Promoting Industrial Robotics Education by Curriculum, Robotic Simulation Software, and Advanced Robotic Workcell Development and Implementation.

A.Sergeyev[1*], N. Alaraje[1], S. Parmar[2], S. Kuhl[3], V. Druschke[3], and J. Hooker[3]
[1]Electrical Engineering Technology – [2]Mechanical Engineering Department – [3]Computer Science Department
Michigan Technological University
Houghton, MI, USA
[*]avsergue@mtu.edu

***Abstract*—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. This 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 order to effectively teach concepts of industrial robotics, the curriculum needs to be supported by the hands on activities utilizing industrial robots or providing training on robotic simulation software. Nowadays, there is no robotic simulation software available to the academic institution at no cost which limits educational opportunities. As part of the NSF sponsored project, team of faculty members and students from Michigan Tech are developing new, open source "RobotRun" robotic simulation software which will be available at no cost for adaptation by the other institutions. This will allow current concepts related to industrial robotics to be taught even in locations without access to current robotics hardware. In addition, to teach emerging concepts of robotics, automation, and controls, authors present the design and development the state-of-the-art robotic workcell consisting of 3 FANUC industrial robots equipped with robotic vision system, programmable logic controller, a conveyer and various sensors. The workcell enables the development and programing of various industry-oriented scenerious and therefore provide students with the opportunity of gaining skills that are relevant to current industry needs.**

Keywords—Industrial robotics; simulation software; robotic workcell; automation; controls, programmable logic controllers.

I. 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. On the other hand, 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. From 2014 to 2016, robot installations were estimated to increase about 6% a year, resulting in an overall 3-year increase [1] of 18%. 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]. 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, automation and controls as well as promoting new software and hardware tools geared to advancing the robotics education.

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A. *Workforse Need*

In 2014, ManpowerGroup surveyed nearly 40,000 employers across 41 countries and territories as part of its annual Talent Shortage Survey [4] and identified that employers are having the most difficulty finding the right people to fill jobs in Japan 81%, Brazil 63% and the US 40%. In fact, two occupations in the US: technicians and engineers top the list of 10 jobs employers have difficulty filling. In addition, the American Society for Training and Development (ASTD) reports major skill gaps in the US. The 2013 ASTD report states that US organizations spent ~$164.2 billion on employee learning [5] in 2012. The US is facing an alarmingly high replacement need for STEM professionals [5, 6]. For instance, the projected replacement rate in mathematical science is 29.5%, in physics it is 28.5%, in mechanical engineering it is 26%, and in electrical engineering it is 23%. It is estimated that during this decade, employers will need to hire about 2.5 million STEM workers, drawing largely from engineering and engineering technology programs that are known for equipping graduates with the tools to enter the workforce, for the first time, prepared [7, 8]. This requires an innovative curriculum that involves hands-on opportunities for practical problem solving. The educational institutions should quickly and effectively respond to this alarming demand in qualified and well educated workforce.

B. *Educational Need*

Robotics is a great tool to promote STEM fields. Educators have been making measurable progress toward improving STEM education from primary to tertiary levels of education, but challenges remain. Given the current shortage of student interest in STEM education, increased attention has been given to the appeal and attraction of Robotics. The novelty of robotics is instrumental in attracting and recruiting diverse STEM students. In the classroom, robotics can easily be used to introduce a variety of mandatory skills needed to pursue a variety of STEM career paths [9-12,17,19]. More specifically, a robotics platform advances students' understanding of both scientific and mathematical principles, develops and enhances problem-solving techniques [9,13,15-18] and promotes cooperative learning [12-14]. While robotics can be used as an interdisciplinary STEM learning tool, there is also a strong need for industrial certification programs in robotics automation. More and more robots are designed to perform tasks that people may not want to do, such as vacuuming, or are not able to do safely, such as dismantling bombs. Millions of domestic/personal robots are already on the market worldwide, from lawn mowers to entertainment robots [20]. As a result, popular interest in robots has increased significantly [20-23]. Global competition, productivity demands, advances in technology, and affordability will force companies to increase the use of robots in the foreseeable future. More than ever, trained and certified workforce is on demand to maintain and monitor existing robots and to develop more advanced robotic technologies.

II. Robotics Automation Curriculum at Michigan Tech

Michigan Tech has built a very strong, multi-faceted curriculum in Robotics and Automation. Fig. 1 depicts in-place and developing course work for two- and four-year institutions, high school teachers and students, industry representatives, and displaced workers. The block at the upper-left corner shows two courses: 1) Existing Michigan Tech, and project partner - Bay de Noc Community College, Real-Time Robotics Systems course and its derivatives and 2) new course in Robotics Vision. The block on the right side demonstrates training curriculum for students from other universities and community colleges, industry representatives and displaced workers. The block at the bottom-left corner outlines a robotics curriculum model for K-12 teachers and hands-on training sessions for high school students conducted as part of this NSF sponsored project. In the previous publications, the authors have provided a very detailed description [29-33] for all the curriculum models, industry certification classes, and K-12 outreach activities depicted in Fig. 1 and therefore this information is omitted here. It is the authors' intention to focus this paper on the developing state-of-the-art "RobotRun" robotic simulation software and advanced, 3-robot, controlled by handshaking protocol, robotic workcell.

A. *"RobotRun" Robotic Simulation Software*

The RobotRun software is an industrial robotics simulator which simulates the core aspects of using a real robot. The software is free and open source and is aimed individuals and students who are interested in learning about robotics, but lack access to an expensive industrial robot or access to costly commercial robot simulator packages. The software was developed to aim for usage by the high school, community college, and university classroom environment to introduce students to robotics in an accessible way. The software includes a realistic teach-pendant that controls the robot in a way that is similar to how real robots are operated. The core of the software support different coordinate frames, collision detection, programming features, end-effectors, and the interactive creation of objects that can be added into the environment for the robot to interact with. We are currently working on providing predefined scenarios which will allow the user to create a specific environment aimed at teaching a particular skill with a click of a button. The simulator is written in Processing, a Java-like language that supports multiple platforms. Current beta versions of the software is available online at http://www.cs.mtu.edu/~kuhl/robotics/. The key features currently implemented in the beta version of the software are discussed next.

<u>End Effectors:</u> The robot has a set of attachments, which can be fastened onto the robot's faceplate: the suction, claw gripper, pointer, glue gun, and wielder end effectors.

<u>Frames:</u> The industrial robots operate in different coordinate systems - frames such as world, user, tool, and jog. Frames are used to configure special types of motion commonly used in industrial settings. Some of the frames are predefined and some can be user configures. User frames are comprised of an origin point and a set of three orthogonal unit vectors, which represent the X, Y, and Z axes. A tool frame consists of an offset vector, which defines the frame's tool tip position with respect to the robot's faceplate position, and the three

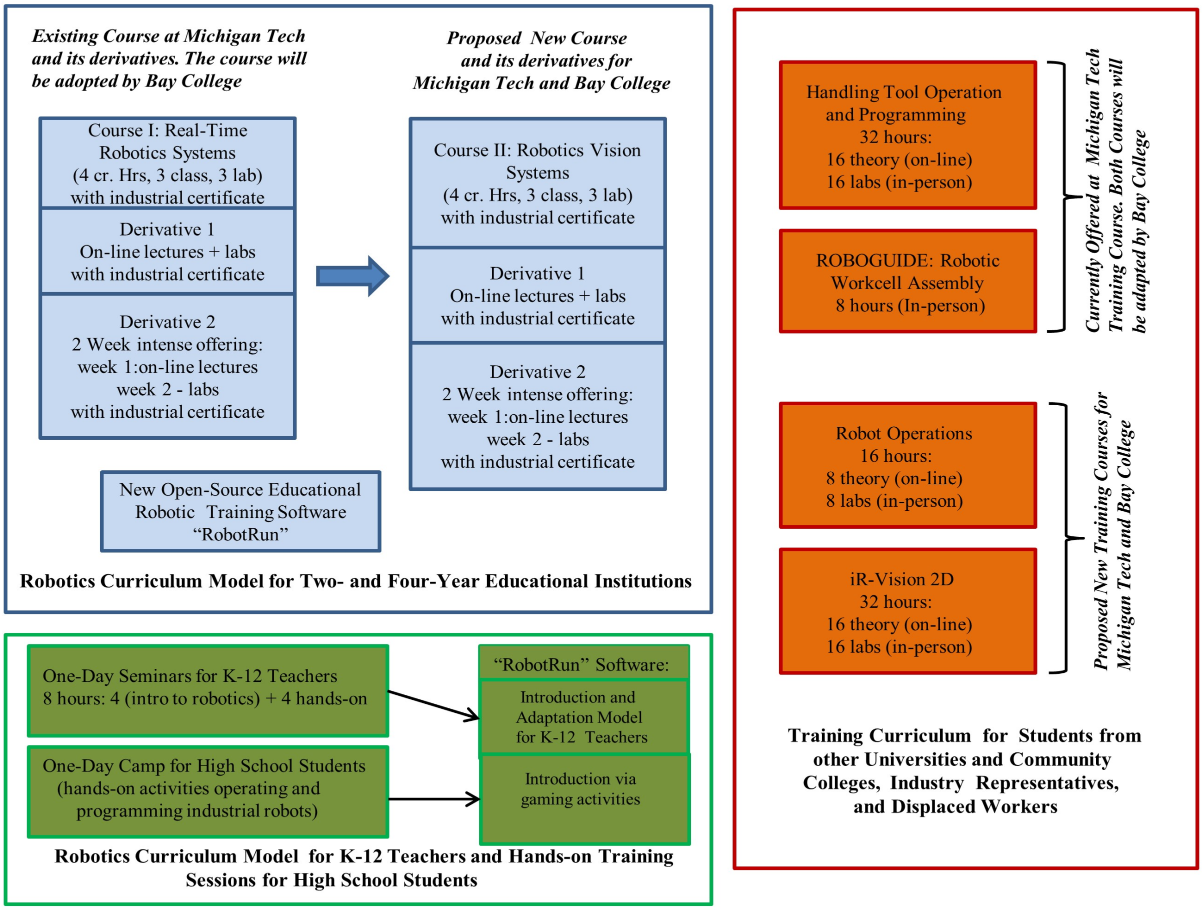

Figure 1: Robotics Automation Curriculum at Michigan Tech

orthogonal unit vectors that define the axes of the frame. The user can define ten user frames and ten tool frames. The tool frames axes function strictly as alternative coordinate systems, in which the robot can jog, to the world frame. Though, positions saved in a program are saved with reference to the tool tip of the active tool frame, they are never saved with reference to the active tool frame's axes. Yet, points are saved with reference to the active User frame's origin and axes, or the world frame in the case that no user frame is active. A tool frames can be taught with the three-point, six-point, and direct entry method. A user frames can be taught with the three-point, four-point, and direct entry methods. Points are taught in the normal fashion: jog the robot to a position and save the values of the robot's position with the teach pendant. The points are color-coded based on the point's relation to the teaching method. In the example shown in Fig. 2, the three tool tip points are shown as the gray points (1, 2, and 3), the orient origin point is orange (4), the x-direction point is red (5), and the y-direction point is light green (6). This example only lacks one type of teach point: the origin point, which is only taught in the user frame four-point method and appears blue in the world environment. Additionally, the user can move to a taught point using the teach pendant. Since every frame stores the last value of each teach point associated with the frame, a taught point can be referenced at any time by the user until it is overridden by another value. Alternatively, the direct entry method can explicitly specify a frame. The user can navigate between the different values of the frame entry with the arrow buttons and use the number pad on the pendant to input each value before confirming the entry. Similar to the taught points of a frame, the last direct entry specified for a frame is saved independent of the current value of the frame, and will appear, when the user returns to the direct entry method of that frame again. The software allows the user to control where the end-effector should jog, at what speed and type of motion termination, how many times it should repeat the movement and other common robotics controls. Besides the option of jogging the robot and performing programming tasks, the software can be configured to present users with different scenarios that mimic real-world industrial scenarios such as pick and place, palletizing, welding, painting, etc. The program also allows users to load and save their programs so that they can turn them in to an instructor for grading. This new software provides all of the options necessary to teach required skills in robotics handling tool operation and programming in a simple and intuitive fashion, but omitting all the unnecessary features of expensive robotic simulation software packages designed for in-depth industrial simulations that are not typically used in educational settings.

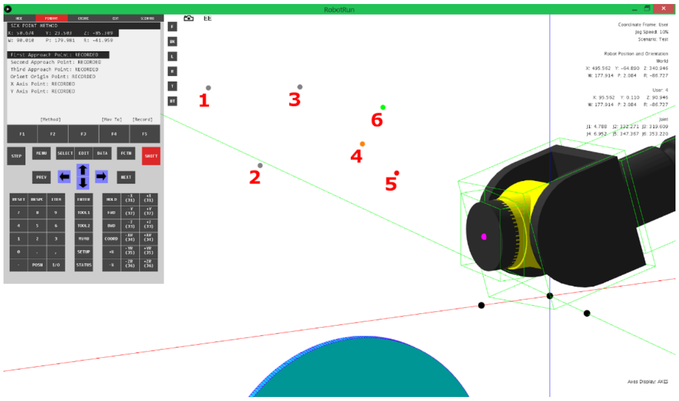

Figure 2: Screenshot of six-point method display

World Objects: The user can create two classes of world objects: parts and fixtures. The main difference between parts and fixtures is that the robot can only interact with parts; fixtures are coordinate frame references for the parts of a specific workcell. The world objects have two basic forms: boxes and cylinders and complex objects can be imported into the program as well. Cylindrical and box-like objects require dimension specifications, while complex objects require a .stl source file and scale value. As their name suggests, complex objects offer the user the ability to define more complex shapes, which allow the robot to perform more practical tasks. Furthermore, each object has a unique name and a color scheme consisting of an outline color and fill color, so that they can be easily distinguished from one another. Additionally, the user may also manually specify the position (x, y, and z) and orientation (w, p, and r) of a world object after the object is created and revise its orientation and position whenever necessary. As mentioned before, fixtures can replace the world frame as a part's coordinate frame reference. So, the position and orientation of the part would be with reference to the fixture's local coordinate system.

Programming Features: The user utilizes the teach pendant interface to create, view, edit, and delete programs, to manipulate robot state information, including robot position, end effector state, internal register values, and coordinate frames. Programs are composed of a sequential list of instructions that are executed in-order, beginning either at the instruction currently selected by the user, and ending at the last instruction. The program instruction set includes a number of different instruction types, including movement instructions to modify the position and orientation of the robot end effector; register modification instructions for I/O, floating point, and position registers; and control flow instructions in the form of conditional constructs ('if' statements), switch statements, labels and jump label instructions, and function calls. Each instruction has a number of individual fields that the user can modify as well.

Motion instructions include fields for manipulating motion type, specifying a locally or globally scoped position to move to, specifying which position index to move to, manipulating the robot's movement speed during the motion, and manipulating smooth interpolation between the current and next point. Supported motion types include joint motion, where movement is performed by simultaneously rotating each joint to a specified angle; linear motion, where inverse kinematics is used to trace a straight line path from the end effector starting point to its destination; and circular motion, which adds an additional point to the movement instruction and traces the robot's end effector in a circular arc that passes through its starting, intermediate, and end points.

Register instructions allow the user to provide a register of any type and an expression to be evaluated at runtime, the value of which will be stored in the given register if the expression returns a compatible, non-null data type. Register statements can perform operations on Boolean, floating point, and positional1 data, and each of these data types correspond to I/O, data, and position registers, respectively; non-matching data types cannot be stored in a register of that type. If an operation is performed on incompatible data types, or if one of the expression elements is uninitialized, the expression will return null, execution will stop, and an error will be generated to notify the user.

Conditional statements also allow the user to define an expression or to compare two expressions' values; the statement will then execute a jump or call instruction only if the value of the expression or comparison evaluates to true. Case statements can also be used to specify conditionally executed instructions, and accept a data register as an argument; if the data register matches any of the case values specified, the instruction associated with that case is executed.

Label and jump instructions are used to arbitrarily manipulate program control flow. Labels are placed into programs as a normal instruction would; a jump instruction to that label then moves execution to wherever the specified label is in the program, and the next instruction is considered to be the instruction immediately following that label. Different labels are identified by numerical IDs, and each label must have a unique ID to ensure that any jump to that ID is not ambiguous.

Call instructions can be used to move execution to another program entirely. A call to a given program will begin executing that program, in its entirety, from its first instruction, and will return execution to the instruction immediately after the call instruction in the calling program once the call is finished executing. By using a combination of movement, register, and control flow operations, the user can specify arbitrarily complex behavior in the robot to complete a variety of tasks.

B. *Application Scenerious*

The software features discussed above are powerful enough to simulate basic robot functioning required to create applications similar to the ones that can commonly exist in industrial settings. Robots are being used drastically across the automation industry for material handling, manufacturing and assembly operations. Efforts have been made to create scenarios that replicate these operations and provide the user with a strong foundation of using the different features of the software. Following are the scenarios created using the developed "Robotrun" software.

Pick and place objects from multiple stations:
The objective of this scenario is to teach the user to create a robotic workcell, shown in Fig. 3, using different fixtures and parts, learn to operate the robot to pick and place parts on fixtures and create a simple program to record different positions to run the simulation process. Two parts are moved around three fixtures in a cyclic manner picking one part at a time using a vaccum cup selected from the set of tools. The programming involves recording pick and place positions and using I/O instruction to turn the vacuum end effector on and off.

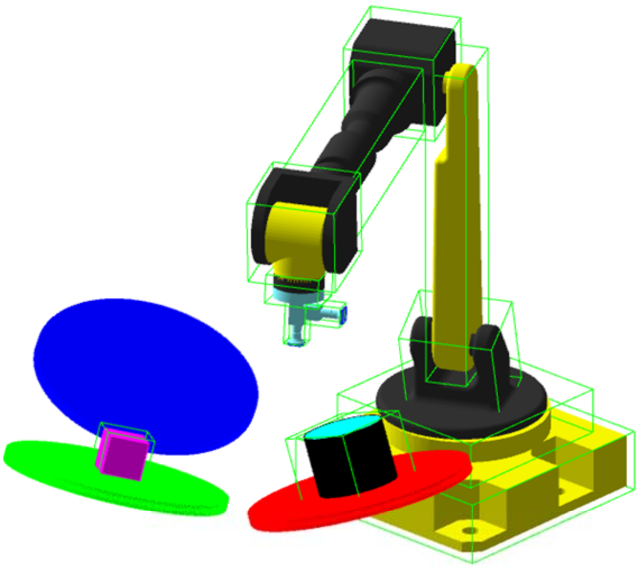

Fig. 3 Workcell created to pick and place the box and cylinder on the **fixtures in a cyclic manner.**

Grinding a part using tool frame and creating a user frame:
A crooked shaped part is attached to the robot face plate as shown in Fig. 4 and the conical surface of this part is required to be grinded. While creating the workcell the user creates a cylindrical object representing the grinding wheel. The application demands the user to create a tool frame with the axis of rotation along the pointed tip utilizing the six-point method. Creating this tool frame helps the user understand the simplicity and comfort of performing this operation. The user frame creates a separate frame of reference for the robot motion. The user inserts a rectangular surface in the robot's environment and provides it a random orientation. The task is to create a frame of reference using the edges of this surface. When the user has successfully created the user frame the user can jog the robot along the edges of the rectangular surface.

Welding application for sheet metal using circular instruction:
There is a sheet metal part available in the software library that is imported twice in the workcell and oriented as shown in Fig. 5. The end effector used for this operation is a welding gun and user's goal is to teach the robot to move along the line joining the parts in order to accomplish a uniform welding pattern. To accomplish this task, the user first creates the tool frame using three-point method and then uses the circular instruction to program the robot to move in the circular paths. The scenario provides the user another important application of tool frame while performing this task avoiding the collision of the robot with the parts.

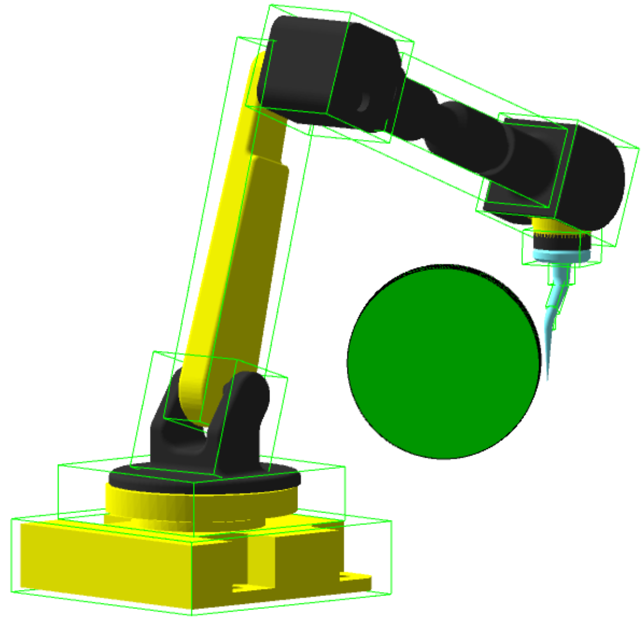

Fig. 4: The robot is shown with the part that is grinded on the grinding wheel by rotating using tool frame created.

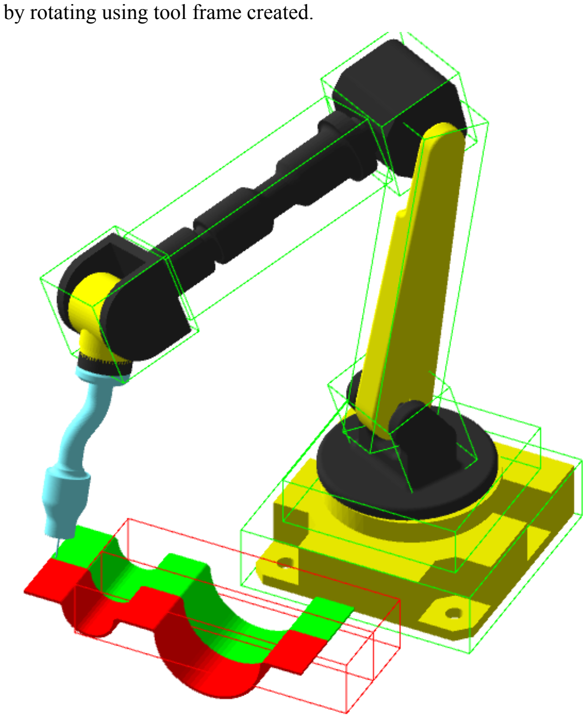

Fig. 5: Welding two sheet metal parts along the path requiring linear and circular motion.

Gluing application using position registers and Offset instruction:

Gluing is generally performed by the robot by moving in a zigzag motion along the length of a part. The user inserts a rectangular sheet in the workcell, as shown in Fig. 8, and uses the glue tool to perform this task. The robot has to perform this motion along the length of the sheet, offset by a certain value along the breadth and repeat the zigzag motion along the length. Firstly, as the robot moves along the rectangular sheet, the user creates a user frame using four-point method. To smartly program this motion the user implements position registers and records the start position in the program. The values of this position register are used to create equations and move the robot to new positions. The offset instruction offsets the value of the position by a certain value and highly simplifies the efforts of programming. There are few other interesting scenarios that include the usage of copying and pasting feature, macro and register equations. All scenarios have been developed with the purpose of highlighting the features by relating them to real time applications. After the completion of these scenarios, the user would have excelled in implementing basic programming of robots with good understanding of using different features for different applications.

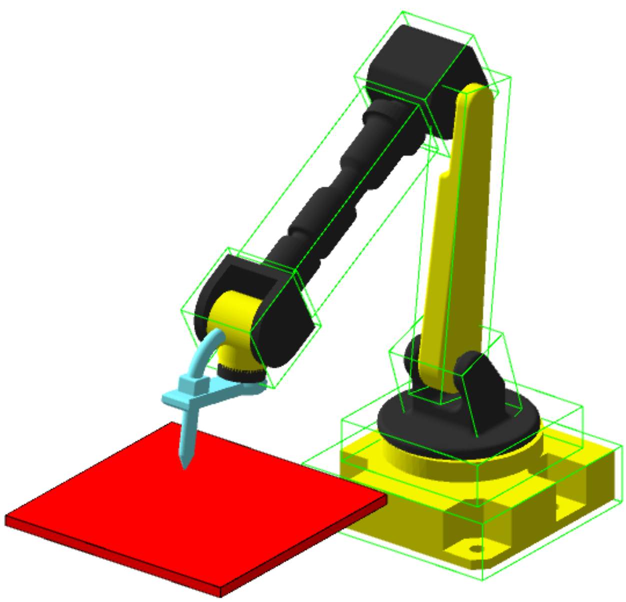

Fig. 6. Applying glue on the rectangular sheet in a zigzag manner over the complete area using register and offset instructions.

III. Robotic Workcell

The industrial automation laboratory at Michigan Tech incorporates three 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 further. Fig. 7 depicts the overall layout of the integrated robotic workcell.

Conveyer System:

The conveyor system, shown in #3 of Fig. 7, 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.

Vision system and sensors:

The vision system 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. 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 that consist of an emitter 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.

Control Panel and PLC Setup:

The control panel consists of the Allen Bradley PLC (Model No. 1769-L32E) with one input and 3 output modules, conveyor VFD and Omron switch mode power supply. 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 control 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. 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. Using the digital I/O 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

A. Application Scenerious

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 Fig. 7.

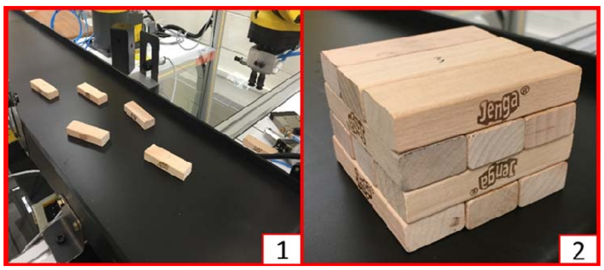

Figure 1. 1) Randomly placed Jenga blocks travelling on conveyor 2) Final Pallet formed **by the robot**

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 Fig. 8, 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).

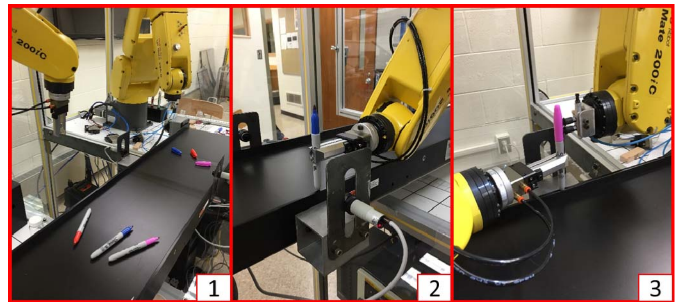

Figure 1. 1) Inital setup with open markers and caps 2) Robot 2 picks the open **marker and places** it for assembly 3) Robot 3 assembles the cap on the marker

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 Fig. 9, and sends signal to the PLC that it has completed its task.

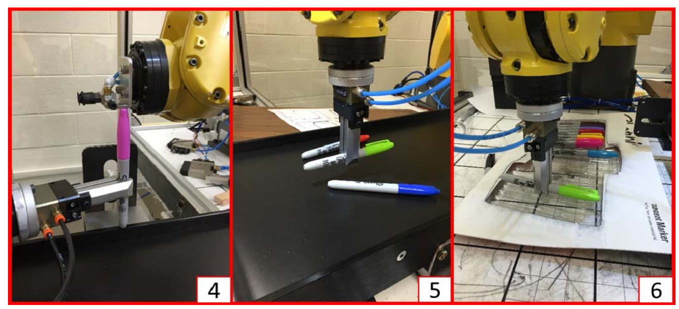

Figure 1. 4) Robot 3 tightens the cap by pressing it on the marker 5) Robot 1 picks the assembled marker 6) Robot 1 places the assembled marker on the tray

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.

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

Development of an advanced, industry-driven, hands-on educational curriculum in robotic automation and controls will improve the quality of STEM education for EET students at two- and four-year institutions. The developed "RobotRun" software is now freely available for adaptation by the other institutions and individual learners, industry representatives and displaced workers, which allows to learn concepts of industrial robotics even when the purchase of industrial robots is not feasible. The software seeks to provide industrial robotics education opportunities in a way that is useful and accessible to students and teachers alike. The software features a teach pendant system that resembles real-world robots. By creating a realistic learning environment and providing features that will help educators, such as built-in screen-recording and audio recording features, we hope that this system will help increase the amount of robotics education opportunities in K-12 and higher education settings. Automation system integrators often design the manufacturing or assembly lines with multiple robots and advanced control systems. The design of the workcell outlined in this paper 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 control 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. 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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