Project

TPK4170 Robotics
Department of Mechanical and Industrial Engineering
NTNU

Due date: 1 December 2021

The report shall be written using LaTeX and consist of 20-30 pages. All code shall be written using Python. You can freely use any Python toolboxes in your work. All code shall be commented. Code snippets can be placed inline in the text and all source code shall be placed in an electronic appendix.

The project can be performed alone or in a group of up to four students.

In the following, the acronym MR refers to the textbook "Modern Robotics: Mechanics, Planning and Control" by Kevin M. Lynch and Frank C. Park, 2017, Cambridge University Press.

Forward Kinematics

Task 1

1. Present the forward kinematics computations for an open-chain manipulator with n joints using the original Denavit-Hartenberg (DH) convention. See, e.g., Chapter 2 in the robotics book by Siciliano et al. [1].
2. Present the differences between the original formulation of the Denavit-Hartenberg convention, as presented in [1], and the modified version as presented in Appendix C in MR.
3. Present the forward kinematics computations for an open-chain manipulator with n joints using both the spatial and the body form of the Power-of-Exponentials formulations.
4. Present the relationship between the original DH-convention and the PoE convention. What are the advantages and disadvantages of both approaches?

Task 2

The workspace and axes of rotations of a KUKA KR6 R900 sixx (Agilus) robot are shown in Figure 1 and Figure 2, respectively. In both figures the joint angles of the manipulator are given by:

$$\theta = \begin{bmatrix} 0 & -\pi/2 & \pi/2 & 0 & 0 & 0 \end{bmatrix}^T$$

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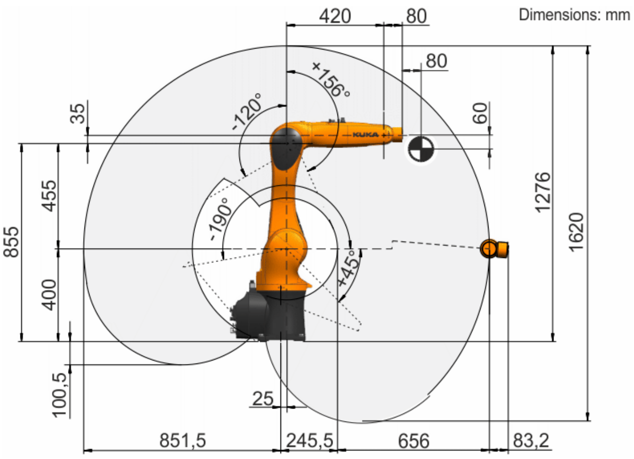

Figure 1: Workspace for the KUKA KR6 R900 sixx (Agilus) robot.

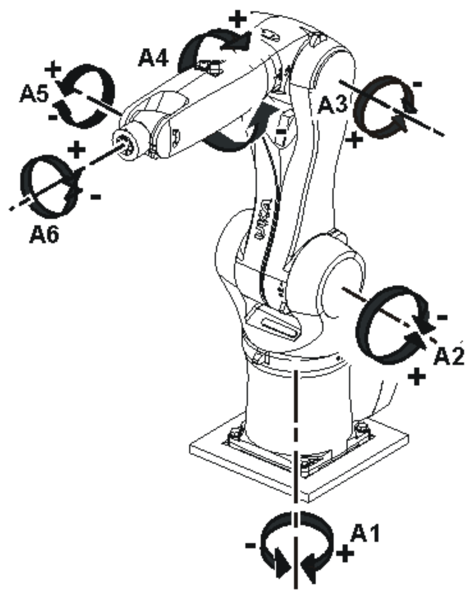

Figure 2: Direction of robot joint axes for the KUKA KR6 R900 sixx (Agilus) robot.

1. Using the original Denavit-Hartenberg convention, determine the Denavit-Hartenberg parameters for the Agilus robot. Note the directions of the joint axes in Figure 2, and the vertical offset of 35 mm on the elbow joint.

   Hint: Perform the analysis when the robot is in the following configuration:

   $$\theta = \begin{bmatrix} 0 & 0 & \pi/2 & 0 & 0 & 0 \end{bmatrix}^T.$$

2. Determine the end-effector zero position configuration $M \in SE(3)$ for the Agilus robot.
3. Determine the space frame screw axes $\mathcal{S}_i$ for the Agilus robot.
4. Determine the body-frame screw axes $\mathcal{B}_i$ for the Agilus robot.
5. Visualize the Denavit-Hartenberg frames; the end-effector zero position configuration $M \in SE(3)$; the space frame screw axes $\mathcal{S}_i$; and the body-frame screw axes $\mathcal{B}_i$ for the Agilus robot.

   Hint: Use a Python module, e.g., Open3D, to visualize the coordinate frames, points, and lines.

6. Using Python, confirm that the forward kinematics solutions using the PoE formulation agrees with the solutions using the DH-convention.

   Hint: Put the robot in several joint configurations and compare the position and orientations of the end-effector frame found using both approaches. Note that you will have to define a suitable metric to compare two rotation matrices. Use the np.allclose function from the Numpy library to compare floating point numbers. You are not expected to provide a mathematical proof.

Inverse Kinematics

Task 3

1. Present an overview of the two methods, analytic and numerical, for solving the inverse kinematics of an open chain manipulator with n joints. What are the advantages and disadvantages of both approaches?
2. Develop and implement a solution for the analytic inverse kinematics for the Agilus robot.

   Hint: Decouple the position and orientation inverse kinematics.

3. Confirm that the solution of the analytical inverse kinematics from the previous point agrees with the solution from a numerical inverse kinematics solver.

   Hint: Put the robot in several different end-effector configurations and compare the numerical joint values using the np.allclose function from the Numpy library.

4. Using the developed analytic inverse kinematics formulation, visualize the Agilus robot in both elbow-up and elbow-down configurations for the same end-effector pose.

   Hint: Select an end-effector pose in front of the robot.

Singularity Analysis

Task 4

1. Perform a singularity analysis of the Agilus robot, and, if any, present the kinematic singularities and in which configurations they appear.

   Hint: Decouple the arm and wrist singularities.

References

[1] "Kinematics". In: *Robotics: Modelling, Planning and Control*. London: Springer London, 2009, pp. 39–103. ISBN: 978-1-84628-642-1. DOI: 10.1007/978-1-84628-642-1_2. URL: https://doi.org/10.1007/978-1-84628-642-1_2.