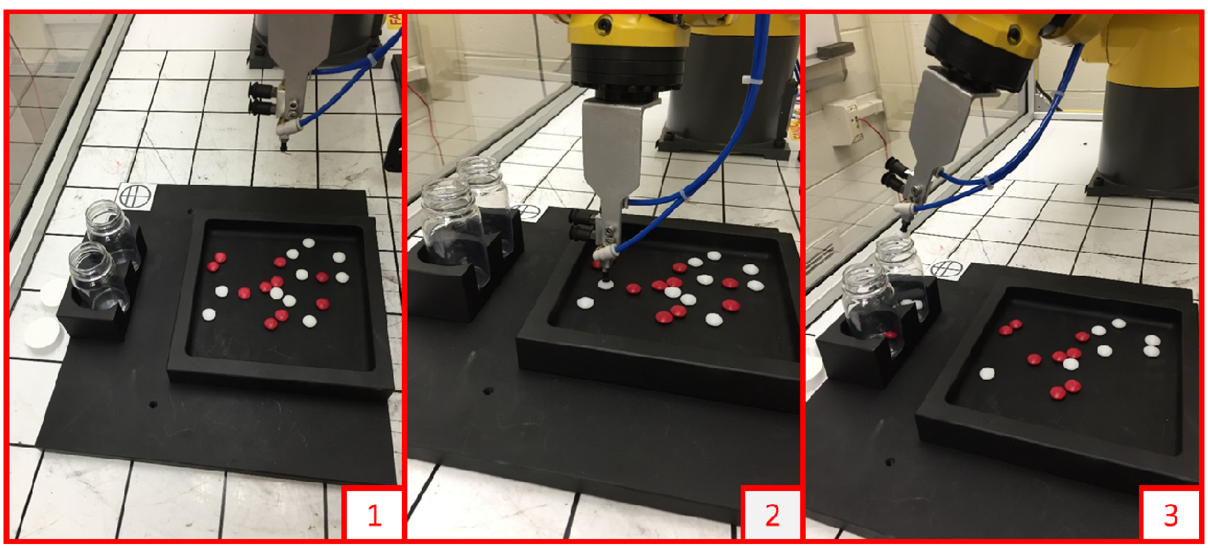

Figure 2: 1) Randomly placed red and white pills, 2) Robot pick up position, 3) White Pills drop position

Palletizing is a process of stacking products on to a pallet with a defined pattern of forming the stack. It is a widely used application in the industry, and the next lab exercise integrates the vision system techniques with the palletizing option installed on the controller of the robot. Round chips with different numbers printed on them are placed randomly, shown in Figure 3, on the base frame and each chip is taught as a different object pattern to the vision system. First program is written on the teach pendant to locate the position of these chips and pick them up using suction cups of the robotic end effector. A second program is written using a pre-installed option on the teach pendant called Palletizing EX. This option teaches the approach, pick up and place points to create a vertical stack of chips in a desired matrix format at pre-defined locations. The students use their programming skills to integrate the above mentioned programs and execute the desired objective.

The objective of the next lab is to recognize the position and orientation of a set of randomly placed batteries, pick them up one at a time, show the positive terminal of the battery to the camera to check for orientation of the battery and drop them in a given slot with the positive terminals of all the batteries on one side. The setup will be provided with the camera placed above the area and all the stepwise functions required to be complete the task are shown in Figure 4.

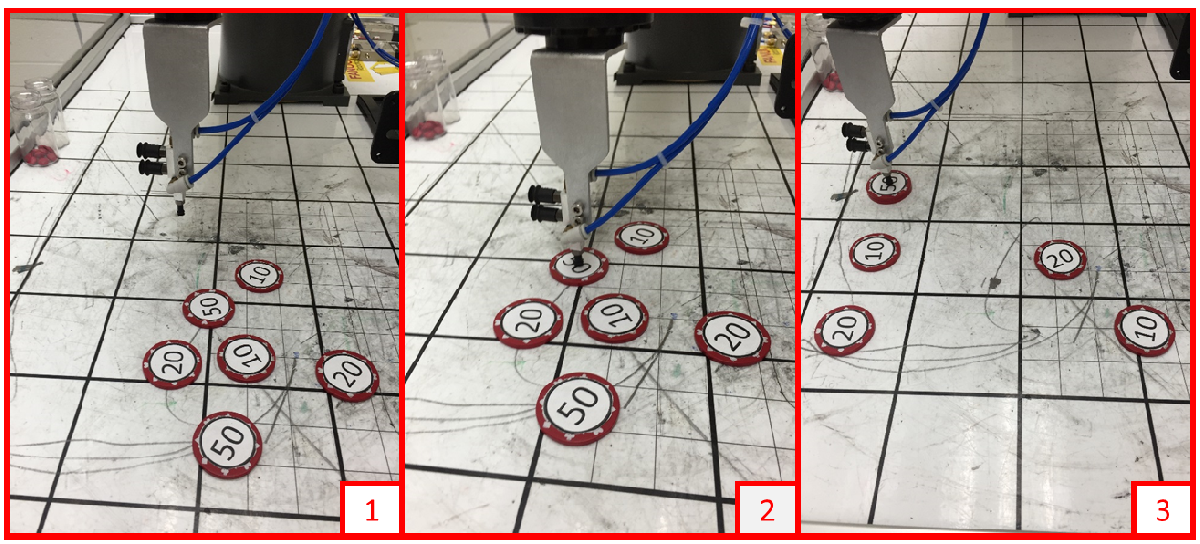

Figure 3: 1) Randomly placed numbered chips, 2) Robot pick up position, 3) Robot orients and places chips at corresponding positions

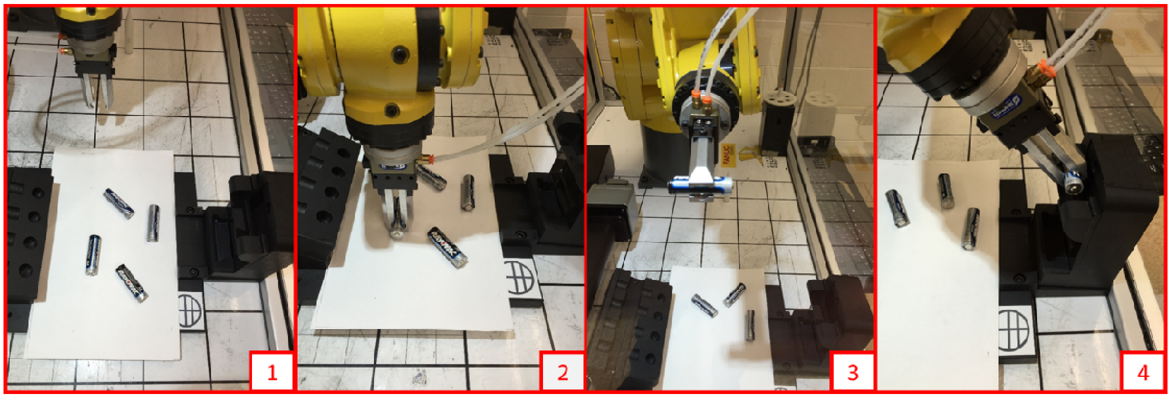

Figure 4: 1) Randomly placed batteries, 2) Pick position, 3) Orientation check position, 4) Drop position

Conclusion

The overall goal of the described in this paper is a collaborative project between Michigan Tech and Bay de Noc Community College. It is to help meet the nation's forthcoming need for highly trained Industrial Robotics workers.
Strategies include developing, testing, and disseminating an updated, model curriculum, laboratory resources, and simulation software package suitable for use in both 2- and 4-year EET programs. To complement this effort, outreach to K-12 students and teachers will work to enlarge the pipeline and diversity of students interested in careers in robotics. Programs will also be offered to students at other institutions and to workers in industry to broaden impact.

Described in this paper robotic vision curriculum development is geared towards not only students enrolled in the university program but also provides opportunity for industry representatives to re-tool their skills in robotics and automation. iR-Vision 2D course and its derivatives is designed to provide significant hands-on training in robotic vision systems and teach the skill that are very relevant to current industry needs.

Future Work

In addition to all described above hands-on activities aimed to provide in depth knowledge on the robotic vision systems, their configurations, and programming options, authors are working towards developing an industrial-like robotic work-cell, shown in Figure 5, consisting of three robots, a few photoelectric sensors, one conveyor, a programmable logic

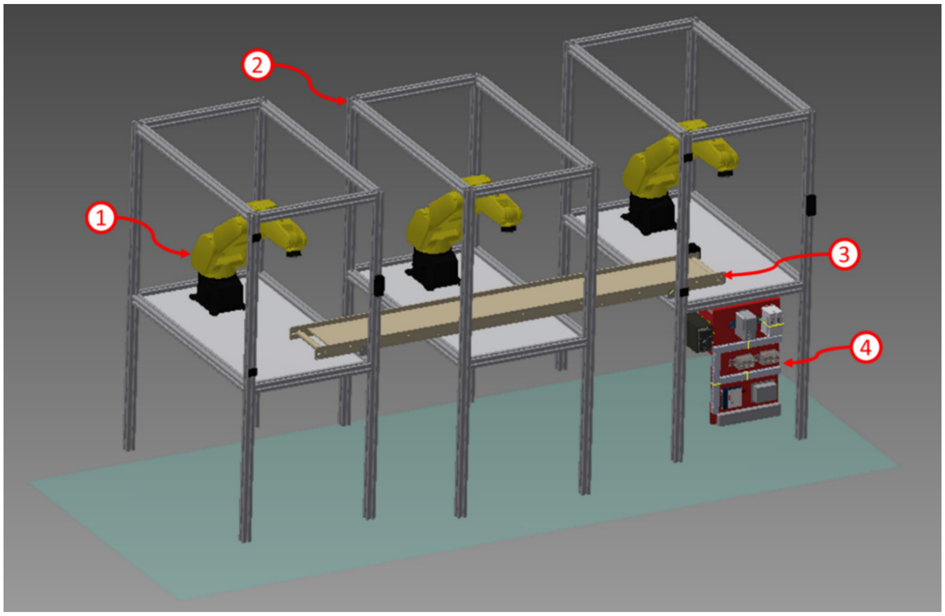

Figure 5: Future Robotic 1) FANUC LR Mate 200iC Robot, 2) Robot Training Cart, 3) Belt Conveyor, 4) Control Panel Board comprising of PLC and Variable Frequency Drive.

controller (PLC), a human machine interface (HMI) and three camera vision systems. Industrial automation applications generally involve all the above devices integrated in single a production or assembly line. The developing work-cell will provide students with an analogous working environment to the industry with the goal to enhance the students' real time problem solving abilities and skills. The design of the work-cell will be such that all the three robots are placed in a straight line parallel to each other and the conveyor will be placed in front of them. Sensors and camera positions will be decided based on the applications for the exercises.

The designed 3-robot industrial work-cell will provide with the opportunity to prototype wide range of industrial robotic automation scenarios. All the components of the system such as the conveyor and robots will be controlled using the PLC which will act as the master controller. The initial lab exercises will cover concepts of teaching all connections and wiring of the complete setup. The next several laboratory sessions will be devoted to creating an assembly line where all the robots will perform different functions at their respective stations. Vision systems installed above the conveyor will help detect the position and orientation of the parts that are moving from one end to the other. The students will be tasked to create various programs for all the robots and run these programs using the master PLC. When the parts arrive at their respective stations the conveyor will stop and the vision system will guide the robot to pick up the parts and perform its operation. Further plans are to design and incorporate into the robot multi-cup end effectors to pick up multiple objects from the conveyor at once and place them at the desired location. A wide variety of applications can be created using this setup and students will have a wider scope to solve different problem statements as a part of the course project.

Acknowledgement

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Biographies

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