
AC 2012-3073: PRACTICAL HANDS-ON INDUSTRIAL ROBOTICS LABORATORY DEVELOPMENT

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Practical Hands-On Industrial Robotics Laboratory Development

Introduction

This paper presents efforts of the author in developing practical hands-on laboratory exercises in Robotics and Automation, based-on his work in two different universities. The laboratory exercises evolved into their current state after more than a decade of teaching with ABB, Eshed, and Fanuc robots. The author's previous laboratory development included programming older ASEA IRB 6 and modern ABB IRB 140 robots using ARLA and RAPID languages respectively as well as integrating conveyors, sensors, Prolight NC machines, and Eshed's Scorbots into a small work-cell structure. After working with ASEA and ABB robots, the author had to go back to the FANUC technology due to change in teaching position. He had worked with GMF S400 robot at his graduate institution. However, a decade later had to refresh on FANUC programming and its tools. Especially the number of FANUC tools available for use presented a challenge including:

- Programming languages of TPP (Teach Pendant Programming) for both ON- and OFFLINE programming, and KAREL for ON-LINE programming
- WINOLPC - Compiling, debug, and download tool for KAREL
- PC File Services – Transfer of programs and data files through download or upload activities between the robots and the PCs as well as amongst multiple PCs
- ROBOGUIDE - the OFFLINE programming tool used in multiple modules including SIMPRO/HANDLINGPRO, PALLETPRO, PAINTPRO, and WELDPRO for pick-and-place to welding related programming
- WINTPE - the Windows-based Teach Pendant editor for generation of TPP files.

After 7 years of teaching at his current institution, the author's laboratory activities in ENGR 4700 Robotics and Automation course has taken the following shape. Working mainly in groups students operate and program 4 FANUC robots, A520, M10, M16, and LRMATE 200. Most of the robots are vertically articulate while A520 is a SCARA (Selectively Compliant Articulate Robot Arm), a horizontally articulate manipulator. 5 PCs are also available for OFF-LINE programming tasks allowing more than 9 groups of students to work simultaneously. Students can also have access to the laboratory almost 24/7, with the only exceptions that they need to be trained on the equipment and a buddy system applies requiring at least 2 persons to be present for after hours work to take place.

Robotics Laboratories

Even with the low enrollment in the manufacturing engineering program, the class has had a good size about 10 students in lowest points and up to 25 in other semesters recently. This section of the paper details each laboratory exercise and relates the exercise to practical requirements for practicing manufacturing engineers.

- **Laboratory 1:** It is about getting familiar with the Fanuc robots, their teach pendants and controllers as well as the major frames associated with the robots including WORLD and TOOL frames. After writing a simple ON-LINE teach pendant program (TPP) to check

robot positional data based on its joints and frames, students conduct an end-effector exchange exercise and learn about the TOOL frame setting process. Details of the laboratory are given below.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 1 – FRAMES
Due in One Week

Objectives

The objectives of this laboratory are:

- Getting familiar with the robots in the Learning Factory, their teach pendants and the controllers.
- Getting familiar with the various FRAMEs associated with the robot including the WORLD and TOOL FRAMEs.

Procedure

- Teach a simple Teach Pendant Program (TPP) using motion commands to draw a rectangle in the air (with respect to the WORLD FRAME). Observe and record the positions of the corner points of the rectangle in the WORLD FRAME.
- While running the program generated in the previous step, please record the positions of the corner points of the rectangle in JOINT POSITIONS.
- Carry an automatic tool change operation by writing and executing a second brief TPP program that uses motion commands and ROBOT I/Os
- Set up the TOOL FRAME for the new end-effector (EOAT).
- Learn how to activate the new TOOL FRAME.
- Learn how to operate the new end-effector.

Deliverables

- Please list the name of your first program and its syntax
- Listing of the positions from the first program for both the WORLD FRAME and JOINT POSITIONS respectively.

Point/Coord.	x	y	z	w	p	r
1						
2						
3						
4						

Briefly elaborate what x, y, z, and w, p, r coordinates are?

Point/Coord.	J1	J2	J3	J4	J5	J6
1						
2						
3						
4						

Is any of your robots' joints are not revolute? Please elaborate briefly.

- Please list the name of your second program and its syntax, and the position of the new TCP (Tool Center Point) compared with the original one.

Instructor Initials _____

Grade _____

- **Laboratory 2 and 3:** They are given together and for programming various motion types including linear, joint, circular, and associated TPP instructions by scribing two words, one in Arial like font while the other is in cursive. The laboratory exercise is furthered with an additional experiment where velocity and motion termination parameters are varied to see the results of them. Students also get exposed to number registers as well as time driven velocity settings.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 2 – INTRODUCTION TO TP MOTION PROGRAMMING
Due in One Week

Objectives

The objective of this laboratory is:

- Getting familiar with the various motion types and associated instructions utilized in TP Programming

Procedure

- Generate a TP program that writes your first or last name in a font system similar to ARIAL and also in cursive.

Deliverables

- Name of your program(s)/robot(s) and its/their output (name written by the robot)

Instructor Initials _____

Grade _____

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 3 – TP MOTION PROGRAMMING
Due in Two Weeks

Objectives

The objectives of this laboratory are:

- To further the understanding of different motion types in LINEAR, JOINT, and CIRCULAR interpolation
- To get familiar with motion speed setting and termination

Procedure

- Generate a short TP program to teach the robot to write the letter “L” (at a large/small scale).
 - Use JOINT and LINEAR interpolation motion commands to distinguish the differences between the two motion types. Use FINE as the motion termination instruction for this lab activity.
- Switch back to LINEAR interpolation motion type and use the following motion termination types to see their effects: FINE, CNT0, CNT 50, CNT 100. You can use two points in a simple program for this activity.
- Teach two (far apart) points above the work surfaces. Set the motion speed in:
 - A number register R[.]
 - Timed motion (sec)
 - TCP (Linear) speed (mm/sec)
 - Angular (Joint) speed (%)
- Draw two arcs complementing each other and making a full circle by using the SMALL and LARGE arc principles of TP Programming.

Deliverables

- Name of your programs/robot(s)
- The outcome of your programs (drawings) – label each clearly and a brief explanation on each outcome
- Explain how the speed settings work. Are there any other alternatives to set the speed? If

Instructor Initials _____

Grade _____

- **Laboratory 4:** It is based on following a tutorial of all available TPP program control structures in branching, decision making, and looping by writing short programs. Number registers (R[x]) are used along with labels (LBL[x]) and IF/JMP statements for generation of loops – FOR or WHILE. Unconditional branching is covered with JMP/LBL coupling. IF THEN ELSE statements are included by use of coupling single IF statement with multiple JMP instructions. Various input and output signal applications including digital input and output signals (DI[x] and DO[x]) as well as position registers (PR[x]) complete the tutorial. Requirements for this laboratory exercise are given below.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 4 – INTRODUCTION TO TP PROGRAM CONTROL
STRUCTURES
Due in One Week

Objectives

The objective of this laboratory is:

- Getting familiar with the various program control structures

Procedure

- Generate a TP program/multiple TP programs utilizing all the available Program Control Structures presented in Chapter.10 of the training materials

Deliverables

- Name of your program(s)/robot(s) and its/their output (name written by the robot)

Instructor Initials _____

Grade _____

- **Laboratory 5:** It is about conducting a physical palletizing and depalletizing exercise by using the Palletizing add on feature of Handling Tool operation system. Students use a (2 x 2 x 2) 3D matrix in defining a palletizing/depalletizing algorithm and work with wooden blocks as boxes for the exercise.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 5 – PALLETIZING AND DEPALLETIZING
Due in One Week

Objectives

The objective of this laboratory is:

- Getting familiar with robotic palletizing and depalletizing.

Procedure

- Generate a TP program that does palletizing in a **ColumnRowLayer (2,2,2)** setting. Once the pallet is made, depalletize the pallet by bringing the blocks back to their original starting point.

Deliverables

- Name of your program and successful demonstration of the process

Instructor Initials _____

Grade _____

- **Laboratory 6 and 7:** This laboratory set employ Fanuc's ROBOGUIDE software HANDLINGPRO and PALLETPRO modules in generation of simple pick and place and palletizing OFF-LINE programs to be downloaded into the controllers. Students work also with WINOLPC and PC File Services for transfer of data and OFF-LINE programs. PALLETPRO exercise is a complement to the previous palletizing and depalletizing laboratory. The students also need to use what they have learned so far since

ROBOGUIDE is basically a virtual environment mimicking the physical programming environment they have been in.

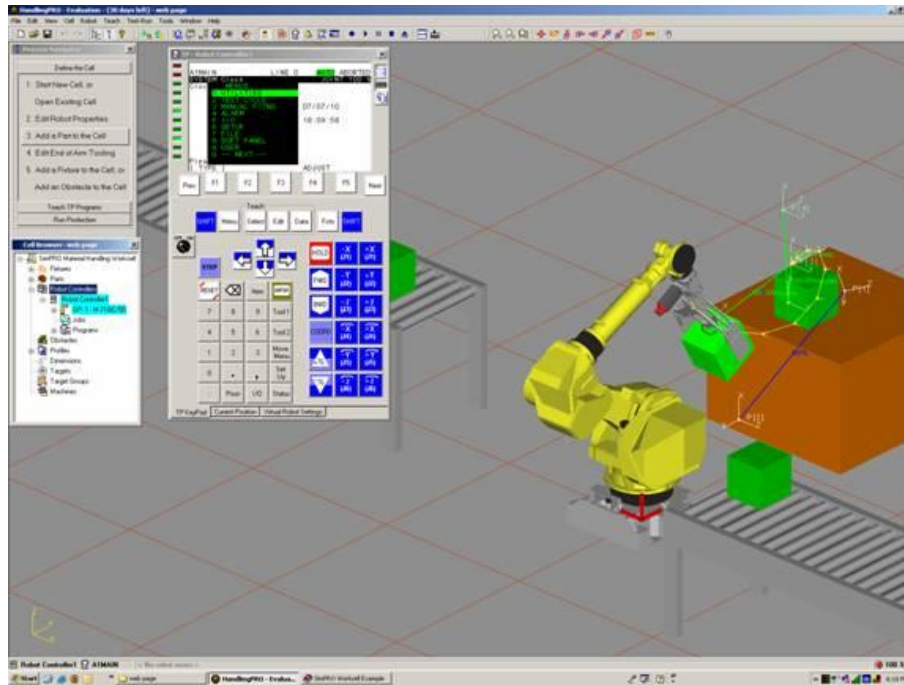


Figure 1. Representative FANUC ROBOGUIDE SIMPRO exercise for a simple pick-and-place operation

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 6/7 – OFF-LINE ROBOT PROGRAMMING
Due in One Week

Objectives

The objective of this laboratory is:

- Getting familiar with OFF-LINE Programming process and its environment

Procedure

- Generate a TP (Simulation) program within the SIMPRO software based on the Work-Cell Example 1. It is a pick-and-place operation utilizing an articulated FANUC Robot (165F), a dynamic gripper, two primitives as pick and place fixtures, and a FANUC LRMATE Robot as a part to be handled.
- Complete the PALLETPRO exercise from the tutorials. This exercise is optional.

Deliverables

- Name of your programs and the computer they are stored

Instructor Initials _____

Grade _____

- **Laboratory 8:** Reverse engineering an Input/Output (I/O) box wired into a robot controller and using it in a virtual automated manufacturing cell problem constitutes this long laboratory assignment. Students need to understand the wiring of the I/O signals by tracing the wires by using meters and draw their circuits. They also incorporate the I/O box to simulate the inputs and outputs of a work-cell program based on a scenario given to them, which is similar to the main work-cell on the laboratory shop floor. The students need to generate an I/O Table, a flow chart for the sequential logic of the cell before they complete their program and test it with the I/O box. Some groups are allowed to SIMULATED input feature of the robot controller as well.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 8 – I/O WIRING, ASSIGNMENT, AND WORK-CELL
DESIGN
Due in Two weeks

Objectives

The objective of this laboratory is:

- Getting familiar with I/O modules, associated wiring and assignment tasks in industrial robots

Procedure

- An I/O box with toggle switches (for input) and LED's (for output) has been connected to one of the LRMATE's Standard Operator Panel (SOP) interfaces. Your job is to trace the wiring of I/O's amongst the I/O box, the 24VDC power supply, and the robot controller interface.
- Once you understand about the new I/O assignments, you are to program for a simple work-cell example utilizing these new I/O's. Additional information will be given later in the class.

Deliverables

- Circuit Diagram for the I/O wiring.
- Name of your program and successful demonstration of the process

Instructor Initials _____

Grade _____

- **Laboratory 9:** In this exercise, the students are asked to study all the end-of-arm-tooling available in the laboratories and build a concept model for the International Space Station's (ISS) Robot Arm. They also have to write a brief on the ISS gripper.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 9 – EOAT/END-EFFECTORS
Due in One week

Objectives

The objective of this laboratory is:

- Getting familiar with EOAT (end-of-arm-tooling)/end-effectors.

Procedure

- Build the foam end-effector model representing the concept for the gripper at the International Space Station.
- Investigate what type of end-effectors we have in our laboratories.

Deliverables

- Completed and working foam gripper.
- List the type of grippers we have in our labs.
- A maximum one page report on ISS Gripper based on the hand-out given or other sources.

Instructor Initials _____**Grade** _____

- **Laboratory 10:** It is a free activity allowing the students to choose from a laboratory activity that will be designed by them or doing research and finding interesting robots including service and research robotics. In the past this laboratory was a very comprehensive activity. The students had to replicate the work-flow in the main laboratory shop floor in a key fob manufacturing operation. The students were given Mastercam generated NC programs to work with their KAREL robot programs. This activity is sometimes employed based on the class-size as a graded one. The last two years class sizes are larger and this activity was turned into a demo lab.

ENGR 4700 - ROBOTICS AND AUTOMATION
LABORATORY ACTIVITY 10 – Research Robotics Video or Free Laboratory
Due in One week

Objectives

The objective of this laboratory is:

- Getting familiar with current robotics research or doing an additional laboratory of your design.

Procedure

- Locate an Internet video relating to state-of-the-art robotics – industrial or service.
- Or design and conduct a laboratory of your choice.

Deliverables

- Link of the video.
- Objective of your program, its name and the robot's name.

Instructor Initials _____**Grade** _____

Conclusions and Future Work

Students in ENGR 4700 Robotics and Automation quickly learn that ON-LINE TPP programming is cumbersome, the variations of the dimensions of the blocks used in simulating the boxes in the palletizing example is critical if the boxes get mixed up, wiring I/Os into a robots controller may not be as hard if you know about basic electricity and safety rules. They also get more or less exposure to the KAREL programming language of the Fanuc robots. This depends on the progress of each class, mainly determined by the size of it. While boosting student confidence for practical work, the approach may also discourage them at times due to rather large class sizes. Having only 4 robots for a class of 15 slows down the progress of students in each laboratory exercise while also putting strain on the instructor. Additional instructional help is occasionally requested from the laboratory engineer during the laboratories. Student performances point out that somewhat effective learning experience is taking place, including the past offering when 100% of the students received at least B- (80%) letter grade. Course evaluations also indicated ratings mainly in the range of 4 - 5 in 5 scale.

In summary, students gain 15 weeks of hands-on practical experience on industrial grade robots. They learn about trajectory planning, program planning and logic with flow-charts and state-flow diagrams. The students also study the wiring process of inputs and outputs to the robot controller. But, most importantly they get exposed to scenarios replicating real-life cases such as hand-exchange and setting of a TOOLFRAME, palletizing and depalletizing, and most importantly wiring and programming of an actual work-cell, possibly twice – one with an I/O box simulator, and the other with the actual work-cell. Valuable demos also strengthened the learning experience.

In the near future, the author plans to incorporate the vibratory bowl feeders (under a second work-cell – where the students will actually wire the entire cell), and a state-of-the-art machine vision system (in place of an outdated one) into his laboratories. The work-cell will sort screws delivered by the feeder. Efforts for this new cell development have already begun. Additional future projects may involve addition of DELMIA Robotics Virtual Simulation tool to this course as well as the capstone project course (ENGR 4950 – Integrated Engineering Design) for seniors.