ECSE 4480/6470, MANE 4560/6120, CSCI 4480 September 27, 2021

Robotics I

Mini-Project 3: Spatial Robot Arm Motion: Rigid Body Motion in $SE(3)$, Forward Kinematics, Inverse Kinematics

Assigned: September 27, 2021
Due: October 19, 2021

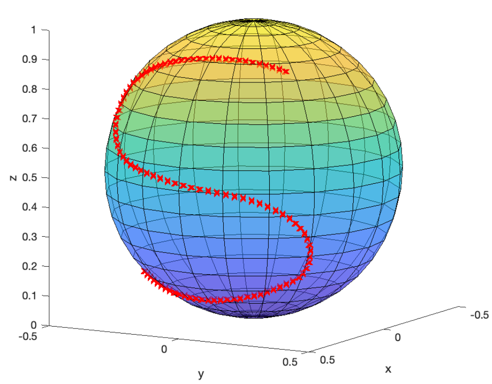
Check back here regularly for the latest update
Submit your project report to Gradescope and your code through your private GitHub repository. Discussion with your peers is encouraged (particularly on WebEx Team and Piazza), but you must hand in your own work and be able to explain what you have done in the project. **Verbatim copying (whether you copy from someone or let someone copy your work) of derivation, writing, software code, etc., is considered cheating and will result in zero for the project grade and notification to the Class Dean and Dean of Students. Multiple instances of cheating will result in failing of the course.**
This course will use the MATLAB Robotics Toolbox. You are welcome to use other simulation platforms such as ROS/Gazebo, MATLAB ROS Toolbox, Webot, Unity, and others. Your are encouraged (but not required) to show the robot motion (in parts 3 and 4) as a movie file (take a look of the MATLAB `movie` command).

Things to Do

- Start using the WebEx Team space for your project team to work on the project proposal (Note the updated due date: October 12).

Task Description

1. Consider the curve S on a sphere as shown. This is obtained from the same S curve in mini-project 2 by using the inverse of stereographic projection. This will be discussed in class and the (x, y, z) coordinate of the curve will be provide. But see if you can generate this by yourself.



Consider the task frame with $\vec{x}_T$ pointing in the normal direction outward from the center of the sphere and $\vec{y}_T$ in the direction of the curve (starting from the lowest point of S). Represent the target robot end effector pose along the curve using the Cartesian positions and orientation of N equally spaced points along the curve (choose $N = 101$). Represent the orientation of the curve using the following representations and include your derivation:

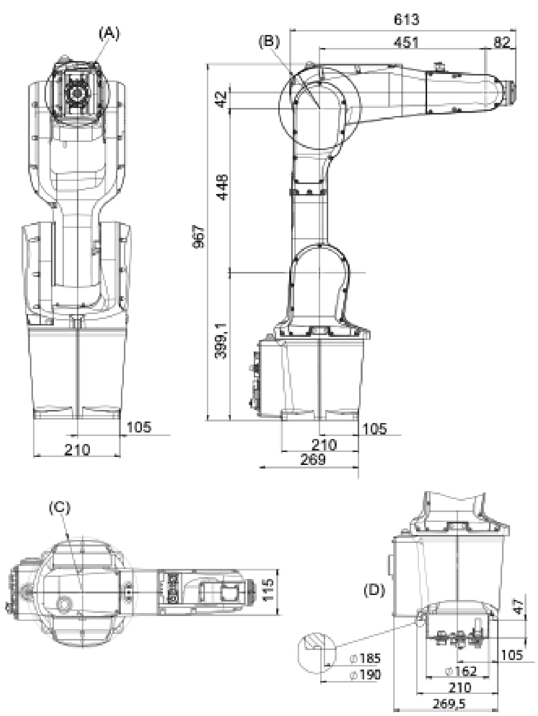
(a) Unit quaternion, $\mathsf{q}= \begin{bmatrix} \cos\frac{\theta}{2} \\ \left(\sin\frac{\theta}{2}\right) k \end{bmatrix}$

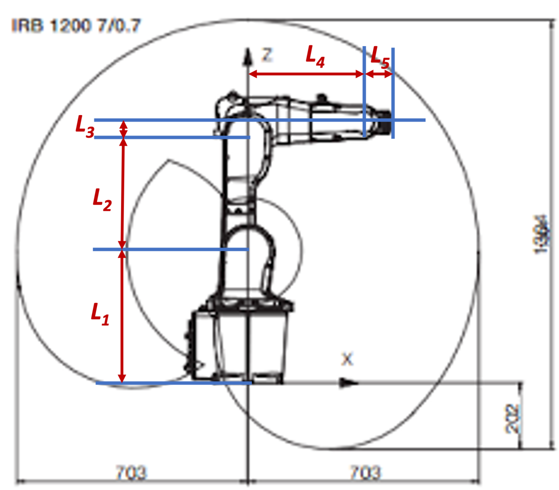
(b) yaw-pitch-roll ZYX (or roll-pitch-yaw xyz) Euler angles, $(\beta_1, \beta_2, \beta_3)$:

$$R = \mathsf{R}_z(\beta_1)\mathsf{R}_y(\beta_2)\mathsf{R}_x(\beta_3).$$

(c) Angle-axis product, $\beta = k\theta$.

2. Consider the ABB IRB 1200-5/0.9 robot as shown in its zero configuration (the manual of the robot will be posted).





(a) Find the Product of Exponential (POE), Standard Denavit-Hartenberg (SDH), Modified Denavit-Hartenberg (MDH) parameters of the robot.

(b) Write the forward kinematics code for a general open-chain robot arm using the POE convention. Apply to IRB 1200 and show the forward kinematics agrees with SDH and MDH convention.

(c) Using subproblem decomposition method, solve for the eight possible solutions of the inverse kinematics of any elbow arm with a spherical wrist. Verify your inverse kinematics code using your forward kinematics code for randomly generated joint angles.

(d) (Grad Section) Use SDH to define a MATLAB robot object. Compare the speed and accuracy of the MATLAB inverse kinematics solver and your solver.

3. Use one of the eight poses of the robot to track the S shaped curve on a sphere from Part 1. Assume the angular velocity of each joint is bounded by 2 rad/sec. If the path speed is constant, which pose gives the highest speed? Which pose gives the smallest variation of the elbow joint q_3?

4. (Grad Section) Find the end effector spatial velocity $\nu = \begin{bmatrix} \omega \\ v \end{bmatrix}$ (6×1 stacked angular and linear velocities) along the path.

Deliverable

1. Your project report should be structured as follows:
   (a) Cover page with your name, course number, date, project title, and a statement on academic integrity (stating that you did this project by yourself):
   I, [name], certify that the following work is my own and completed in accordance with the academic integrity policy as described in the Robotics I course syllabus.
   (b) Summary: what did you try to do and accomplished.
   (c) Technical Content: containing the following for each section:
      i. Description of the problem
      ii. Derivation of the solution
      iii. Results based on your simulation

      The key is to **show that you understand what you are doing**, not just tweaking the code.
   (d) Conclusion: what you learned and what can be improved.
2. Put your code in your private GitHub repository (shared with the Instructor and TA).
3. If you have any video of your results (e.g., movies of the robot motion), provide a link (e.g., YouTube), or put them in your GitHub repository (in a separate folder under the miniproject1 folder).