Medical Robotics Group Coursework

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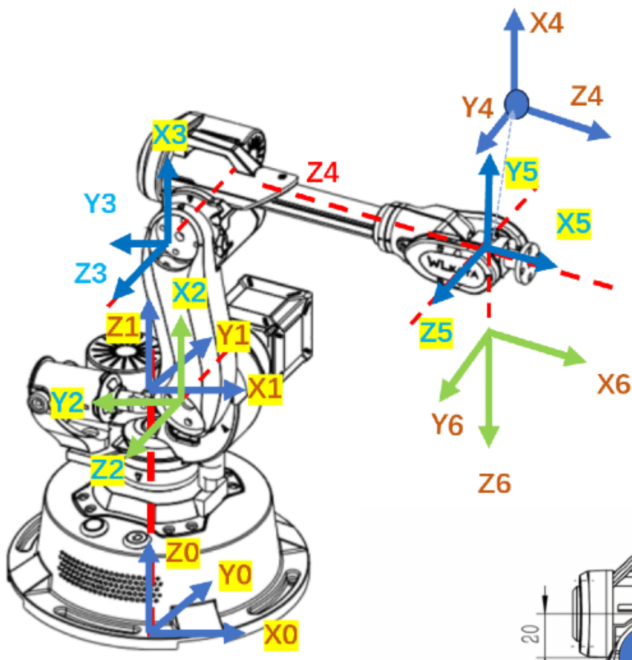
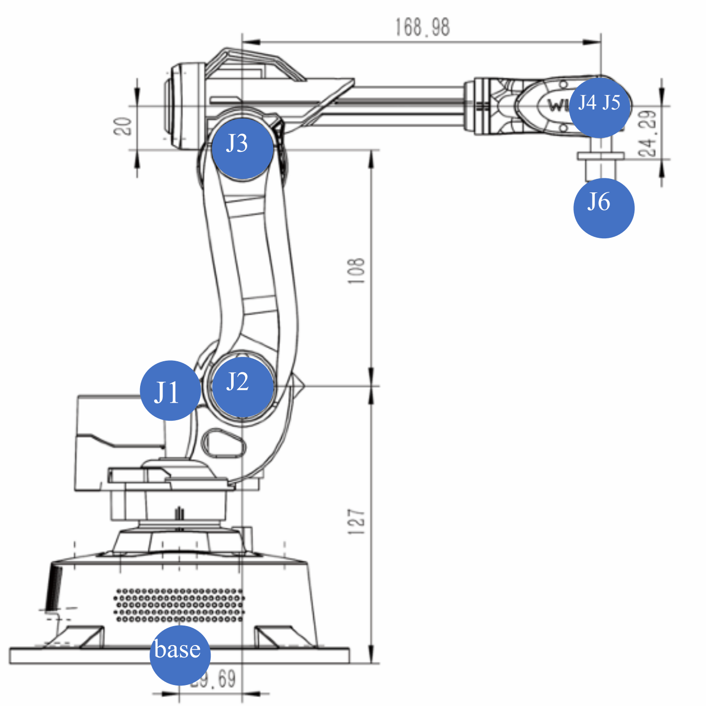
Task 1

Robot Modelling and MDH Table

Task 1 :MDH Table 1



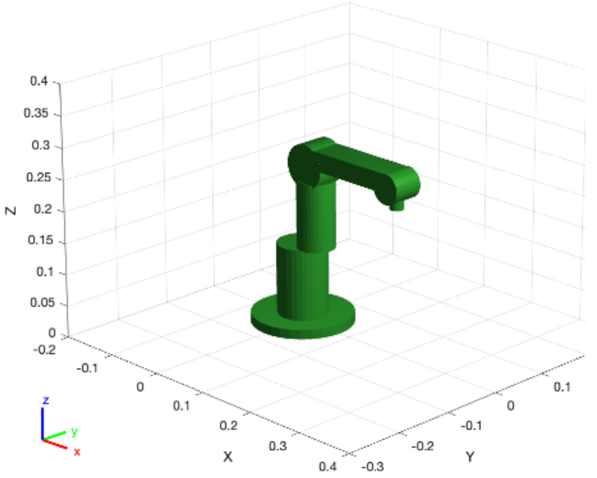
Defined frames

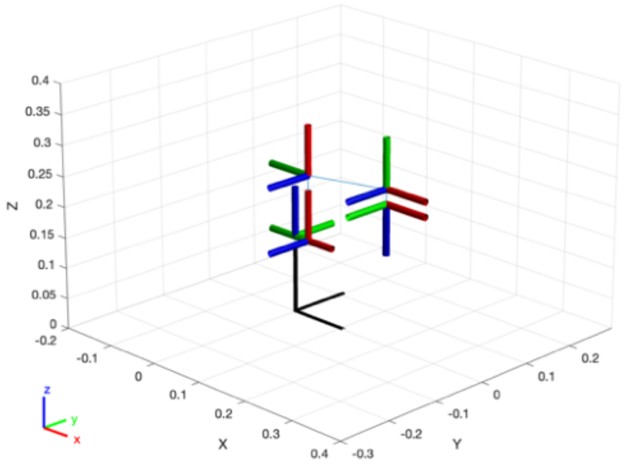


Origin of frames

MDH for CoppeliaSim

frame i	a (i-1)	alpha (i-1)	d (i)	theta (i)
1	0	0	127	0+θ1
2	29.69	90	0	90+θ2
3	108	0	0	0+θ3
4	20	90	168.98	0+θ4
5	0	-90	0	-90+θ5
6	0	90	24.29	0+θ6





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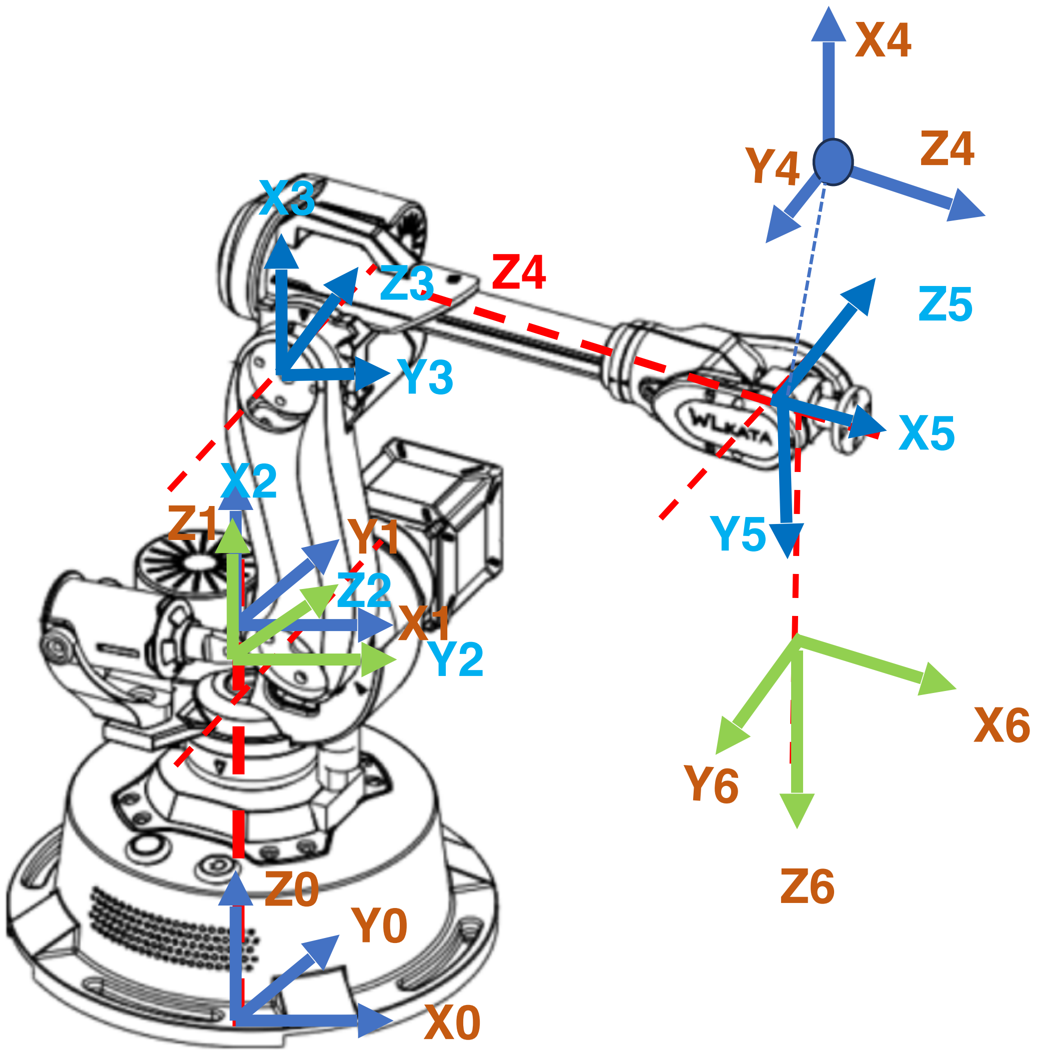
Task 1 :MDH Table 2



MDH for Real Robot

frame i	a (i-1)	alpha (i-1)	d (i)	theta (i)
1	0	0	127	0+θ1
2	29.69	-90	0	-90+θ2
3	108	0	0	0+θ3
4	20	-90	168.98	0+θ4
5	0	+90	0	+90+θ5
6	0	-90	24.29	0+θ6

Task 2

Joint Space Control

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Task 2: Model

Path Planning

Initial Pose
Intermediate Pose
Final Pose

Path 1
Path 2

Quintic Polynomial

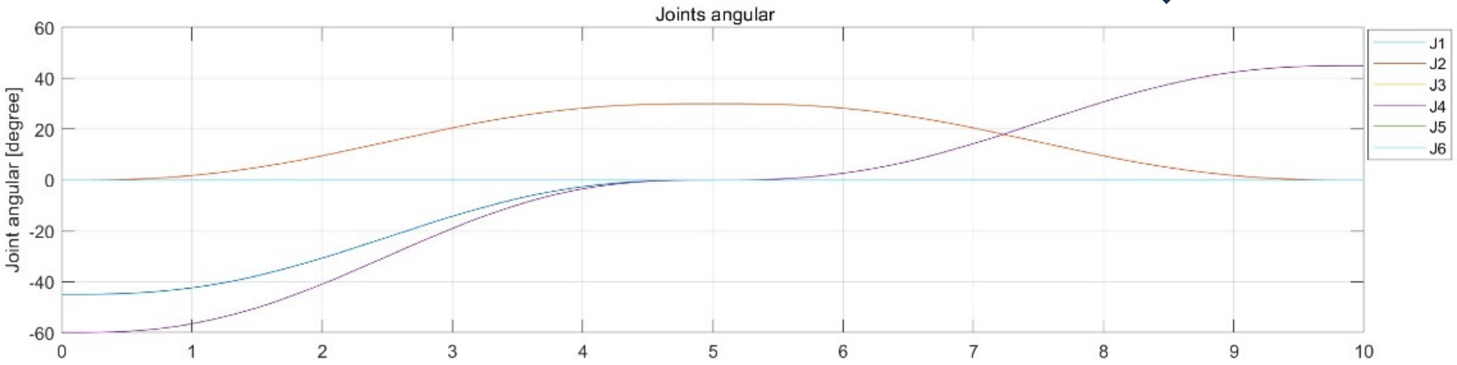
$$\begin{cases}\theta(0)=\theta_0\\ \theta(t_f)=\theta_f\end{cases}\quad\begin{cases}\dot{\theta}(0)=0\\ \dot{\theta}(t_f)=0\end{cases}\quad\begin{cases}\ddot{\theta}(0)=0\\ \ddot{\theta}(t_f)=0\end{cases}$$

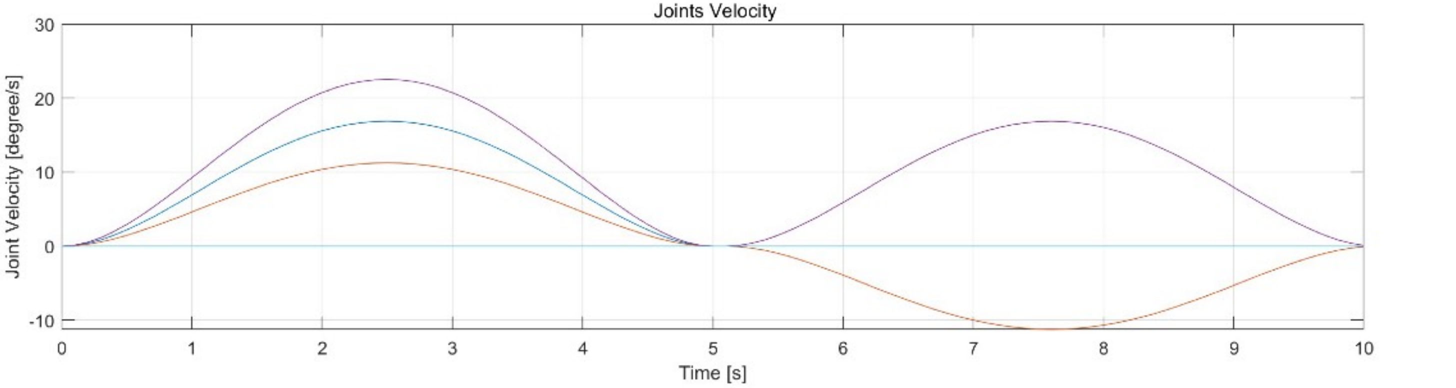
$$\begin{cases}\theta(t)=a_0+a_1t+a_2t^2+a_3t^3+a_4t^4+a_5t^5\\ \dot{\theta}(t)=a_1+2a_2t+3a_3t^2+4a_4t^3+5a_5t^4\\ \ddot{\theta}(t)=2a_2+6a_3t+12a_4t^2+20a_5t^3\end{cases}$$

Forward Kinematics

End-Effector Position
In Cartesian Space

Result





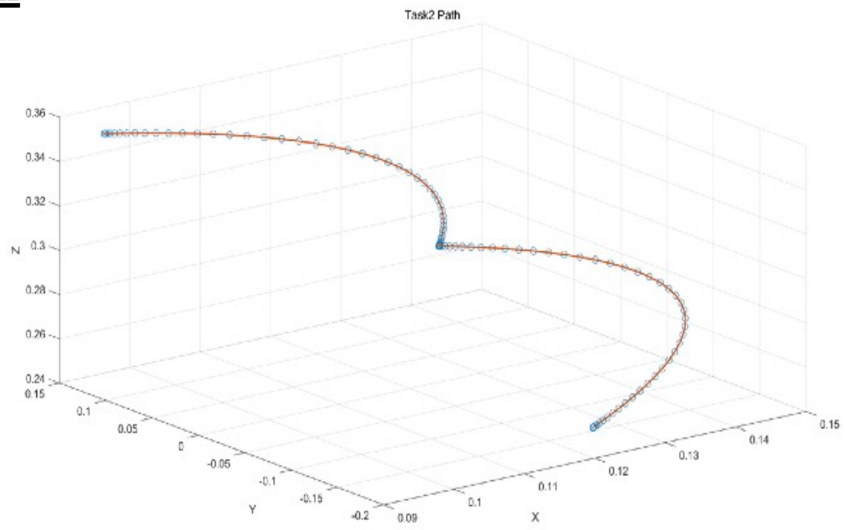
Guarantee Joint Limits

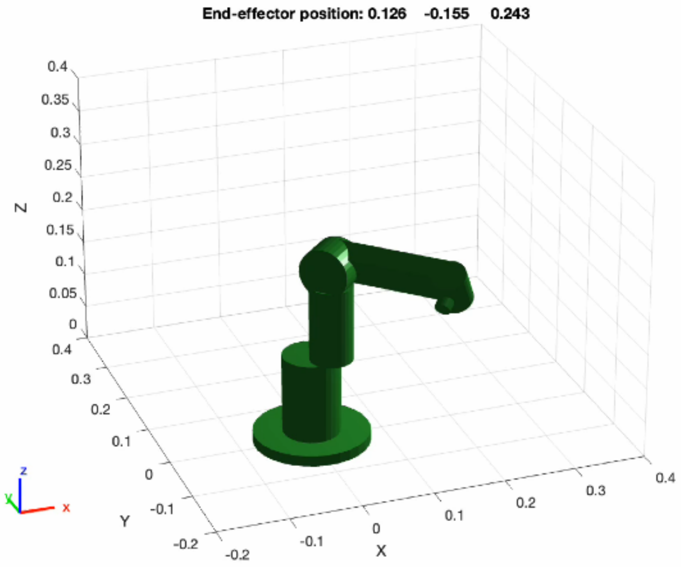
	Angular limit (deg)		Velocity limit (deg/s)
J1	-110	160	85
J2	-35	70	60
J3	-120	60	65
J4	-180	180	200
J5	-200	30	200
J6	-360	360	450

Task 2: Validation

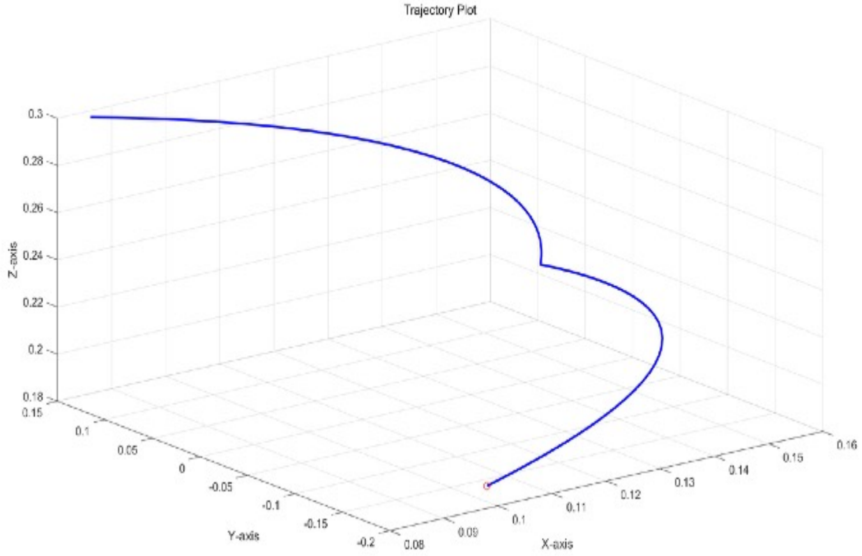
Trajectory Validation

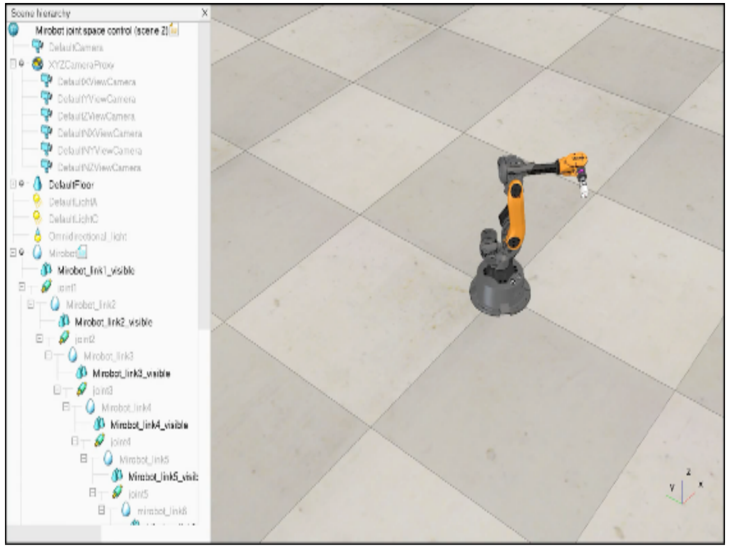
In Matlab





In Coppelia





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Task 3

Cartesian Space Control

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Task 3

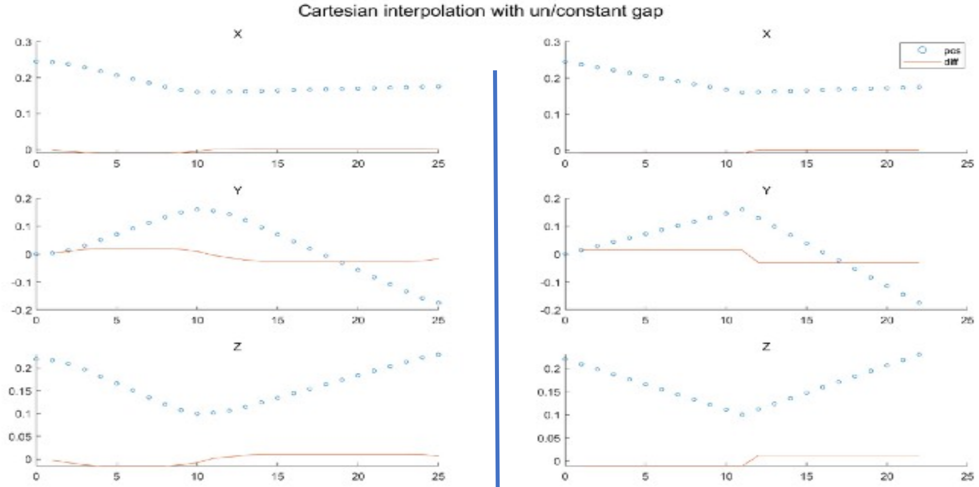
Path Planning

InitialPose
IntermediatePose
FinalPose

Straight line → Interpolation → Path Planning in Cartesian Space

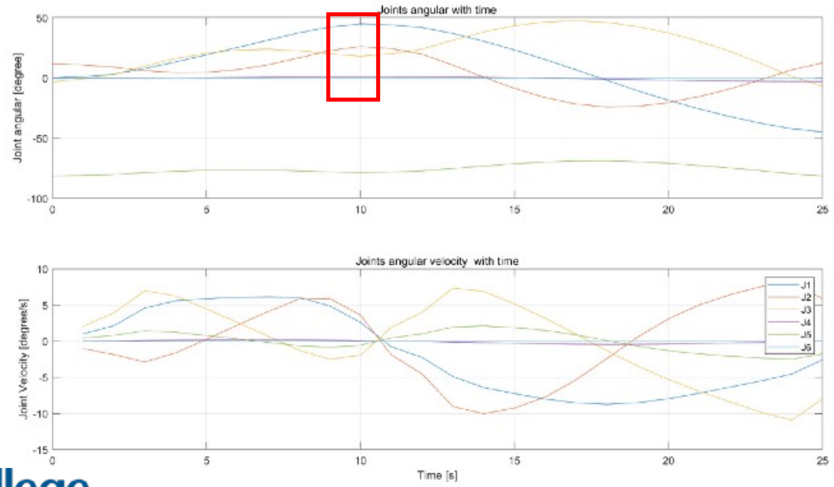
Inverse Kinematics → Jacobian, Joint limits, Newton Iteration → Joints Pose

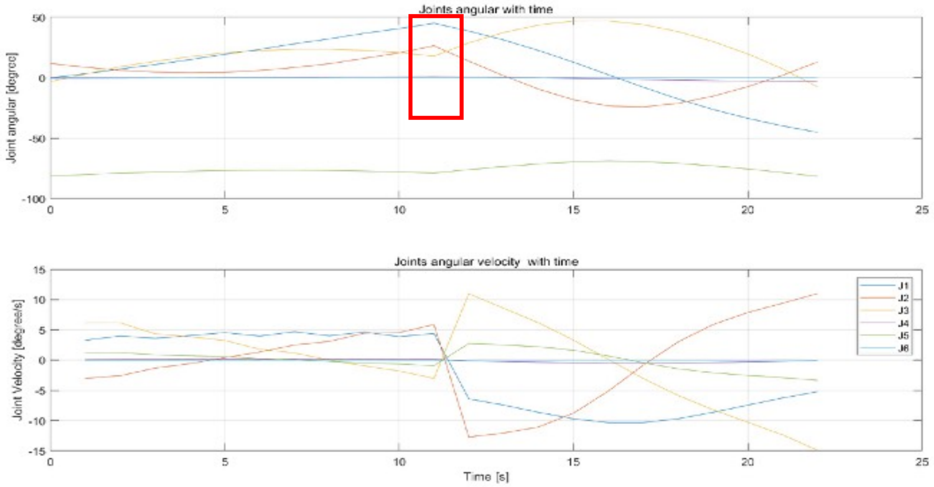
Joint Movement → Trajectory



Interpolate with different gap

Interpolate with same gap

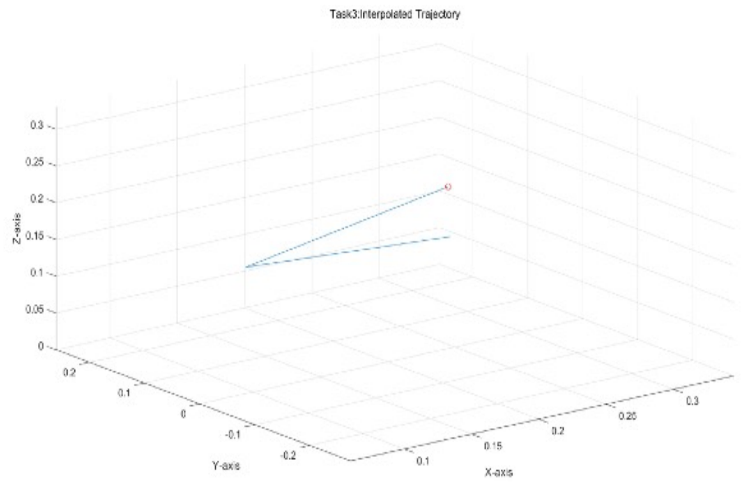


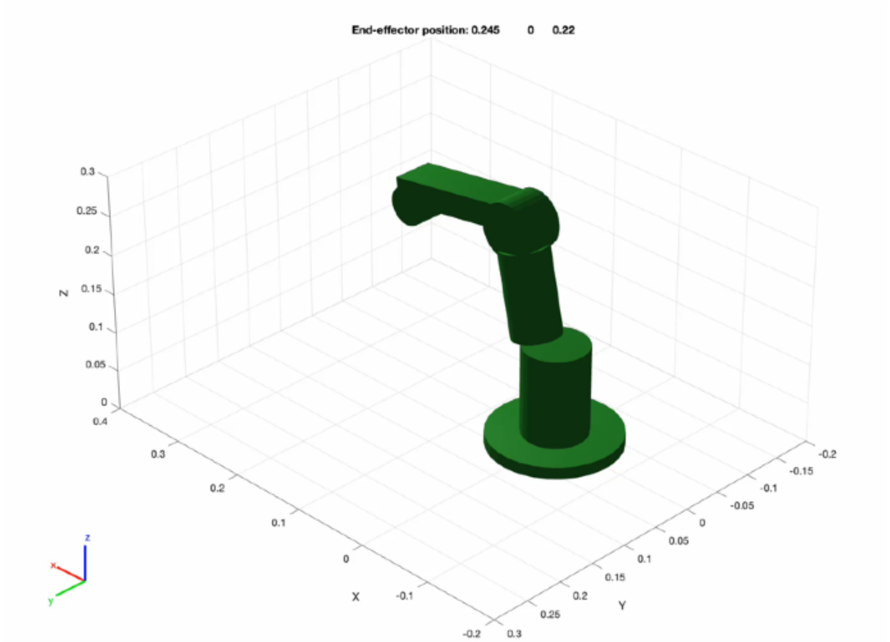


Task 3 : Validation

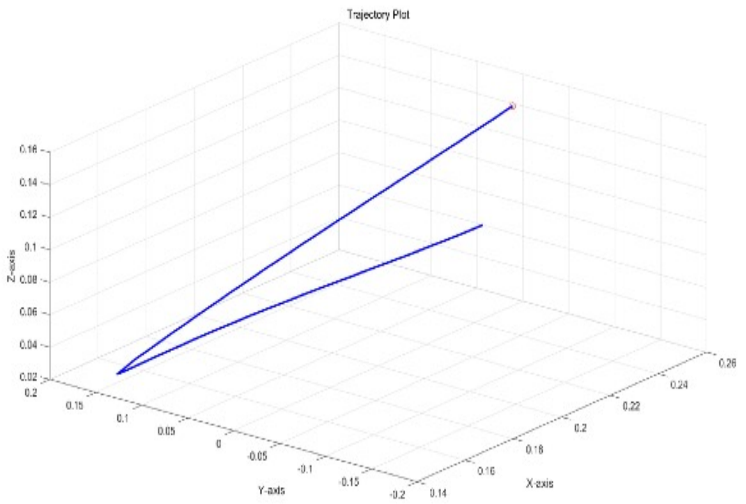
Trajectory Validation

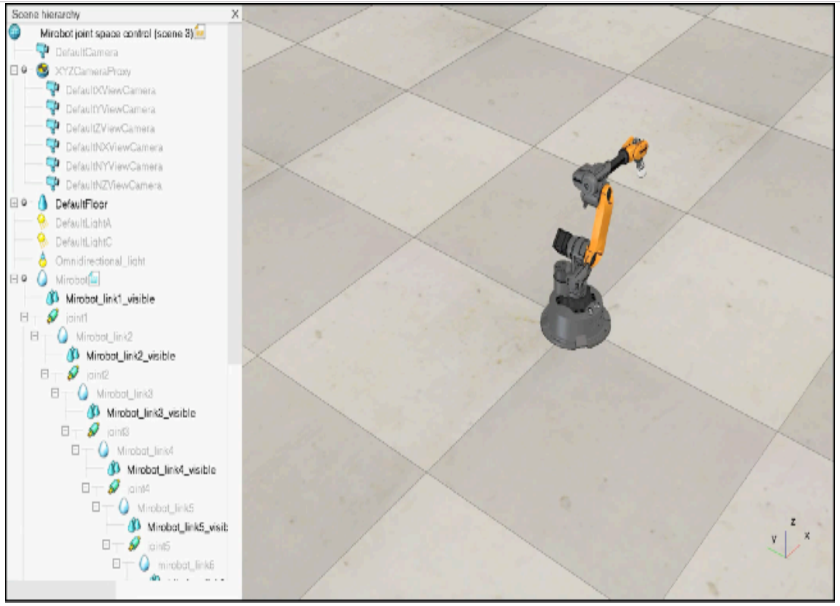
In Matlab





In CoppeliaSim





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Difference between Cartesian and Joint space control

Cartesian space control

- Trajectory defined in end effector position
- Easy to visualise trajectory
- Joint motion derived from end effector path through inverse kinematics
- Joint speeds and acceleration can be non-uniform
- Instability near singularities or areas where large changes in joint spaces are required
- Robot independent
- Preferred when control of end effector position is key

  e.g. robotic surgery, drawing etc

Joint space control

- Trajectory defined in terms of joint angles/positions
- Not easy to visualize trajectory
- Joint motion controlled hence uniform motion
- The performance is less prone to vibration
- No problem with singularities
- Robot dependent
- Preferred method when space is limited or when carrying out tasks where control over joints is key e.g. obstacle avoidance

Task 4: Robot Pick-and-Place
Three-Finger Soft Gripper

3-Finger Soft Gripper X 1

[1]

Pneumatic Box X 1

Joint-Space Method

Trajectory planning using waypoints

Waypoints Initiating → (Jacobian & IK) → Joint-Space → (Polynomial Interpolation) → Path planning in Joint-Space → Joint Pose

Waypoints	X	Y	Z	Comment
Point 1	0.200	0.150	0.040	Above Cube
Point 2	0.200	0.150	0.025	Pick Cube
Point 3	0.200	0.150	0.070	Up
Point 4	0.000	0.290	0.030	Move
Point 5	0.000	0.290	0.030	Place
Point 6	0.000	0.280	0.070	Up

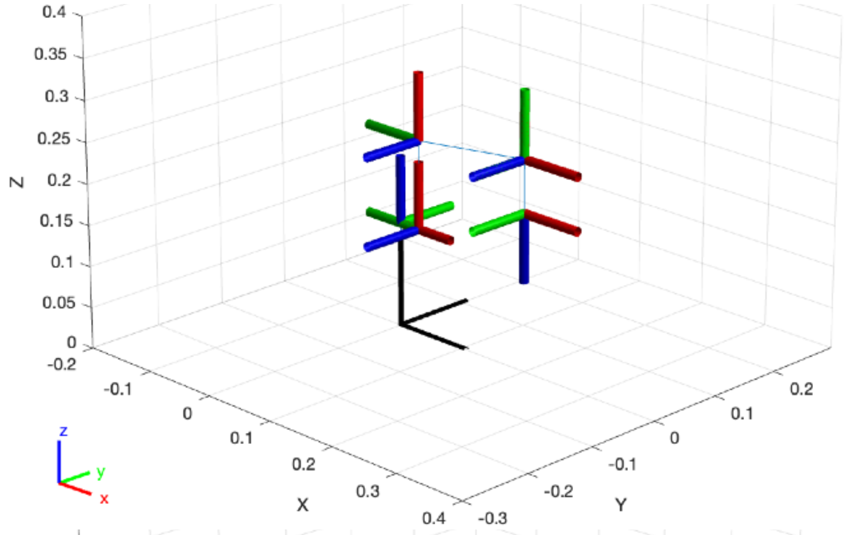
Task 4

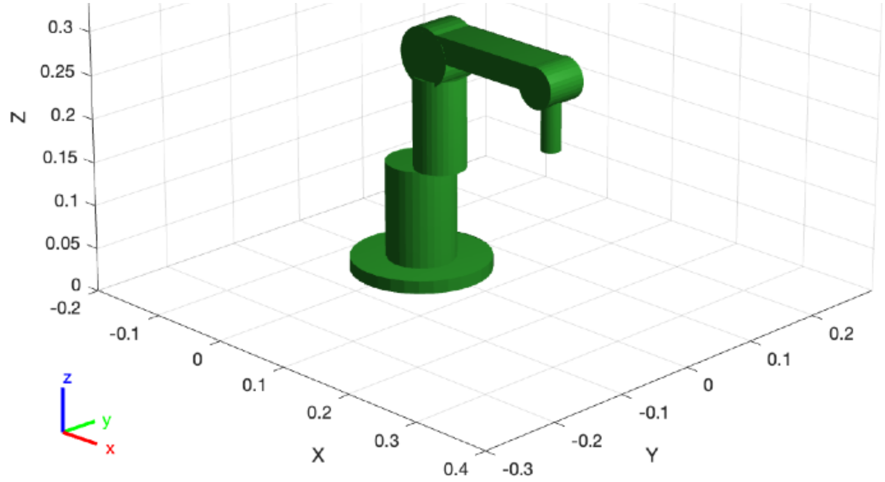
Challenge 1: Mounting E-E

New DH table to extend link 6 length

frame (i)	a (i-1)	alpha (i-1)	d (i)	theta (i)
1	0	0	127	0+θ1
2	29.69	-90	0	-90+θ2
3	108	0	0	0+θ3
4	20	-90	168.98	0+θ4
5	0	+90	0	+90+θ5
6	0	-90	24.29+40	0+θ6

New robot model with end-effector





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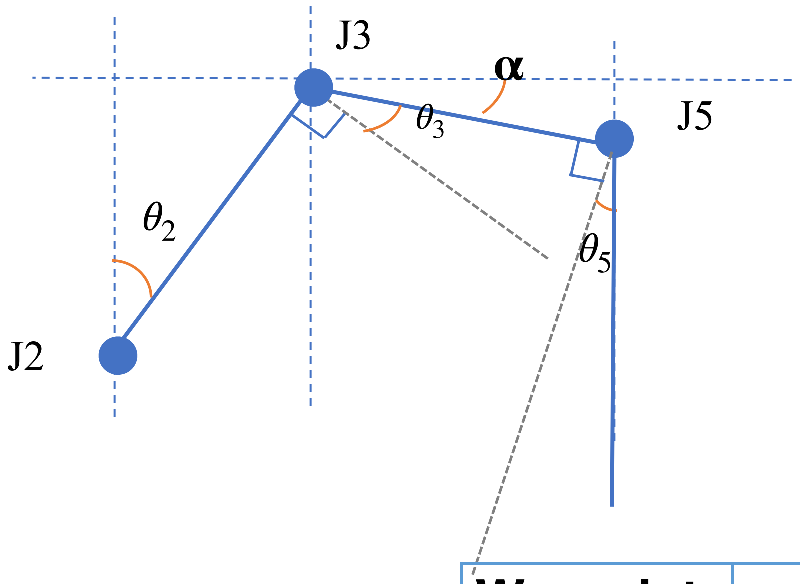
Challenge 2: Gripper downwards



During Jacobian and IK

$$\theta_5 = -(\theta_2 + \theta_3) = \alpha$$

$$\theta_4 = \theta_6 = 0$$

Reach the destination:
No θ constraints at Point 5

Waypoints	X	Y	Z	Comment
Point 1	0.200	0.150	0.040	Above Cube
Point 2	0.200	0.150	0.025	Pick Cube
Point 3	0.200	0.150	0.070	Up
Point 4	0.000	0.290	0.030	Move
Point 5	0.000	0.290	0.030	Place
Point 6	0.000	0.280	0.070	Up

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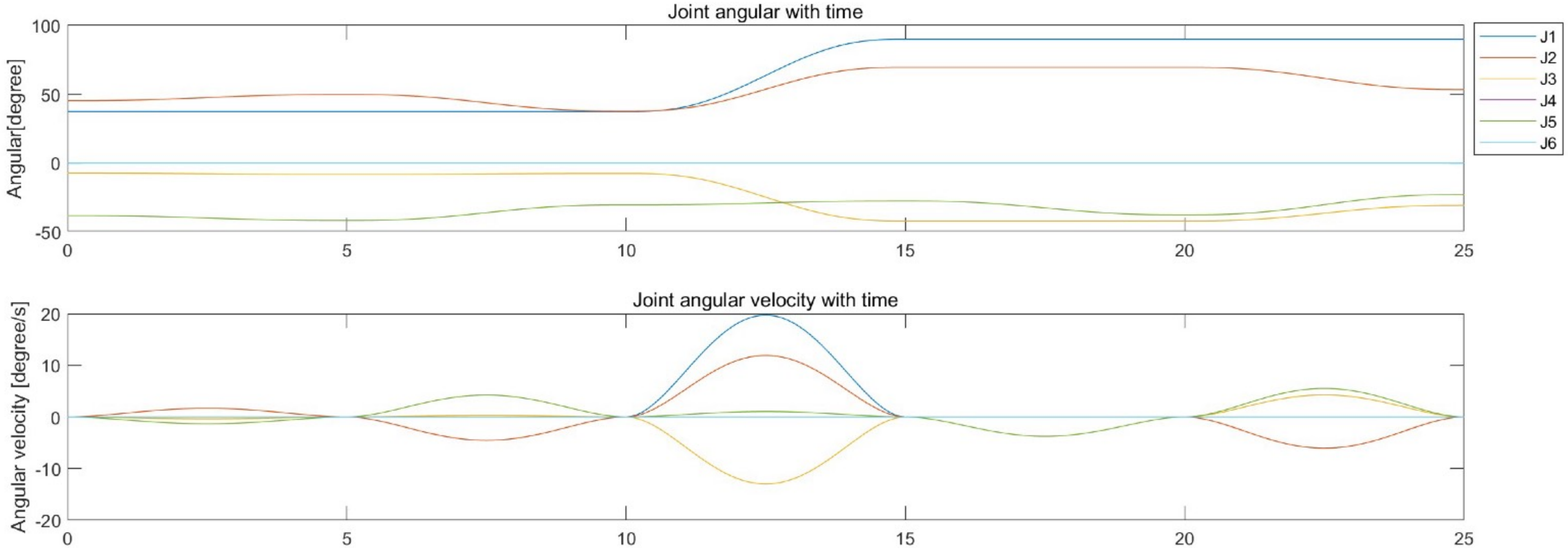
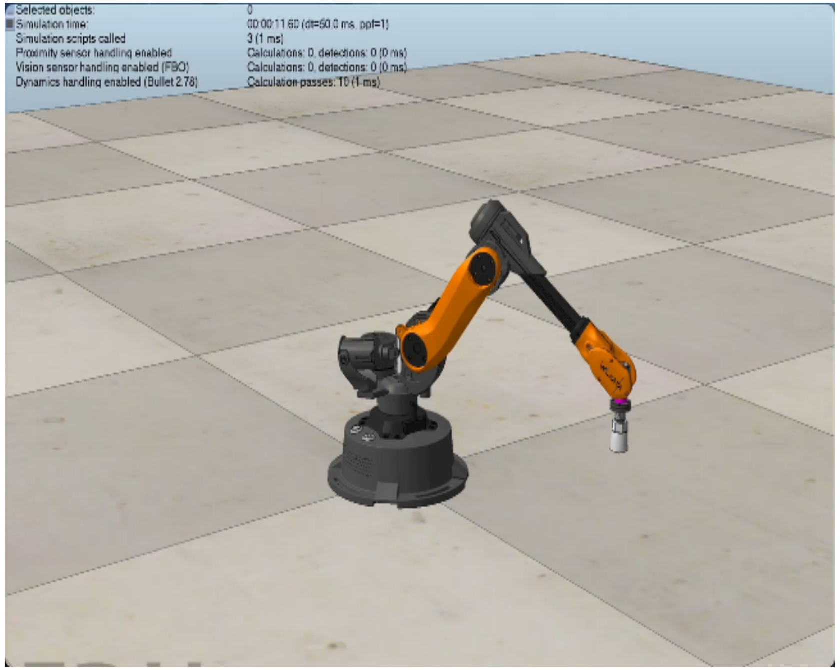
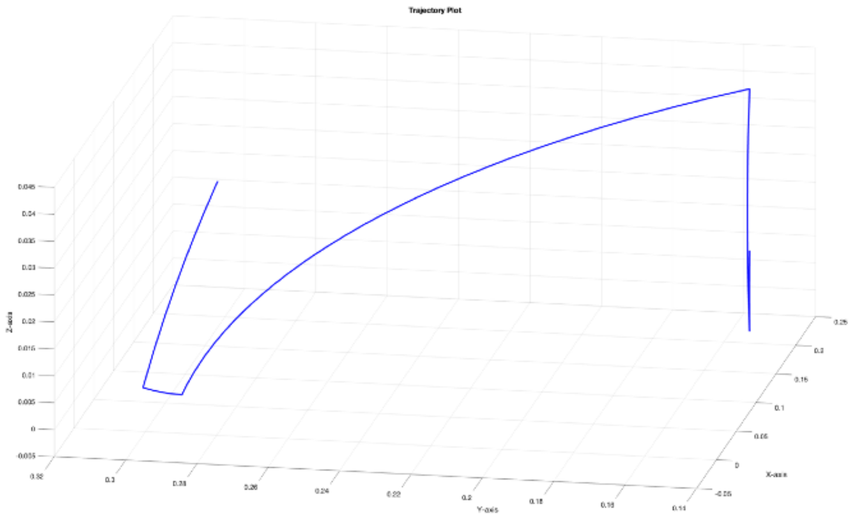
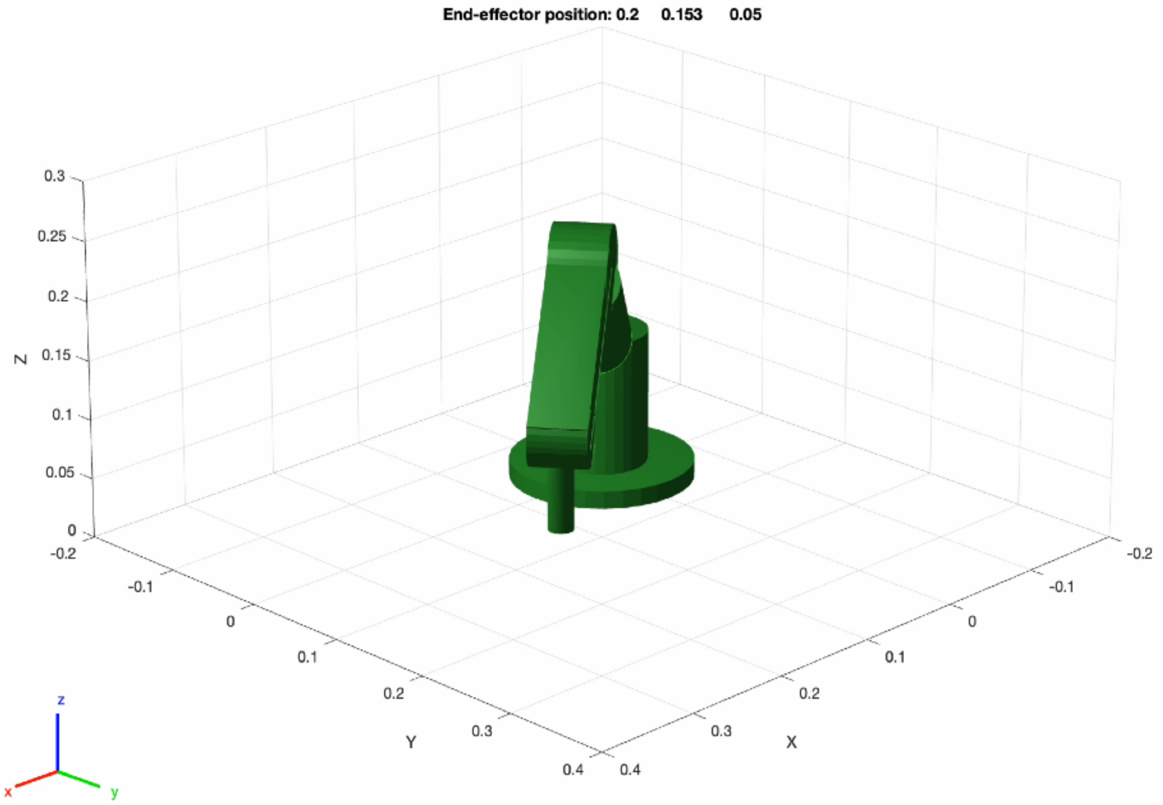
Simulation Result

Angular Velocity









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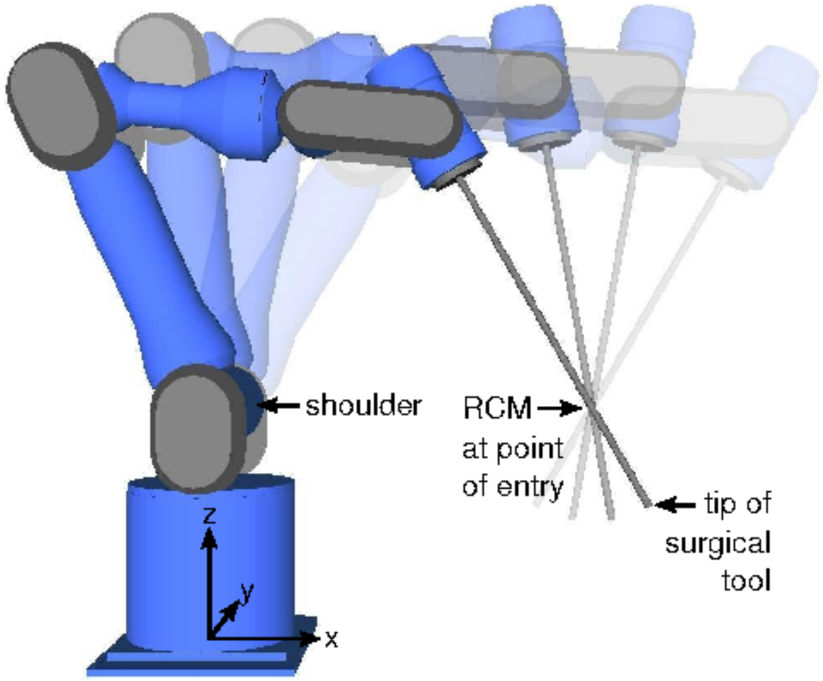
Bonus Task

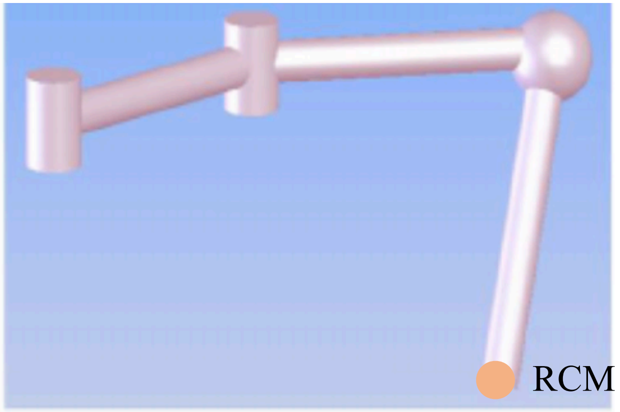
Minimally Invasive Surgery



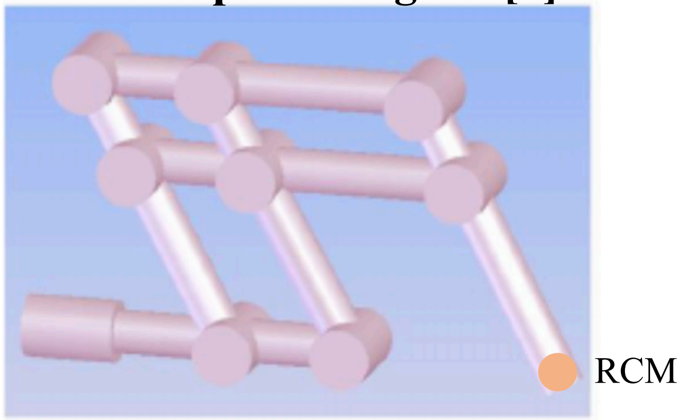
A Robot arm with RCM point illustration [2]

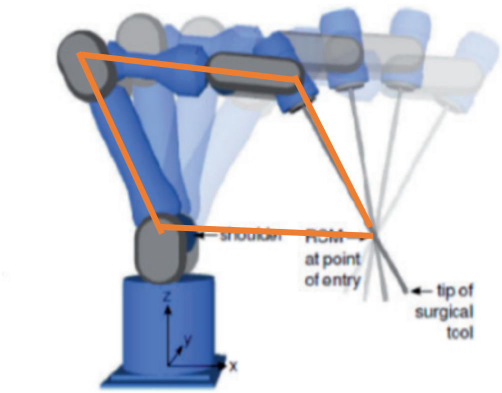
Geometry Solution

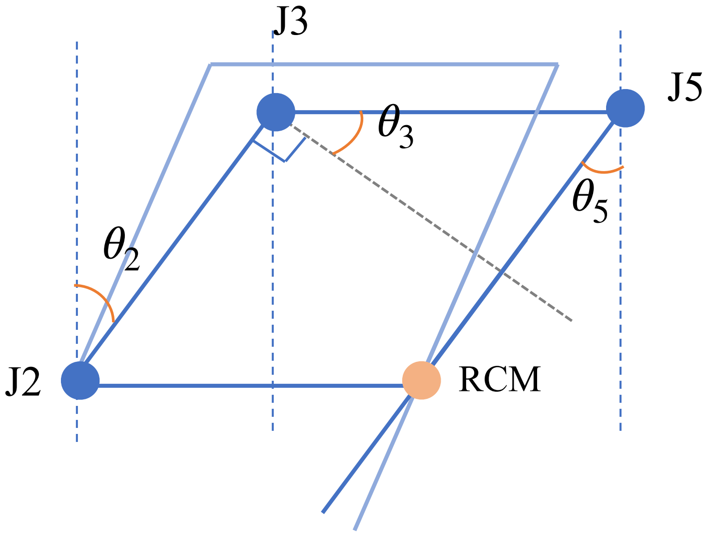
Passive Joint



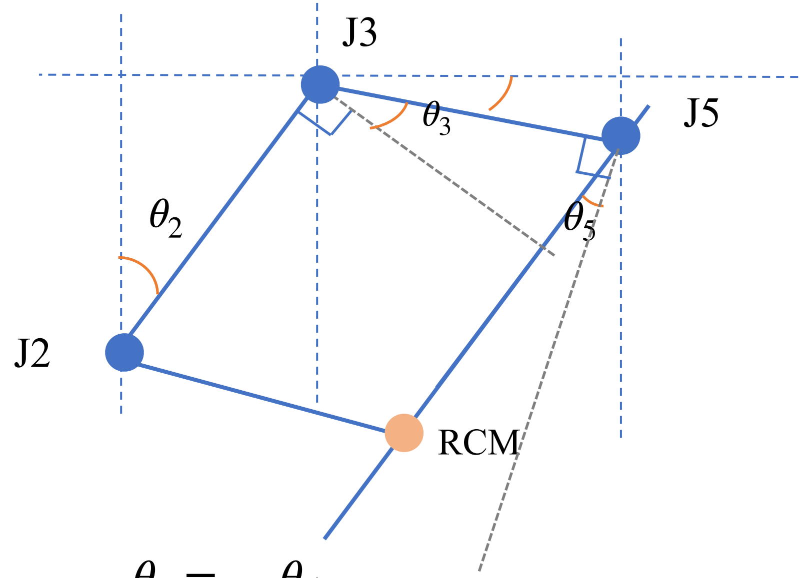
Double parallelogram[3]







$$\theta_2 = -\theta_3 = \theta_5$$



$$\theta_3 = -\theta_5$$

$$\theta_2 = \theta_5 + \alpha$$

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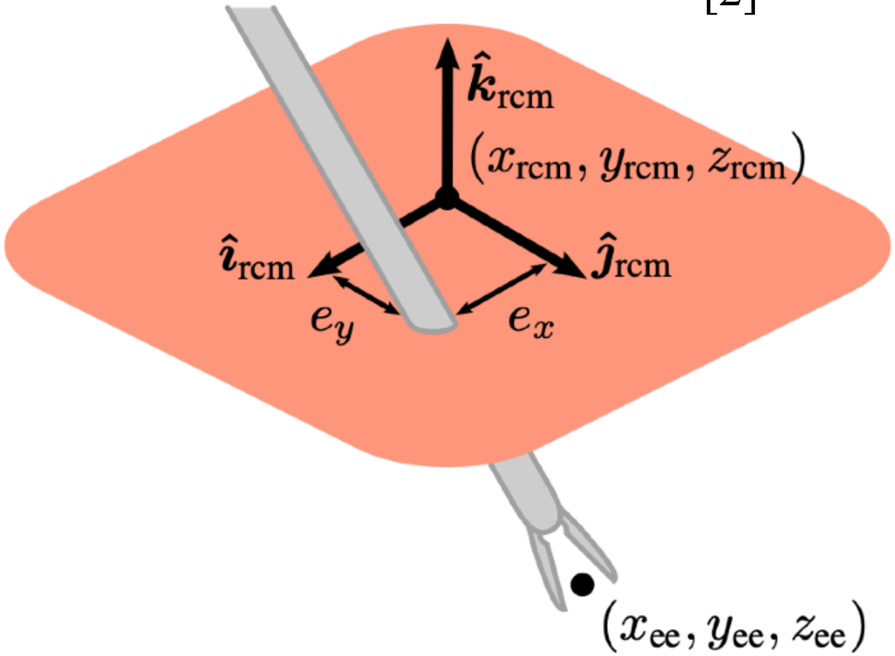
Combined with Algebra Solution

[2]



$$J_a = \frac{\partial(x_{ee}, y_{ee}, z_{ee}, e_e, e_y)}{\partial(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5)}$$

Only 3 Variables

Keep End-Effector Horizontal Direction

$$\theta_5 = \theta_2 + \theta_3 - pi/2$$

Vertical Direction

$$\theta_5 = -(\theta_2 + \theta_3)$$

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Reference

[1] WLKATA Robotics, “WLKATA Robotics Documents” Available at https://document.wlkata.com/?doc=/
[2] Locke, R.C., & Patel, R.V. (2007). Optimal Remote Center-of-Motion Location for Robotics-Assisted Minimally-Invasive Surgery. Proceedings 2007 IEEE International Conference on Robotics and Automation, 1900-1905.
[3] Kim, Sung-Kyun & Shin, Won-Ho & Ko, Seong Young & Kim, Jonathan & Kwon, Dong-Soo. (2008). Design of a compact 5-DOF surgical robot of a spherical mechanism: CURES. IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM. 990 - 995. 10.1109/AIM.2008.4601796.

Q & A
Thanks for listening!