Introducing an Industrial Robotics Course to Manufacturing Engineering Program at GSU

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Introduction

Manufacturing in North America is experiencing a significant jump in "Bring manufacturing jobs back to the United States." Many products such as electronics components, mechanical parts are being manufactured in the U.S. again.[1,3] Today, industrial robots are widely used in many manufacturing factories. They can help manufacturers become more competitive and efficient. The most obvious impact of industrial robots is that they eliminate many dirty, repetitive, and dangerous tasks with hazardous materials and in challenging environments. The Manufacturing Engineering Department at Georgia Southern University (GSU) has been involved in a continuous effort to introduce new industrial robotics and vision system courses in manufacturing engineering laboratory and curriculum. The purpose of Industrial Robotics course is to respond to the demand for Georgia regional industries and meet 21st Century Workforce needs. This course includes several new lab activities and projects to provide students hands-on experience. The selected industrial robotics topics are (1) pick-and-place, (2) stacking and sorting, (3) robotic palletizing, and (4) robotic machine tending. The manufacturing engineering curriculum developing also involves the integration of previous laboratory activities with new projects on existing and new equipment.

Overview of Manufacturing Engineering Program at GSU

Georgia Southern University is the state's largest and most comprehensive center for higher education south and east of Atlanta[14]. GSU has been granted the first undergraduate manufacturing engineering program in the state of Georgia, and in fact, there is no similar program within a 500-mile radius of the Georgia Southern campus[1]. The introduction of industrial robots into manufacturing engineering program at GSU not only can enhance students' hands-on practices and real world experiences, but also motivates them to pursue advanced research and education in robotic vision, simulation, and off-line programming[1]. Industrial robotics hands-on experience plays a key role in manufacturing engineering education. It is a useful tool for student learning, as well as for encouraging participation in class learning and research outside the classroom. In general, industrial robotics course can be integrated with the manufacturing engineering program curriculum in three different courses (See figure 1). The first course is manufacturing automation class that is specifically designed to teach students how to program different industrial robots. The second course is Computer Integrated Manufacturing (CIM) class that is designed to teach students how to integrate industrial robots into a production system. The third course is advanced level programming classes or other specific topics such as robotic simulation where robotic projects can be used to facilitate the real-world experience for the students and motivate their interests in the various topics.

Industrial Robotics Course Overview

Industrial Robotics course is commonly found in many Manufacturing Engineering programs in the USA[2]. This course includes coverage of robot programming and often utilize robot motion simulation software such as ROBOGUIDE 8.0, WORKSPACE 4.0. Many Manufacturing

Engineering curricula include both Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) and Robotics course. The course focuses on different robotic work cell designs and manufacturing process analysis, which often involves several design and development issues and theoretical concepts. Here is a table which shows teaching and learning topics for industrial robotics course in manufacturing engineering program at GSU (see Table 2).

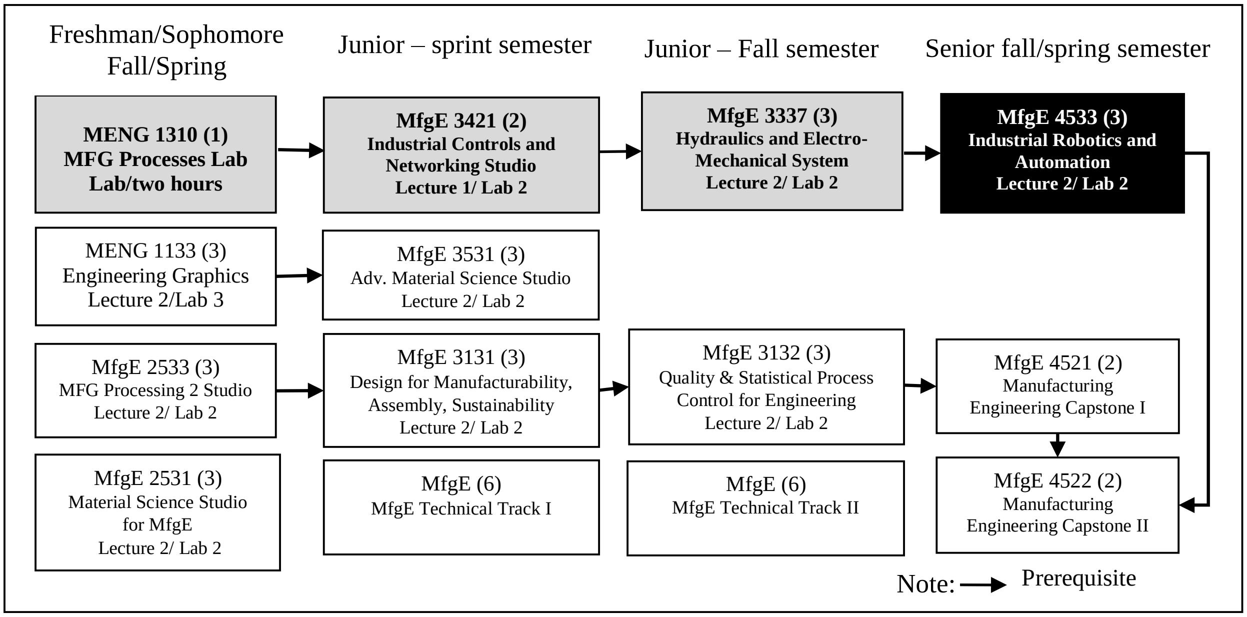

Figure 1 – GSU Manufacturing Engineering – program of study (Partial view)

Table 2 – Learning Topics and Lessons for Industrial Robotics Course

Topics	Lessons	Learning Outcomes
Fundamentals of Robotics	1. What is an Industrial Robot? 2. Characteristics of an Industrial Robot 3. Manipulator Configurations (number of Axes) 4. Robot Coordinate Systems (Ex. World, Joint) 5. Repeatability, Precision, and Accuracy 6. Industrial Applications of Robotics 7. Advantages and Disadvantages of Robots	1. Define an Industrial Robot 2. Identify robot configurations 3. Describe the operating principles of an Industrial Robot 4. Recognize Robot degrees of freedom 5. Identify six factors which should be considered when selecting an Industrial Robot 6.Differentiate between robot links and joints
Components of an Industrial Robot	1. General components of an Industrial Robot 2. Types of Actuator Drive 3. Tool frames and user frames 4. Work-Envelop Geometries 5. Sensor Areas for Robots 6. Motion Control Methods	1. List the main components of an industrial robot 2. Identify four types of actuators 3. Name two types of robot arms 4. Name the two most popular types of drive systems used in Industrial Robots 5. Define point-to-point control 6. Describe three characteristics of a continuous path robot 7. Differentiate between servo and non-serve control systems
Manipulators and End-of-Tooling	1. Characteristics of End-of-Arm Tooling 2. Calculating Gripper Payload and Gripper Force 3. Manipulator Power Supplies 4. End Effectors and Grippers Design	1. Determine tool length using a tool center point (TCP) 2. Name the most common type of manipulator 3. List six end effectors used in Industrial Robotics 4. Name the three types of revolute joints
Robot Programming	1. Robot Programming Methods 2. Online and Offline Programming 3. Programming Languages 4. Types of Programming 5. Voice Recognition	1. Name the two major categories of robot programming 2. Differentiate between teach pendant and offline programming 3. Identify five different types of motion instructions 4. Describe the most popular type of robot programming language 5. Explain how program touch-up is used when programming
Robotic Applications	1. Integrating Industrial Robots into the Manufacturing Process 2. Industrial Applications of Robotics 3. Justifying the Cost of Robots 4. Robot Safety and Maintenance	1. Describe the most Common Application for Industrial Robots 2. List eight Applications for Industrial Robots 3. Identify the three most common functions performed by inspection robots 4. Differentiate between robot handling and assembly 5. Define the term Palletizing

Bloom's Cognitive Domain vs. Industrial Robotics Learning Modules

In 1956, Benjamin Bloom created a taxonomy of cognitive development levels[10].They are (1) B1- Knowledge, (2) B2 - Comprehension, (3) B3 - Application, (4) B4 - Analysis, (5) B5 - Synthesis, and (6) B6 – Evaluation. These six levels of cognitive development help us describe and classify observable learning outcomes, knowledge, skills, behaviors and abilities. By creating industrial robotics learning modules using measurable verbs (see Table 3), we indicate explicitly what the students must do, complete, and demonstrate student learning outcomes and thinking skills.

Table 3 - Mapping Learning Modules into Bloom's Taxonomy of Cognitive Development

Level of Taxonomy	Bloom's Taxonomy Verbs	Industrial Robotics Learning Modules	Thinking skills
B1: Knowledge - To recall or remember facts without necessarily understanding them	Define, list, name (label), count, order, assign, record, recognize	Module 1: **Define** an Industrial Robot Module 2: **Recognize** Robot degrees of freedom Module 3: **List** the main components of an industrial robot Module 4: **Name** two types of robot arms Module 5: **Name** the two major categories of robot programming Module 6: **Define** point-to-point control	Lower Order Thinking Skills
B2: Comprehension - To understand and interpret learned information	Identify, indicate, classify, discuss, locate, explain, review	Module 1: **Identify** robot configurations Module 2: **Identify** six factors which should be considered when selecting an Industrial Robot Module 3: **Identify** four types of actuators Module 4: **Identify** five different types of motion instructions Module 5: **Identify** the three most common functions performed by inspection robots Module 6: **Explain** how program touch-up is used when programming	
B3: Application - To put ideas and concepts to work in solving problems	Determine, apply, construct, operate, select, practice, sketch, use, solve	Module 1: **Determine** tool length using a tool center point (TCP) Module 2: **Describe** three characteristics of a continuous path robot	
B4: Analysis - To break information into its components to see interrelationships and ideas	Analyze, calculate, categorize, test, examine, inspect, question, differentiate contrast	Module 1: **Analyze** Collision situation Module 2: **Differentiate** between servo and non-serve control systems Module 3: **Differentiate** between manual and offline programming Module 4: **Differentiate** between robot handling and assembly	Higher Order Thinking Skills
B5: Synthesis - To use creativity to compose and design something original	Create, design, develop, collect, formulate, propose, compose	Module 1: **Create** and **Generate** offline path generation Module 2: **Design** appropriate robotic work cells for different manufacturing processes	
B6: Evaluation - To judge the value of information based on established criteria	Evaluate, appraise, assess, judge, justify, value, select	Module 1: **Evaluate** and Visualize Manufacturing Processes Module 2: **Optimize** different process cycle times	

Learning Outcomes for Industrial Robotics Course

Upon completion of the course, the students will be able to perform all the following outcomes:

1. Select an appropriate robot type for a specific manufacturing application.
2. Plan robot motions and paths
3. Create, modify, and execute different robot programs (Ex. FANUC, Mitsubishi)
4. Create MACROs and subprograms to conduct recurring (repetitive) tasks
5. Use robot inputs and outputs to control operation sequence
6. Design and develop a robotic work cell system for a specific manufacturing application
7. Troubleshoot and recover from common robot program errors and faults

The above table of learning modules contains six different levels of cognitive domains. In the learning process, critical thinking involves logical thinking and reasoning including skills such as creating, analyzing, designing, and comparison. Creative thinking involves creating and generating something new. It also involves the skills of brainstorming, modification, attribute listing, and originality[10]. The purpose of creative thinking is to stimulate curiosity among students and promote operation and process simplification. Bloom's Taxonomy provides a useful structure in which to categorize learning modules when assessing student learning outcomes[10]. Asking students to think at higher levels is an excellent way to stimulate student's thought processes. In the learning process, the purpose of writing Bloom's questions is to apply Bloom's theory of developing higher levels of thought processes to Industrial Robotics classroom. Asking high-level questions of your shared inquiry groups is one way of making personal connections to literature, creating a bridge to your imagination, and developing your self-understanding[10].

Learning Activities - Laboratories and Projects

Research has shown that project-based learning is an incredibly useful learning activity[12]. Many university professors accept this method to help students make the transition from passive to active learning learners in their classrooms[8]. This section of the paper details each laboratory activity and relates the projects to practical requirements for practicing manufacturing applications. (Due to maximum 6 pages/paper, the author omits the details of lab 1 – lab 5)

Student Project: Robotic Workcell Design

If robots could only move around in their “Work Envelope,” they would not have been very useful. The process of connecting the robots to interact with other equipment is called interfacing. In this project, students learn how to use inputs/outputs such as WAIT IO[30], IF_THEN_ELSEIF, and GOSUB commands and program robot to grasp the block from the conveyor and place it to the drop-off point. Wait for 2 seconds at home position and then check the conveyor frequently. Students should be familiar with Cartesian coordinate system and RT Toolbox2 for Windows.

Figure 9 – Mitsubishi RV-7F Robot and conveyor layout

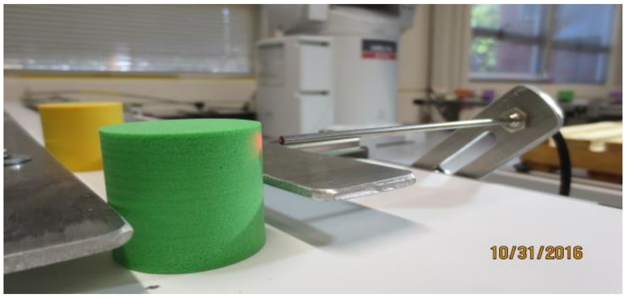

Figure 10 – I/O sensors on the conveyor

Figure 11 – Parts line up on the conveyor

Figure 12 – Robot pick up a part from the conveyor

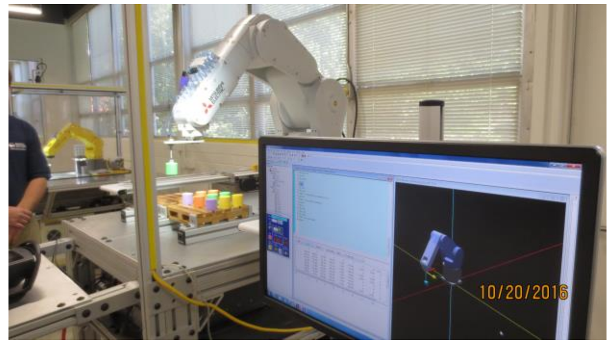

Figure 13 – Robotic Palletizing Workcell

Project Activities: (see figure 9 – 13)

1. Setup up the experimental equipment (conveyor and inputs/outputs) with the partners
2. Draw an I/O connection diagram for the project
3. Draw a process flow chart for robot subroutines, subprogram(s), and main program.
4. Each group must complete and present the project to the instructor

```
10 '***Define First layer*****************
11 Def Plt 1, P2, P3, P4, P5, 5, 5, 2
12 M1=1
13 *Loop
14 CallP "PL05SUBPICK"
15 P10 = Plt 1, M1
16 CallP "PL05SUBPLACE", P10
17 M1=M1+1
18 If M1<=25 Then *Loop
19 '**********************************
29 '***Define Pallet 2******************
30 Def Plt 2, P12, P13, P14, P15, 5, 5, 2
31 M2=1
32 *Loop2
33 CallP "PL05SUBPICK"
34 P20 = Plt 2, M2
35 CallP "PL05SUBPLACE", P20
36 M2=M2+1
37 If M2<=25 Then *Loop2
38 End
```

```
Pick and Place Subprograms:

Sub_Pick name: PL05SUBPICK
1 Mov P50, -75 *1
2 Ovrd 35
3 Mvs P50
4 HClose 1
5 Dly 0.5
6 Ovrd 60
7 Mvs , -150 *1
8 End

Sub_Place name: PL05SUBPLACE
1 FPrm P55
2 Mov P55, -75 *1
3 Ovrd 35
4 Mvs P55
5 HOpen 1
6 Dly 0.5
7 Ovrd 65
8 Mvs , -150 *1
9 End
```

Figure 14 - Mitsubishi Robot Program - Workcell Design (not a complete program)

Table 3 summarizes a list of the course activities such as quizzes, tests, labs, and projects.

Table 3 – Mapping Outcomes and Activities into Bloom's Taxonomy of Cognitive Development Levels

Expertise / Outcome	B1: Knowledge	B2: Comprehensive	B3: Application	B4: Analysis	B5: Synthesis	B6: Evolution
Outcome 1 Select an appropriate robot type for a specific robotic application	In-class Ex Quiz 1	Quiz 2		Test 1		
Outcome 2 Plan robot motions and paths		In-class EX	Lab 1 Pick-&-Place	Test 2		
Outcome 3 Create, modify, and execute different robot programs		In-class EX Test 3	Lab 1 Pick-&-Place	Lab 2 Block stacking		
Outcome 4 Create MACROs and subprograms to conduct recurring tasks			Lab 1 Pick-&-Place	Lab 3 Robotic Palletizing	Lab 2 Block stacking	
Outcome 5			Lab 5	Lab 5	Lab 5	

Use robot inputs and outputs to control operation sequence			Sensor Technology	Sensor Technology	Sensor Technology	
Outcome 6 Design and develop a robotic work cell system for a specific manufacturing application			Lab 4 Offline Programming	Student Project - Workcell Design	Lab 4 Offline Programming	Student Project - Workcell Design
Outcome 7 Troubleshoot and recover from common program and robot faults				Lab 3 Robotic Palletizing	Student Project - Workcell Design	Student Project - Workcell Design

Course Outcome Evaluation

Course outcome evaluation is a key factor for recognizing the benefits, identifying the deficiencies, and improving course contents. Through the evaluation, the author should be able to assess students' feedback in class. The typical evaluation process includes assessing students' labs, projects, and exams. Also, the author can get feedback from students through the use of questionnaires. These outcomes can be mapped into Bloom's Taxonomy expertise levels to see how much the students have learned from the course. There are several approaches to assessing student learning outcomes. Each assessment method has different advantages and disadvantages and yields only partial insight into student learning and teaching effectiveness. However, a combination of direct and indirect outcome measures can provide valuable information that can be used to address students' problems and enhance instructional materials and delivery. To measure the learning performance, the author used the following methods to assess the outcomes and collect all the necessary data:

(1) Course-based quizzes and examinations - What basic knowledge and abilities have students acquired from lecture, lab, and project activities (see Table 3),
(2) In-class observation - Many students can demonstrate their robot programming knowledge and skills in the classroom (see Table 3),
(3) Student survey - according to our university policy, we have to collect and conduct student surveys for each course at the end of the semester,
(4) Project Presentations - Students present their results and findings to the class (use project rubric for outcome assessment: peer evaluations 50% + instructor grading 50%),
(5) Project reports - students' reports include written assignment, designs, analysis worksheets, portfolios, or work cell design drawings.

The author will continuously use the above student evaluation methods and information to support and improve instructor teaching materials and contents, not contribute to instructors' fear, stress and alienation. In the last few year, there were 18 students who took the course and responded the student survey. Some of the results from the student survey presented as follows:

1. 94% of the students had strong confidence in their ability to apply industrial robotics knowledge and correctly solve a similar problem in the future,
2. 85% of the students were able to create and run industrial robot programs, recover from robot error and fault, and create alternative work cell designs,
3. 16 students ranked robotic design project experience in the top two activities they liked in the overall course activities,
4. 17 students agreed that they are more likely to remember the content delivered in these courses because of this new curriculum,
5. When compared to a traditionally-taught course, 16 students preferred this approach over the traditional one.

The result of the evaluation indicated that the workcell design project has a great potential impact on industrial robotics learning outcomes. These findings also showed that project-based learning was an incredibly useful learning method to involve all the students in the class.

Conclusion

Today, industrial robots are widely used throughout many manufacturing factories. Since the advent of industrial robots, many manufacturing tasks have been shared between man and robot. To prepare manufacturing engineering students to meet 21st Century workforce needs, the author has successfully developed and implemented several lab and project activities into an industrial robotics course in the manufacturing engineering program at GSU. This paper also presented new course contents of industrial robotics knowledge and skills that students need for a successful future career. At the end of the class, the student project was a motivational, fun, and enlightening project that provided students a hands-on opportunity while combining and practicing manufacturing, design, and project management skills. Finally, all of the students demonstrated their fundamental knowledge and insight by redesigning their robotic work cells and then estimating cycle time and operational costs.

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