Homework 5: Forward Kinematics of Kinova's Gen 3 6-DOF Robot Arm Using Screw Theory and Verifying Using RoboDK

Course Name: Modern Robotics I: Arm-type Manipulators

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Structure of This Homework

This submission is divided into two parts:

1. Part I contains the Forward Kinematics for the Kinova Gen 3 6 DOF Robot arm, written by hand. You will find these answers starting in the **last page** of this PDF file (after the Bibliography!). The code and documents used to answer this section can be found in this GitHub repository. The verification video with RoboDK can be found here.

2. Part II will be answered immediately in the next section.

Part II: Screw Theory in Robotics in the Literature

The three examples of screw theory in the literature that I found were:

1. "Solving the Kinematics and Dynamics of a Modular Spatial Hyper-redundant Manipulator by Means of Screw Theory" [1]. This file is called "paper1.pdf" in the repo.

   This paper presented the methodology to solve the kinematic and dynamic analyses of a redundant manipulator with additional connected three-legged in-parallel manipulators. Forward kinematics are described in Section 3.1: Finite Kinematics. In equation 6, the authors express the transformation matrix T from frame 0 to frame 1. Additionally, in equation 8, the authors express that if the robot is composed of n modules, then the transformation matrix from frame 0 to frame k can be expressed as the multiplication of all the corresponding transformation matrices. Both concepts have been covered in class!

2. "Kinematics and Dynamics of 2(3-RPS) Manipulators by Means of Screw Theory and the Principle of Virtual Work" [2]. This file is called "paper2.pdf" in the repo.

   This paper discussed the kinematic and dynamic analysis of a specific class of series-parallel manipulators, known as a 2(3-RPS) manipulators. Its forward kinematics are described in equations 7, 8, and 9. Equation 7 expresses the structure of the 4x4 homogeneous transformation matrix between frames 1 and 0. Equation 8 explains how the sequential multiplication of transformation matrices can be used to obtain the transformation matrix from frame i to frame k. Finally, equation 9 expresses how the coordinates of the centers of the robots' spherical joints can be expressed in any desired frame (be it the fixed platform or the output platform of the robot).

3. "Kinematics of a Five-degrees-of-freedom Parallel Manipulator Using Screw Theory" [3]. This file is called "paper3.pdf" in the repo.

   This paper discussed the kinematic analysis of a 5-DOF decoupled parallel manipulator. It utilized forward kinematics in Equation 1, where it expressed the centers of the spherical joints and the center of the moving platform in the flobal reference frame. The matrix pre-multiplying the the vector on the right side of the equation is the homogenous transformation matrix we have discussed in class!

Bibliography

[1] J. Gallardo-Alvarado, C. Aguilar-Nájera, L. Casique-Rosas, L. Pérez González, and J. Rico, "Solving the kinematics and dynamics of a modular spatial hyper-redundant manipulator by means of screw theory," *Multibody System Dynamics*, vol. 20, pp. 307–325, Apr. 2008. DOI: 10.1007/s11044-008-9121-7.

[2] J. Gallardo-Alvarado, C. R. Aguilar-Nájera, L. Casique-Rosas, J. M. Rico-Martínez, and M. N. Islam, "Kinematics and dynamics of 2(3-rps) manipulators by means of screw theory and the principle of virtual work," *Mechanism and Machine Theory*, vol. 43, no. 10, pp. 1281–1294, 2008, ISSN: 0094-114X. DOI: https://doi.org/10.1016/j.mechmachtheory.2007.10.009. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0094114X07001607.

[3] J. Gallardo-Alvarado, B. Arroyo, and H. Rojas, "Kinematics of a five-degrees-of-freedom parallel manipulator using screw theory," *International Journal of*

Advanced Manufacturing Technology, vol. 45, pp. 830–840, Apr. 2009. DOI: 10.1007/s00170-009-1998-7.

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Homework 5

$$R = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad p = \begin{bmatrix} 0 \\ 1 \\ 1176.50 \end{bmatrix}$$

} Dimensions taken from RoboDK

$$M = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 \\ 0 & 0 & 1 & 1176.50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$q = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \\ \theta_6 \end{bmatrix} \quad S\omega_1 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \quad S\omega_2 = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \quad S\omega_3 = \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}$$

$$S\omega_4 = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} \quad S\omega_5 = \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \quad S\omega_6 = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}$$

For the $S\omega_i$, the positive rotation direction was obtained with RoboDK rotation tests.

$a_1 = [0, 0, 0]$ $\quad a_2 = [0, 0, 284.8]$ $\quad a_3 = [0, 0, 694.8]$

$a_4 = [0, 1, 0]$ $\quad a_5 = [0, 0, 1009.1]$ $\quad a_6 = [0, 1, 0]$

Measurements gotten from the User Guide linked in the homework wiki: Page 94/301. Now, to get T, we use the Python code developed in previous labs. Now for $\theta_1 = 90°$, $\theta_2 = -90°$, $\theta_3 = \theta_4 = \theta_5 = \theta_6 = 0°$:

$$T = \begin{bmatrix} 0 & 1 & 0 & -1 \\ 0 & 0 & -1 & -891.7 \\ -1 & 0 & 0 & 284.8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The comparison of this result and RoboDK are shown in the video in the repo!