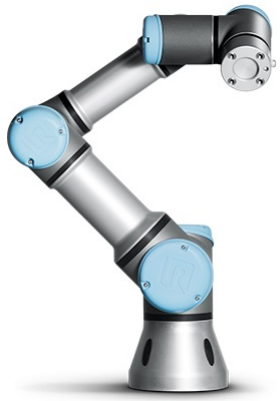
ECE 470
Introduction to Robotics
Lab Manual

Online ver 1.0



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UR3 Python - ROS Interface

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Preface

This is a set of laboratory assignments designed to complement the introductory robotics lecture taught in the College of Engineering at the University of Illinois at Urbana-Champaign. Together, the lecture and labs introduce students to robot manipulators and computer vision along with the Robot Operating System (ROS) and serve as the foundation for more advanced courses on robot dynamics, control and computer vision. The course is cross-listed in three departments (Electrical & Computer Engineering, Aerospace Engineering, and Mechanical Science & Engineering) and consequently includes students from a variety of academic backgrounds.

For success in the laboratory, each student should have completed a course in linear algebra and be comfortable with three-dimensional geometry. In addition, it is imperative that all students have completed a freshman-level course in computer programming. *MODERN ROBOTICS MECHANICS, PLANNING, AND CONTROL* (Kevin M. Lynch and Frank C. Park, 2017) is required for the lectures and will be used as a reference for many of the lab assignments. We will hereafter refer to the textbook as *MR* in this lab manual.

These laboratories are simultaneously challenging, stimulating, and enjoyable. It is the author's hope that you, the reader, share a similar experience.

Enjoy the course!

LAB 1

Introduction to the UR3

1.1 Lab Introduction

1.1.1 Important

Read the entire lab before starting and especially the "Grading" section so you know what needs to be accomplished before finishing the lab.

1.1.2 Objectives

The purpose of this lab is to familiarize you with the UR3 robot arm and its industrial programming interface called the teach pendant. In this lab, you will:

- Learn how to turn on and activate the UR3, and work with the teach pendant to create a simple program for the UR3
- Use the teach pendant to turn on and off the suction cup gripper and use the gripper in a program
- Demonstrate a sequence of motions that places one block on top of another.

1.1.3 References

- UR3 Owner's Manual:

  `https://www.universal-robots.com/download/?option=52870#section52851`
- UR3 Software Manual:

  `https://www.universal-robots.com/download/?option=53077#section53064`
- Universal Robots Academy

  `https://www.universal-robots.com/academy/`

1.1.4 Pre-Lab

Before you come to lab it is very important that you go through the training videos found at Universal Robots website `https://www.universal-robots.com/academy/`. These training sessions get into some areas that we will not be using in this class (for example you will not be changing safety settings), but go through all of the assignments as they will help you get familiar with the UR3 and its teach pendant. You also may want to reference these sessions when you are in lab.

1.2 Lab Activity

1.2.1 Task

Using the teach pendant, each team will "program" the UR3 to pick and place blocks. The program may do whatever you want, but all programs must check three predefined locations for two blocks and stack one block on top of another at a fourth predefined position. You will use the gripper's suction feedback to determine if a block is located at one of the three starting block locations. The blocks must be aligned with each other in the stack of two.

1.2.2 Procedure

1. The Pre-Lab asked you to go through the basic UR3 training at Universal Robots website. This training should have shown you how to make simple programs to move the UR3. Initially your TA will demonstrate how to turn on and enable the UR3 as well as how to use the emergency stop button. Then use this lab time to familiarize yourself with the UR3 robot. First play around with simple programs that move the robot between a number of points.

2. To turn on the suction for the suction cup gripper, **Digital output 0** needs to be set high. Set low to turn off the suction. Also **Digital input 0** indicates if the suction cup is gripping something. It will return 1 if it is gripping an object and 0 if not. Modify your above program (or make a new one) to add activating on and off the suction cup gripper.

3. Create a program that defines four spots on the robot's table. Three of these spots are where it is possible a block will be initially located and with a certain orientation. There will only be two blocks. The user will place the blocks in two of the positions. The goal for the robot is to collect the two blocks and stack them on top of each other in the fourth define place on the robot's table. So you will need to use the suction cup gripper's feedback that indicates whether an object is being gripped or not. Then with some "**If**" instructions complete this task such that the user can put the two blocks in any of the three starting positions. When you are finished, you will demo your program to your TA showning that

your program works when two blocks are placed and aligned in the three different configurations and also does not have a problem if only one block or even no blocks are placed at their starting positions. Tips for creating this program:

- To turn on the suction cup, use the **Set** command and select **Digital Output 0** and turn it on or true. Set it to off or false to turn off the suction.
- **Digital Input 0** indicates if something has been gripped by the suction cup. Go to the **I/O** tab and turn on and off **Digital Output 0** and check which state of Digital Input 0 indicates gripped and upgripped.
- In the Structure tab under Advanced besides "**If ... else**", you may also want to use the Assignment to create a global worker variable that, for example, stores the number of blocks collected. In addition the **SubProg** item creates a subroutine that you may call when performing the same steps. The subroutine's scope allows it to see the variables you create with the **Assignment** item.
- You may want to name your **Waypoints**. This makes your program easier to read. In addition if the robot needs to go to the same point multiple times in your program you can command it to go to the same waypoint name.
- Under the Structure tab you can use the **Copy** and **Paste** buttons to copy a line of code and past it in a different subsection of your code. This cuts down on extra typing. Also note the **Move** up and down buttons along with the **Cut** and **Delete** buttons. Suppress is like commenting out a line of code.
- When you add an "**If**" statement and then click on the **Command** tab, tap in the long white box to pull up the keyboard for entering the if condition.

4. Demo this working program to your TA. Your TA may ask you to improve your positioning if the stack does not end up aligned well.

1.3 Lab Deliverable and Grading for In-Person Students

1.3.1 Report

None required.

1.3.2 Demo

Show your TA the program you created.

1.3.3 Grading

- 100 points, successful demonstration.

1.4 Lab Deliverable and Grading for Online Students

This lab requires access to the UR3 teach pendant. While we would like you to experience this, it is simple not possible. Instead we will ask you to think about the logic of how the robot completes tasks and show your understanding of what you learned in the UR Academy.

1.4.1 Report

You will submit a report that uses pseudo-code to describe how you would solve the task described in Section 1.2.

- Please organize your code using Python style indentation. If you are unfamiliar with Python, please discuss this with your TA.
- Try to use clear terminology similar to what you learned in the Academy e.g. Move, If... Else..., Set, etc.
- Your TA will inform you how and when they wish you to deliver the completed report (Gradescope/Email).
- There is no specified format for the report as long as it is typed and well organized. Please submit as a pdf.

We understand that this task is a bit abstract and may not be easy to visualize without the robot in front of you. Try your best and think about what you learned in the Academy.

1.4.2 Demo

None required.

1.4.3 Grading

- 100 points for satisfactorily completing the report.

1.5 Preparation for Lab 2

In Lab 2, we will be moving on to use ROS to control the UR3. We will use it to solve a modified version of the famous Towers of Hanoi problem. Some suggested reading:

- Consult Appendix A of this lab manual for details of ROS and Python functions used to control the UR3.
- "*A Gentle Introduction to ROS*", Chapter 2 and 3. `http://coecsl.ece.illinois.edu/ece470/agitr-letter.pdf`
  - Chapter 2: 2.4 Packages, 2.5 The Master, 2.6 Nodes, 2.7.2 Messages and message types.
  - Chapter 3 Writing ROS programs.
- `http://wiki.ros.org/`
- Since this is a robotics lab and not a course in computer science or discrete math, feel free to Google for solutions to the Tower of Hanoi problem.[1] You are not required to implement a recursive solution.

[1] `http://www.cut-the-knot.org/recurrence/hanoi.shtml` (an active site, as of this writing.)

Appendix A

ROS Programming with Python

A.1 Overview

ROS is an open-source, meta-operating system for your robot. It provides the services you would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It also provides tools and libraries for obtaining, building, writing, and running code across multiple computers.

- The ROS runtime "graph" is a peer-to-peer network of processes (potentially distributed across machines) that are loosely coupled using the ROS communication infrastructure. ROS implements several different styles of communication, including synchronous RPC-style communication over services, asynchronous streaming of data over topics, and storage of data on a Parameter Server.

- For more details about ROS: `http://wiki.ros.org/`
- How to install on your own Ubuntu: `http://wiki.ros.org/ROS/Installation`
- For detailed tutorials: `http://wiki.ros.org/ROS/Tutorials`

A.2 ROS Concepts

The basic concepts of ROS are nodes, Master, messages, topics, Parameter Server, services, and bags. However, in this course, we will only be encountering

the first four.

- `Nodes` "programs" or "processes" in ROS that perform computation. For example, one node controls a laser range-finder, one node controls he wheel motors, one node performs localization ...
- `Master` Enable nodes to locate one another, provides parameter server, tracks publishers and subscribers to topics, services. In order to start ROS, open a terminal and type:

  ```
  $ roscore
  ```

  roscore can also be started automatically when using roslaunch in terminal, for example:

  ```
  $ roslaunch <package name> <launch file name>.launch
  # the launch file for all our labs:
  $ roslaunch ur3_driver ur3_driver.launch
  ```

- `Messages` Nodes communicate with each other via messages. A message is simply a data structure, comprising typed fields.
- `Topics` Each node publish/subscribe message topics via send/receive messages. A node sends out a message by publishing it to a given topic. There may be multiple concurrent publishers and subscribers for a single topic, and a single node may publish and/or subscribe to multiple topics.In general, publishers and subscribers are not aware of each others' existence.

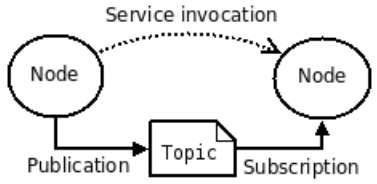

Figure A.1: source: `http://wiki.ros.org/ROS/Concepts`

A.3 Before we start..

Here are some useful Linux/ROS commands

- The command "ls" stands for (List Directory Contents), List the contents of the folder, be it file or folder, from which it runs.

  ```
  $ ls
  ```

- The "mkdir" (Make directory) command create a new directory with name path. However is the directory already exists, it will return an error message "cannot create folder, folder already exists".

  ```
  $ mkdir <new_directory_name>
  ```

- The command "pwd" (print working directory), prints the current working directory with full path name from terminal

  ```
  $ pwd
  ```

- The frequently used "cd" command stands for change directory.

  ```
  $ cd /home/user/Desktop
  ```

  return to previous directory

  ```
  $ cd ..
  ```

  Change to home directory

  ```
  $ cd ~
  ```

- The hot key "ctrl+c" in command line **terminates** current running executable. If "ctrl+c" does not work, closing your terminal as that will also end the running Python program. **DO NOT USE "ctrl+z" as it can leave some unknown applications running in the background**.

- If you want to know the location of any specific ROS package/executable from in your system, you can use "rospack" find "package name" command. For example, if you would like to find 'lab2pkg_py' package, you can type in your console

  ```
  $ rospack find lab2pkg_py
  ```

- To move directly to the directory of a ROS package, use roscd. For example, go to lab2pkg_py package directory

  ```
  $ roscd lab2pkg_py
  ```

- Display Message data structure definitions with rosmsg

  ```
  $ rosmsg show <message_type>     #Display the fields in the msg
  ```

- rostopic, A tool for displaying debug information about ROS topics, including publishers, subscribers, publishing rate, and messages.

  ```
  $ rostopic echo /topic_name      #Print messages to screen
  $ rostopic list          #List all the topics available
  $ rostopic pub <topic-name> <topic-type> [data...]
  #Publish data to topic
  ```

A.4 Create your own workspace

Since other groups will be working on your same computer, you should backup your code to a USB drive or cloud drive everytime you come to lab. This way if your code is tampered with (probably by accident) you will have a backup.

- First create a folder in the home directory, mkdir catkin_(yourNETID). It is not required to have "catkin" in the folder name but it is recommended.

```
$ mkdir -p catkin_(yourNETID)/src
$ cd catkin_(yourNETID)/src
$ catkin_init_workspace
```

- Even though the workspace is empty (there are no packages in the 'src' folder, just a single CMakeLists.txt link) you can still "build" the workspace. Just for practice, build the workspace.

```
$ cd ~/catkin_(yourNETID)/
$ catkin_make
```

- **VERY IMPORTANT**: Remember to **ALWAYS** source when you open a new command prompt, so you can utilize the full convenience of Tab completion in ROS. Under workspace root directory:

```
$ cd catkin_(yourNETID)
$ source devel/setup.bash
```

A.5 Running a Node

- Once you have your catkin folder initialized, add the UR3 driver and lab starter files. The compressed file lab2andDanDriver.tar.gz, found at the class website contains the driver code you will need for all the ECE 470 labs along with the starter code for LAB 2. Future lab compressed files will only contain the new starter code for that lab. Copy lab2andDriverPy.tar.gz to your catkin directories "src" directory. Change directory to your "src" folder and uncompress by typing "tar -zxvf lab2andDriver.tar.gz".

  "cd .." back to your catkin_(yourNETID) folder and build the code with "catkin_make"

- After compilation is complete, we can start running our own nodes. For example our lab2node node. However, before running any nodes, we must have roscore running. This is taken care of by running a launch file.

```
$ roslaunch ur3_driver ur3_driver.launch
```

  This command runs both roscore and the UR3 driver that acts as a subscriber waiting for a command message that controls the UR3's motors.

- Open a new command prompt with "ctrl+shift+N", cd to your root workspace directory, and source it "source devel/setup.bash".
- We also need to make lab2_exec.py executable.

  ```
  $ chmod +x lab2_exec.py
  ```

- Run your node with the command rosrun in the new command prompt. Example of running lab2dannode node in lab2danpkg package:

  ```
  $ rosrun lab2pkg_py lab2_exec.py
  ```

A.6 More Publisher and Subscriber Tutorial

Please refer to the webpage: `http://wiki.ros.org/ROS/Tutorials/Writing PublisherSubscriber(c%2B%2B)`