Lab 5 Report: Exploring DOFs and Joint Types in the PincherX 100 Robot Arm plus DOFs Practice Questions

Course Name: Modern Robotics I: Arm-type Manipulators

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Abstract

Lab 5 was centered around the examination of the degree of freedom exhibited by the objects. In this module, we will explore the various classifications of joints and their role in restricting the motion of interconnected links. By employing "Grübler's formula," the total degrees of freedom (DOFs) were computed for a given set of cases. Furthermore, we extend the use of this methodology to the px100 robot. Subsequently, we employ "Grübler's formula" to theoretically determine the degree of freedom. Additionally, we have developed a Python function to calculate the degree of freedom using "Grübler's formula" by manually inputting values for m, n, j, and Fi. Furthermore, we proceed to implement the code that visually represents and explains the degree of freedom on px100. This is accomplished through the creation of a video presentation.

List of Hardware and Software Used

Hardware: PincherX 100 robot arm.

Software: ROS2, Python-ROS interface and Visual Studio Code.

Tasks Completed & Answers to Question

Task 1: Evaluating the PincherX 100's Degrees of Freedom

Identifying Joint Types

The PincherX 100 robot arm is equipped with four revolute joints as seen in Figure 1, each allowing rotation around a single axis but not permitting linear movement. This means that each joint has 1 degree of freedom - rotation around a single axis.

These joints grant the arm its flexibility, enabling it to achieve various orientations and configurations. However, the inherent constraints of revolute joints, such as rotation limits and a fixed axis of rotation, ensure the arm's movements are controlled and predictable. Consequently, while the arm can perform tasks like grasping and precise placement effectively.

Calculating the PincherX 100's Degrees of Freedom

1. Evaluating the Robot: To calculate the degrees of freedom (DOF) for the PincherX 100 robot arm, we started by understanding the individual components used in Grübler's formula.

- `Single Body DoF (`m`):` A single free-floating body in space has 6 degrees of freedom: 3 for translation (along x, y, and z axes) and 3 for rotation (around x, y, and z axes). Hence, m=6.
- `Number of Links (`N`):` The robot arm consists of 5 links: 3 between the joints of the robot, 1 between $J1$ and ground, and 1 between $J4$ and the base.
- `Number of Joints (`J`):` The robot arm has 4 revolute joints.
- `DoF for each Joint (`f_i`):` Each revolute joint allows rotation about a single axis. Thus, its DOF, f_i, is 1 for all the joints.

2. Applying Grübler's Formula: Using this information, we can calculate the mechanism's degrees of freedom:

$$dof = m(N-1-J) + \sum_{i=1}^{J} f_i$$

$$m = 6; N = 5; J = 4;$$

$$f_i = 1 \textit{ for all joints}$$

$$\begin{aligned} dof &= 6(5-1-4) + \sum_{i=1}^{4} 1 \\ dof &= 6(0) + (1+1+1+1) \\ dof &= 0 + 4 \\ dof &= 4 \end{aligned}$$

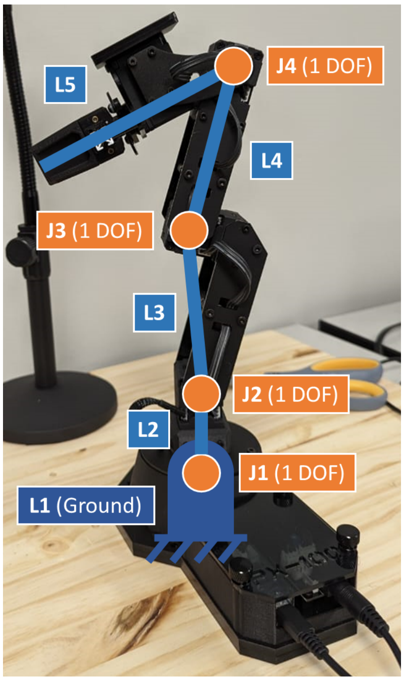

Figure 1: An annotated picture of the PincherX 100 robot which labels its links and joints.

Validating Calculations Using Joint Control Code

In this step, the goal was to validate the number of Degrees of Freedom (DOFs) of the robot using the joint control code provided in Lab 4. The approach was twofold: first, to test the code in a simulation environment, and then to run the same code on the actual robot arm to observe its movement. The videos of both being performance are available on our team's github page.

1. Code Explanation: The provided code is a Python script of Joint Control is available to view on our team's github page that utilizes the `InterbotixManipulatorXS` class from the `interbotix_xs_modules.xs_robot.arm` module. This class allows for controlling the Interbotix robot model 'px100'.

The code first defines four joint angles in degrees:

- `joint_1` for the waist, with a range of -180 to 180 degrees.
- `joint_2` for the shoulder, ranging from -111 to 107 degrees.
- `joint_3` for the elbow, spanning -121 to 92 degrees.
- `joint_4` for the waist angle, with a limit between -100 to 123 degrees.

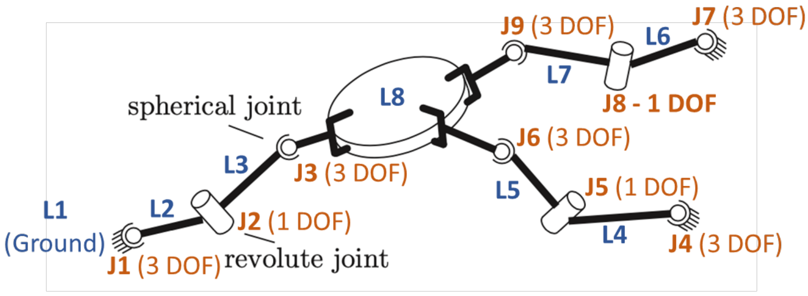

Figure 2: An annotated picture of the 3 SRS arm mechanism which labels its links and joints.

These angles are then converted to radian formula.

2. Simulation Results: Upon running the code in a simulation environment, the robot model 'px100' successfully moved each of the distinct joints to the predefined positions. This movement confirmed that the robot arm possesses at least the four DOFs defined in our calculations.

3. Experimental Results: When the code was executed on the actual robot arm, it successfully mimicked the movements observed in the simulation. The physical robot's ability to accurately replicate the joint movements further reinforced the conclusion that it possesses the defined number of DOFs.

Through both simulation and experimental tests using the joint control code from Lab 4, it has been validated that the robot model 'px100' possesses at least four DOFs, as defined in the code.

Task 2: Practice Exercises

Calculating Degrees of Freedom for a Complex Mechanism

The first exercise revolved around calculating the degrees of freedom for the a mechanism with three identical SRS open-chain arms (Figure 2).

1. Evaluating the Mechanism: To calculate the degrees of freedom for this mechanism, we needed to determine the values of the variables required for Grübler's formula.

- `Single Body DoF` (m): Since the mechanism operates in three-dimensional space like the PincherX 100, a single free-floating body will also have 6 degrees of freedom.
- `Number of Links` (N): Each arm has 2 links connecting the its joints. There is also a single link which connects all the arms and a ground link. Because this mechanism contains 3 arms, this totals to 8 links.
- `Number of Joints` (J): Each arm has 2 spherical joints and 1 revolute joint. This results in 6 spherical and 3 revolute joints for a total of 9 joints.
- `DoF for each Joint` (f_i): Spherical joints have 3 degrees of freedom and revolute joints have 1 degree of freedom.

2. Calcuating the DoF using Grübler's Formula: Using the information from the previous section, we can calculate the mechanism's degrees of freedom:

$$dof = m(N - 1 - J) + \sum_{i=1}^{J} f_i$$

$$m = 6; N = 8; J = 9;$$

$$f_i = 3 \ for \ spherical \ joints;$$

$$f_i = 1 \ for \ revolute \ joints$$

$$dof = 6(8 - 1 - 9) + \sum_{i=1}^{9} f_i$$

$$dof = 6(-2) + (6(3) + 3(1))$$

$$dof = -12 + 21$$

$$dof = 9$$

Writing a Python Script to Calculate the Degrees of Freedom

This exercise consisted of writing a python script which calculates a mechanism degrees of freedom given:

- the number of degrees of freedom a single body contains (m),

- the number of bodies in the mechanism (N),
- the number of joints in the mechanism (J),
- and the number of joints with 1, 2, and 3 degrees of freedom (f_1, f_3, f_3).

1. Getting User Required Variables: Using Python's `input()` function, we queried users for each of the required parameters listed above. Since the `input()` function returns a string value, the `int()` function was used to convert the strings to integers.

2. Calculating Degrees of Freedom: We then wrote a function which took the integer input parameters and used Grübler's formula to calculate degrees of freedom. The result of this calculation was returned and printed to the console.

The python script written for this exercise can be found at `https://github.com/akashvidyaX/ME4903_Lab5/blob/main/grubler_formula_1.py`

Conclusion

Lab 5 examined degrees of freedom (DOFs) and their use in robotic system motion analysis. We identified joint types in the PincherX 100 robot arm and calculated its DOFs using Grübler's algorithm, yielding 4 DOFs. Furthermore, we used the joint control codes to validate the joints and its motion in the various degrees of freedom in simulation and real world. Our study was subsequently extended to a more sophisticated system with three collaborating SRS arms. We found that this system has 9 DOFs using Grübler's formula again, demonstrating its practical use. We wrote a Python script that calculated the degrees of freedom for a mechanism based on input values for the m, linkages (N), joints (J), and joint types' DOFs, which made DOF evaluation of various systems easy.

Bibliography

To complete this lab, we used the class' Lab 5 assignment page [1] and Lesson 2 page [2] as a reference.

Bibliography

[1] M. Babaiasl. (2023) Lab 5: Exploring dofs and joint types in the pincherx 100 robot arm plus dofs practice questions. [Online]. Available: https://github.com/madibabaiasl/modern-robotics-I-course/wiki/Lab-5:-Exploring-DOFs-and-Joint-Types-in-the-PincherX-100-Robot-Arm-plus-DOFs-Practice-Que

[2] ——. (2023) Lesson 2: Degrees of freedom (dof) in robotics. [Online]. Available: https://github.com/madibabaiasl/modern-robotics-I-course/wiki/Lesson-2:-Degrees-of-Freedom-(DOF)-in-Robotics