Assignment 1 (10 Marks)

MCEN90028 Robotics Systems 2021

Due date: as per shown on Canvas LMS

1 Overview

This assessment aims to provide you with the practice on (and assess your understanding of) the topics covered in Modules 2 and 3 (which requires Module 1).

- Before you start, make sure you understand the terms dictating the integrity of your academic work, the Department late submission policies. Given you are in an advanced elective of your Master of Engineering candidature, ignorance is not a valid reason for academic misconducts.

- You will be awarded (marks) for the merit of your work. Incorrect answers or badly argued claims therefore do not merit any marks. It is important for you to change your mindset, if you are currently of the habit of thinking about your assignment as a mechanism where you **lose** marks. (By that approach, if you submit nothing and therefore make no mistakes, you deserve a mark of 100%.) The right question should be how your work can be improved in its merit.

1.1 Objectives

The following are the objectives of this assessment. You are to address these objectives **explicitly**.

1. To derive the forward kinematics of the robot of your design: to output the end-effector pose as a function of joint displacements and physical parameters (link lengths and offset angles, as defined by the Denavit-Hartenberg (DH) convention)

2. To derive the inverse kinematics of the robot of your design: to output the joint displacements as a function of the end-effector pose and the physical parameters.

3. To determine the link lengths of the robot of your design such that it can reach the necessary workspace dictated by your chess set.

4. To provide practice opportunity for students and to evaluate their ability to communicate effectively in written form on the details of the exercise, as well as the ability to convince the reader of the validity of the outcomes. The evaluation of this aspect is implicit in the presentation of your answers to the first three objectives.

2 Description of Task

This assignment will focus on the forward and inverse kinematics of your robot. Note that in this project, your robot is tasked to move pieces in a chess game. The robot kinematics is therefore of your design, specific to your group, to fit the size of the chessboard (that your group selects) and to some extent, the weight of the pieces of your chess set. There is a very large variety of chess sets out there in the world, you are encouraged to select one (that is not too costly if you have to purchase one) or use an existing set in your possession. Therefore, there should be very little chance of having two identical chessboards in the class, making each of your assignment unique.
Given we are using rather small DC motors, I suggest that you do not expect a large amount of torque to be produced at high speed by the motors. By this, I mean to suggest that you do not choose an excessively large chessboard.

In this assignment, you are required to write a self-contained report to construct the forward and inverse kinematics of your chess playing robot. **It should actually be a report, to be read and understood by a third party outside of this class. It should not be just an answer sheet**.

2.1 Forward Kinematics (up to 3 marks)

The first part of your assignment is to determine the forward kinematics of your robot. As this is the first assignment in the subject, more prescriptive guide will be provided. To appropriately present your answer, you are expected to:

1. produce the kinematic definition of your robot through: a schematic diagram that is appropriately sketched (with robot in "zero position"), variables that are clearly defined and labelled on the diagram and the coordinate frames defined according to the DH convention. (up to **0.5 mark**)

2. produce the DH table containing the parameters. (up to **0.5 mark**)

3. derive and produce the transformation matrix of Frame E attached at the end effector with respect to Frame 0 at the base of the manipulator to (up to **1 mark**)

4. provide a logically clear argument to demonstrate that your forward kinematics solution is correct. An immediate suggestion is to plot the robot configuration (using stick figure on Matlab plot function) for the zero position, i.e. at $\mathbf{q} = [0, 0, 0, 0, 0]^T$, supposing your robot has 5 joints (5 degrees of freedom - dofs). The onus is on you to convince the reader that your derived forward kinematics is correct. Write in grammatically correct full sentences to explain your thoughts in a concise and logically clear manner. (up to **1 marks**)

2.2 Determination of Link Lengths (up to 3 marks)

A numerical exercise can be carried out using the outcome of the Forward Kinematics exercise above to verify if a given set of link lengths are suitable for our project. To do so, you can use the following steps:

1. numerically estimate the workspace of your robot by plotting the reachable workspace of the robot end-effector. This is done by initially selecting arbitrary values for the link lengths for your robot, calculating the forward kinematics and plotting the resulting end-effector poses for all possible values of the joint space coordinates on:

   - the XY plane at the expected height of the chessboard (i.e. ${}^{0}Z = Z_{constant}$ representing the chessboard height.
   - the ZX plane at ${}^{0}Y = 0$, representing a vertical cross section of the reachable workspace.

   A nested for-loop can be used to do that. Remember to only utilise inverse kinematics solutions belonging to the same manifold (though in the case of your problem, you will almost certainly be confined to the elbow up manifold). Superimpose onto the resulting plot XY workspace plot the outline of the chessboard and verify visually if the chessboard fits inside the workspace. Superimpose onto the resulting plot of ZX workspace the expected height of the chess pieces to ensure that each location can be reached, including the need to lift each piece up to a height of at least twice the height of a piece in order to move the pieces. Comment on whether or not your initial (arbitrary) choice of link lengths are suitable to produce the required workspace (up to **2 marks**)

   For practical considerations, please consider that a revolute joint generally has a non-zero minimum angular displacement between the two rigid bodies, as in, it cannot be completely folded into itself. This is a fabrication and mechanical design consideration. We also want to avoid having a completely straight elbows when designing a robotic manipulator. You want to be safe and include these in your considerations in this assignment.

2. iterate the process above until you find a set of link lengths that result in a good fit of your chessboard in the reachable workspace of your robot. You do not want the robot too long nor too short. (up to **1 mark**)

3. In your report, add a remark as to why you do not want the link lengths too long or too short. (up to **0.5 mark**) (yes yes, it adds up to more than the intended 3 marks, I know)

2.3 Inverse Kinematics (up to 4 marks)

In the second part of the assignment, you are required to:

1. produce the derivation and the (symbolic) expressions of the inverse kinematics solutions for the robot you designed. (up to **2 marks**)

2. argue and demonstrate that your inverse kinematics solution is correct, by selecting 2 specific locations to place a given piece on the chessboard and calculating the joint space solutions associated with each of the locations. Use the numerical values of the link lengths determined in the second part of the assignment (Determination of Link Lengths) in this calculation. Indicate the existence (or otherwise) of multiple solutions, and which of the solutions is/are valid and should be selected. (up to **2 marks**)

3 Submission

You need to submit one report and one MATLAB script to run your code per assignment group of 3 students, submitted as ONE ZIPPED file.

The report should be submitted as a PDF of **no more than 20 pages** (everything included) with **12pt font size**.

Submit them on Canvas as .zip file: one pdf file, one MATLAB script and any customised MATLAB function if used.
The title of your:

- .zip file should be "Assignment1_AG[#]";
- report should be "Assignment1_Report_AG[#]";
- main MATLAB file should be "Assignment1_Matlab_AG[#]"

NOTE: put your assignment group (AG) number in "[#]", eg. AG07.

The Matlab script is expected to demonstrate your workings for the following: For the Forward Kinematics part:

- to produce the transformation matrices of frame i with respect to i-1, symbolically, and to show the final transformation matrix expressing the end-effector pose with respect to the inertial frame;
- to produce the end-effector pose given trivial joint space displacement, e.g. for $\mathbf{q} = [0, 0, 0, 0, 0]^T$;

For the Link Length Determination part:

- to plot the resulting workspace based on the forward kinematics evaluation of joint space displacement within the joint limits, for a given XY plane representing the chessboard.

For the Inverse Kinematics part:

- to produce the inverse kinematics function to convert an end-effector pose to the joint space displacement (solution sets) for Part 2.4.2.

NOTE: structure the MATLAB code according to the Tasks.

Submission checklist:

- ☐ Report is no more than 20 pages
- ☐ Report has 12pt font size
- ☐ Report saved as PDF
- ☐ Titles of files are in the right format
- ☐ Files are compressed into ONE .zip file