SimulatorBot

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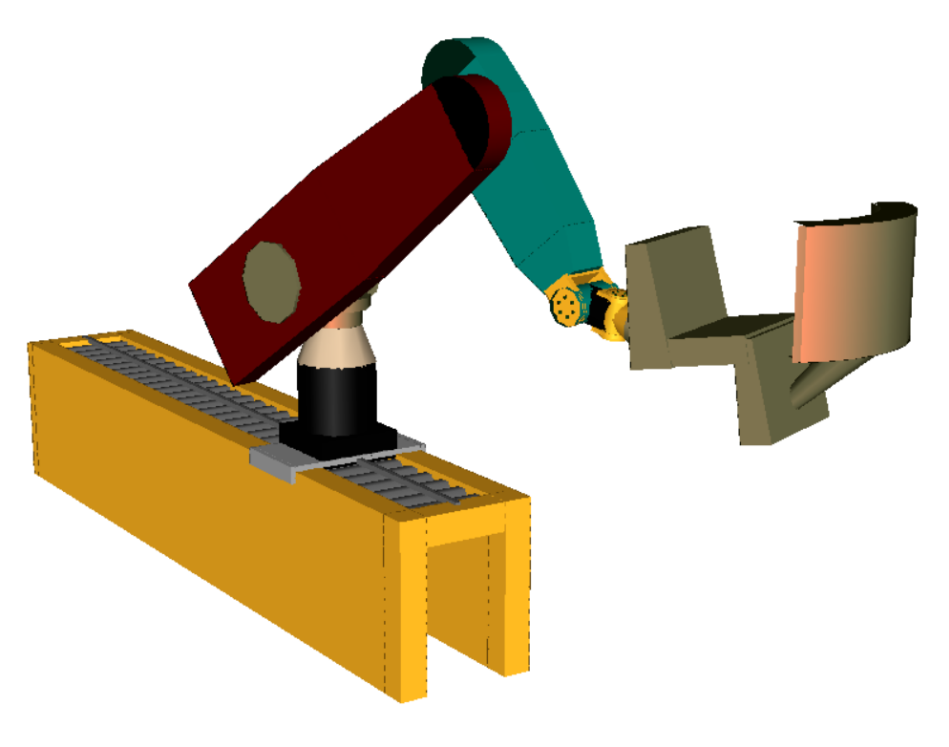
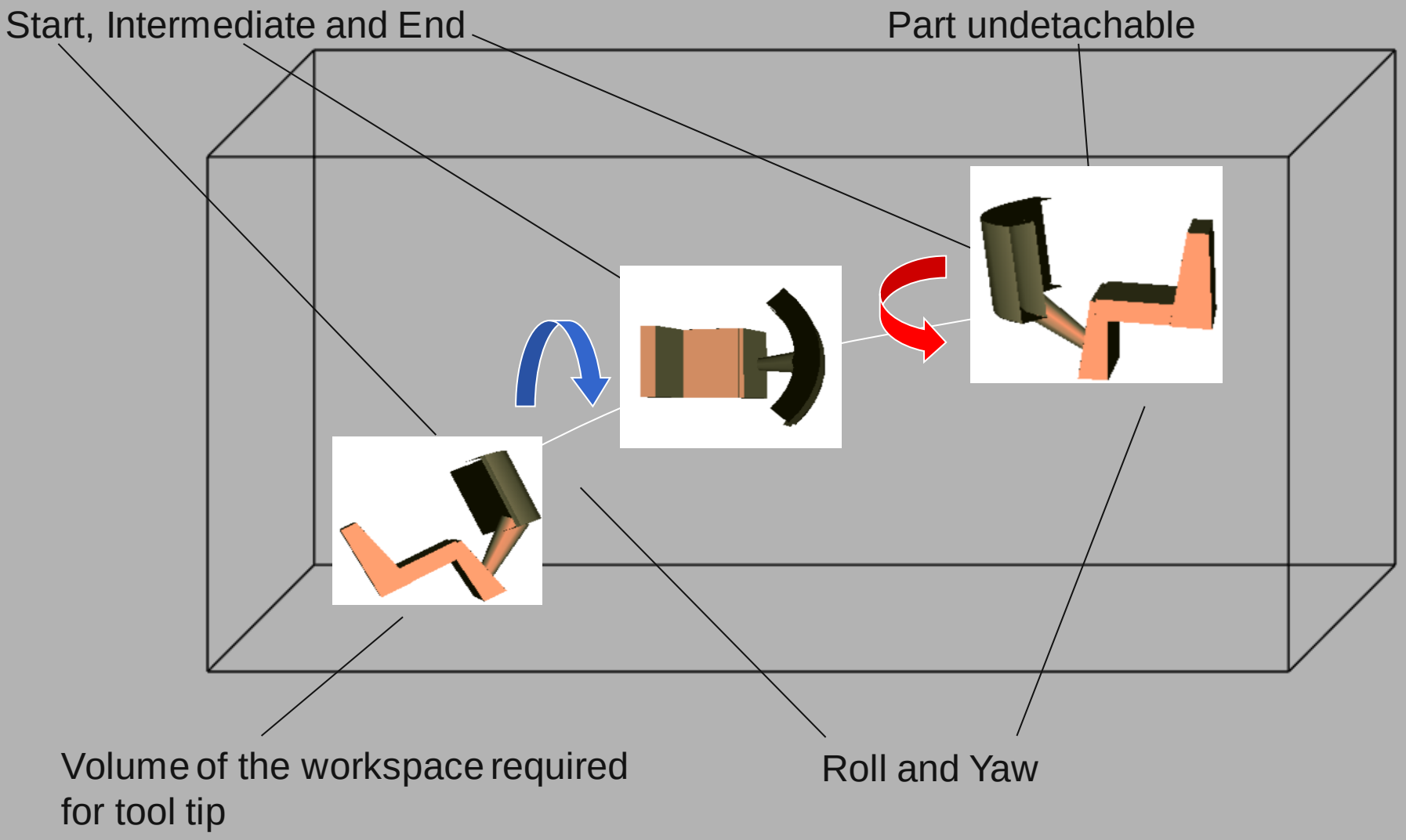


Robotic Task (Description)



Robotic Task (Requirements)

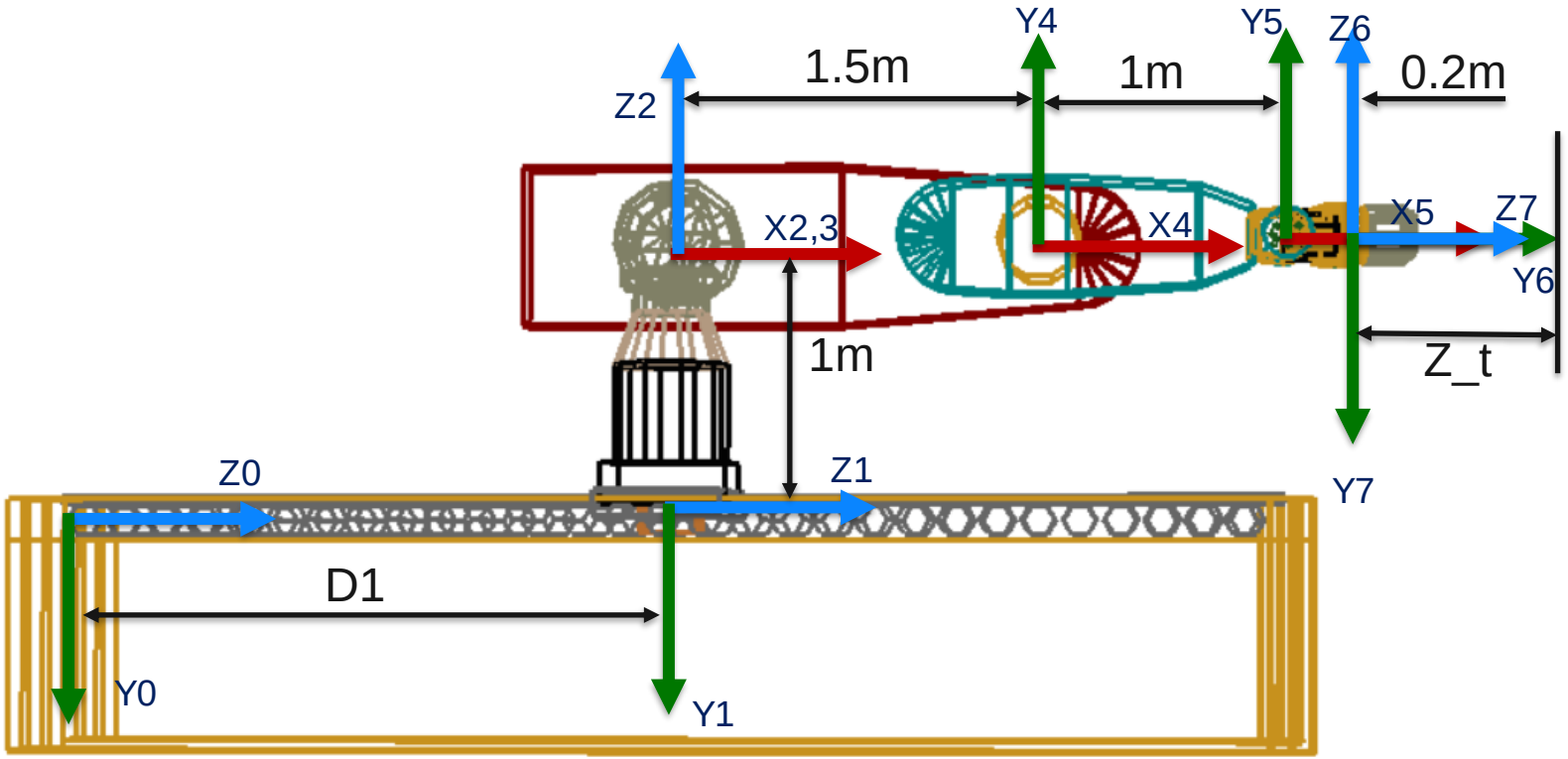
- **Kinematic Requirements**
  - 3 DOF to position the simulator
  - 3 DOF orientation of the simulator
- **Workspace Requirements**
  - Reachable – $306\ m^3$ to the end of the simulator.
  - Dexterous – $80\ \%$ of the reachable workspace.
- **Force Requirements**
  - Force – at least $[0,1000,0]^T N$
  - Moment - No moments applied
- **Other**
  - Redundant joint to avoid internal workspace Singularities

Robot Design (Specifications)

Description	Specification
Total Degrees of Freedom	7
Arm Type*	DYPP
Wrist Type†	PYR (IAW-No)
Redundancy	Prismatic joint at base
Length Sum (L)	$5.7\ m$
Structural Length Index (Q)	≈ 0.85

**R=roll, P=pitch, Y=yaw, D=prismatic*
†IAW-intersecting axis wrist

Robot Design (Link Frames)



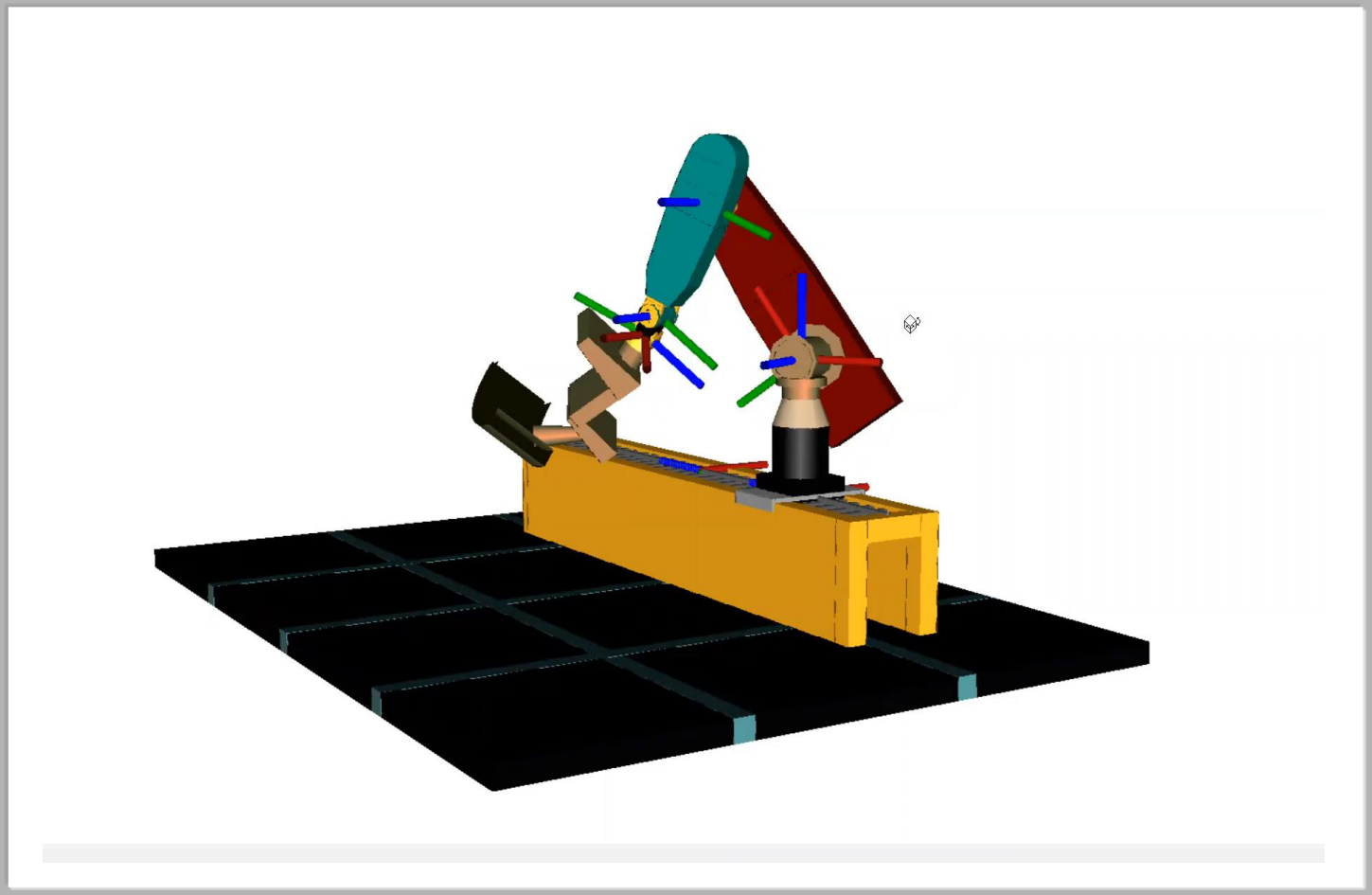
$\underline{\theta}_{HOME}=[0, \pi/2, 0, 0, 0, -\pi/2, 0]^T$

Robot Design (D-H Table)

i	α_{i-1} (deg)	a_{i-1} (m)	d_i (m)	θ_i (deg)	JL^- (deg)	JL^+ (deg)
1	0	0	d1	0	-1m	1m
2	90	0	1	θ_2	-360	360
3	90	0	0	θ_3	-160	160
4	0	1.5	0	θ_4	-160	160
5	0	1	0	θ_5	-135	135
6	-90	0.2	0	θ_6	-135	135
7	-90	0	0	θ_7	-360	360

JL = JOINT LIMIT

Robot Design (Joint Animation)



Forward Kinematics

$$p0T = \begin{pmatrix} 0.1\,\mathrm{Cos}[\theta[2]-\theta[3]-\theta[4]-\theta[5]] + 0.1\,c_{2345} + c_2\,(c_3\,(1.5+c_4) - 1.\,s_3\,s_4) - 1.2\,(c_6\,s_2 + c_2\,c_{345}\,s_6) \\ -1. + 1.2\times(0.5\,\mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]-\theta[6]] - 0.5\,c_{3456}) - 1.5\,s_3 - 1.\,s_{34} - 0.2\,s_{345} \\ 0.1\,\mathrm{Sin}[\theta[2]-\theta[3]-\theta[4]-\theta[5]] + 0.1\,c_{2345} + d_1 + 1.5\,c_3\,s_2 + c_3\,c_4\,s_2 - s_2\,s_3\,s_4 + 1.2\,(c_2\,c_6 - c_{345}\,s_2\,s_6) \end{pmatrix}$$

$$R0T[1,1] = -c_7\,s_2\,s_6 + c_2\,(c_6\,c_7\,c_{345} + s_7\,s_{345})$$

$$R0T[1,2] = s_2\,s_6\,s_7 + c_2\,(c_7\,c_{34}\,s_5 - c_6\,c_{345}\,s_7 + c_5\,c_7\,s_{34})$$

$$R0T[1,3] = -c_6\,s_2 - c_2\,c_{345}\,s_6$$

$$R0T[2,1] = -\frac{1}{4}\times(-2\,\mathrm{Sin}[\theta[3]+\theta[4]+\theta[5]-\theta[7]] - \mathrm{Sin}[\theta[3]+\theta[4]+\theta[5]-\theta[6]-\theta[7]] - \mathrm{Sin}[\theta[3]+\theta[4]+\theta[5]+\theta[6]-\theta[7]] - \mathrm{Sin}[\theta[3]+\theta[4]+\theta[5]-\theta[6]+\theta[7]] - \mathrm{Sin}[\theta[3]+\theta[4]+\theta[5]+\theta[6]+\theta[7]] + 2\,s_{3457})$$

$$R0T[2,2] = -\frac{1}{4}\times(2\,\mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]-\theta[7]] + \mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]-\theta[6]-\theta[7]] + \mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]+\theta[6]-\theta[7]] - \mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]-\theta[6]+\theta[7]] - \mathrm{Cos}[\theta[3]+\theta[4]+\theta[5]+\theta[6]+\theta[7]] + 2\,c_{3457})$$

$$R0T[2,3] = s_6\,s_{345}$$

$$R0T[2,3] = s_6\,s_{345}$$

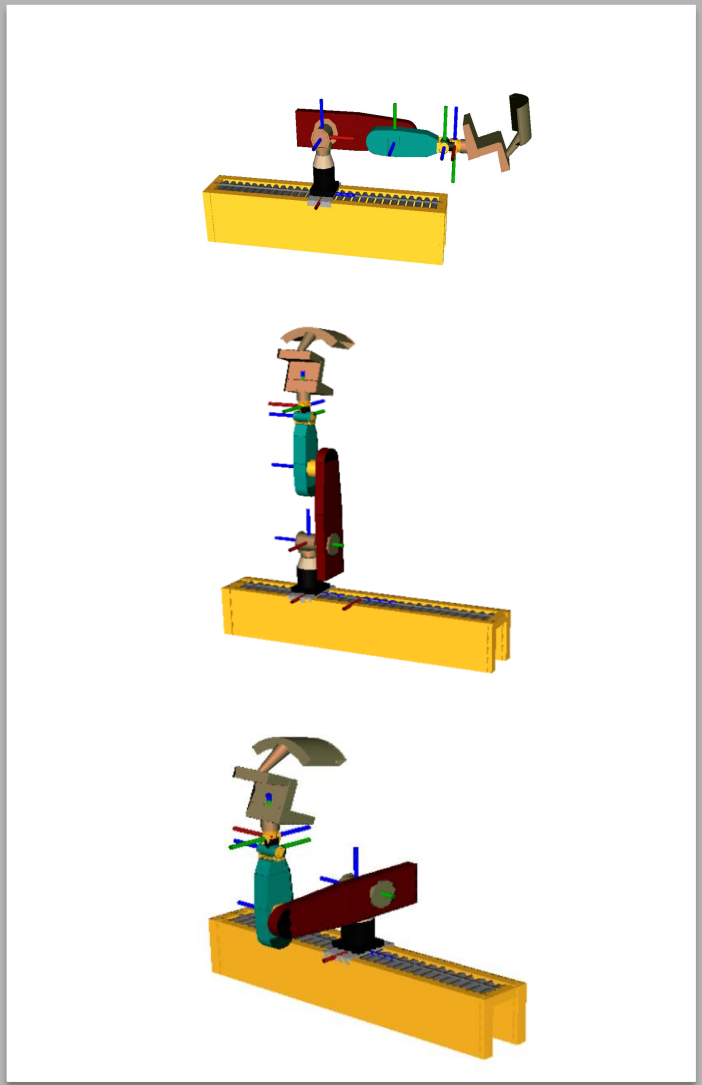
$$R0T[3,1] = c_7\,(c_6\,c_{345}\,s_2 + c_2\,s_6) + s_2\,s_7\,s_{345}$$

$$R0T[3,2] = -((c_6\,c_{345}\,s_2 + c_2\,s_6)\,s_7) + c_7\,s_2\,s_{345}$$

$$R0T[3,3] = c_2\,c_6 - c_{345}\,s_2\,s_6$$

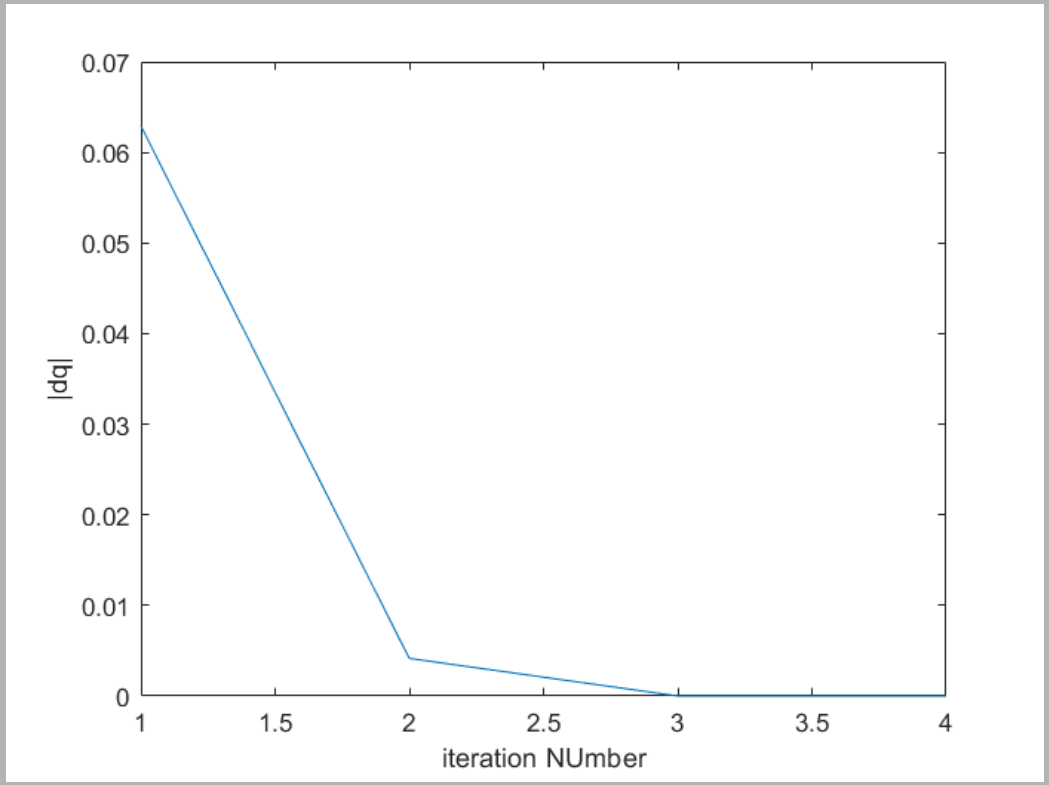
Forward Kinematics (Test)

- **q = [0,π/2,0,0,0,-π/2,0]:**
  - p0T=[0,-1,4.9]
  - R0T=[1,0,0; 0,1,0; 0,0,1]
- **q = [-1,0,π/2,0,0,-π/2,0]:**
  - p0T=[0,-4.9,-1]
  - R0T=[0,1,0; 0,0,-1; -1,0,0]
- **q = [0,0,0,π/2,0,-π/2,0]:**
  - p0T=[1.5,-3.4,1]
  - R0T=[0,1,0; 0,0,-1; -1,0,0]



Inverse Kinematics (Solution)

ITERATIVE METHOD



Inverse Kinematics (Test)

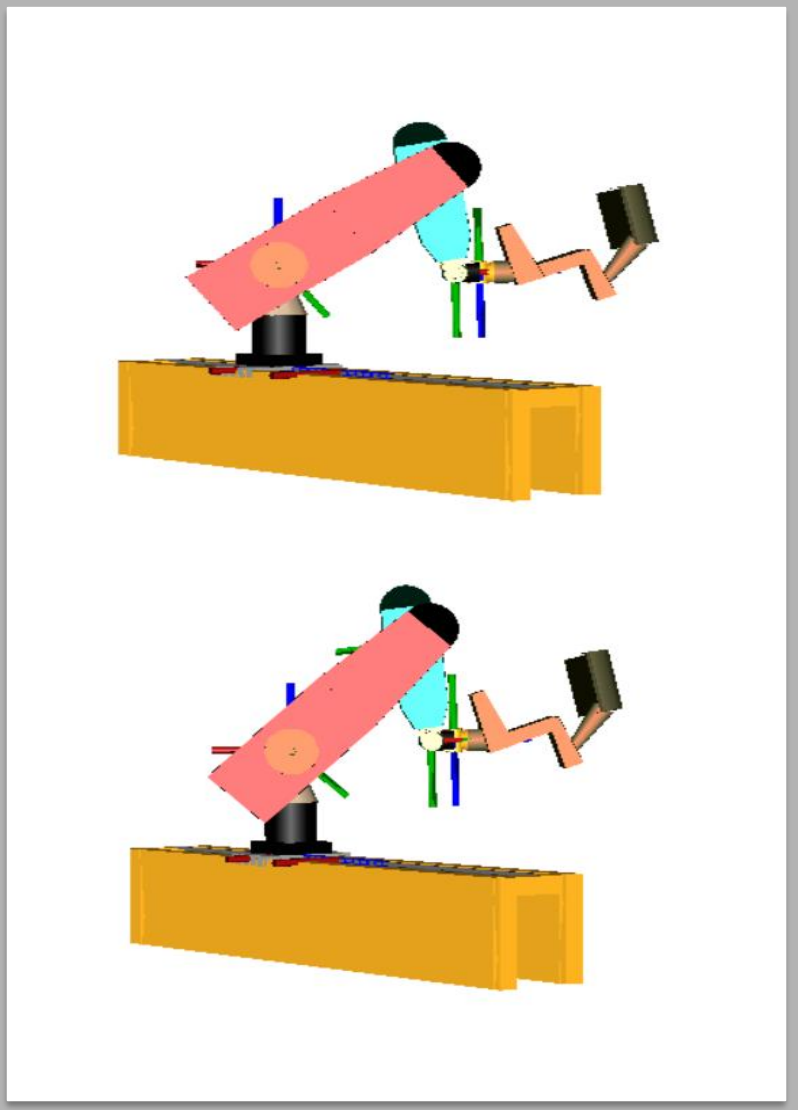
- q_{START} = [-0.9, -.61, 2.59, 1.86, -1.3, -1.5, 0]
- ${}^0p_{GOAL}$= [-2.288, -.963, .826],
- ${}^0R_{GOAL}$=[-.6, .03, .8; -.001, -.99, -.03; .8, .02, .36]

- Solution:

  q_{GOAL} = [-.8,-.6,2.5,1.98,.-1.39,-1.53,0]

  - Solution Check:

    ${}^0p_T(q_{GOAL})$ - [${}^0p_{GOAL}$]= [-2,4,2]*10^-16



Jacobian (Simplest Frame)

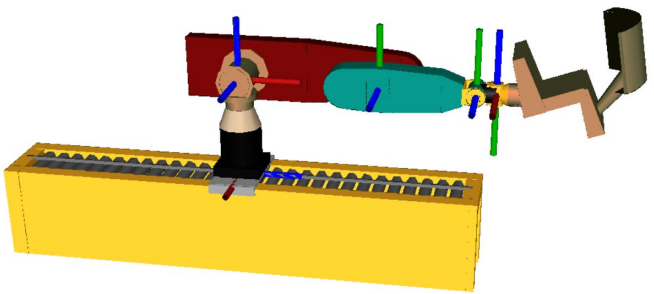
$$J_{tran} = \begin{pmatrix} c_{345}\, s_2 & -zt\, c_6\, c_{345} & 1.5\, c_5\, s_4 + (1 + 1.5\, c_4)\, s_5 & s_5 & 0. & -zt\, c_6 & 0. \\ -s_2\, s_{345} & zt\, c_6\, s_{345} & 0.2 + (1 + 1.5\, c_4)\, c_5 - 1.5\, s_4\, s_5 - zt\, s_6 & 0.2 + c_5 - zt\, s_6 & 0.2 - zt\, s_6 & 0 & 0 \\ -c_2 & c_{345}\,(-0.2 + (-1 - 1.5\, c_4)\, c_5 + 1.5\, s_4\, s_5 + zt\, s_6) + (-1.5\, c_5\, s_4 + (-1. - 1.5\, c_4)\, s_5)\, s_{345} & 0 & 0 & 0. & zt\, s_6 & 0. \end{pmatrix}$$

$$J_{rot} = \begin{pmatrix} 0 & s_{345} & 0 & 0 & 0 & 0 & -s_6 \\ 0 & c_{345} & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & -c_6 \end{pmatrix}$$

Singularities

- **Boundary:**

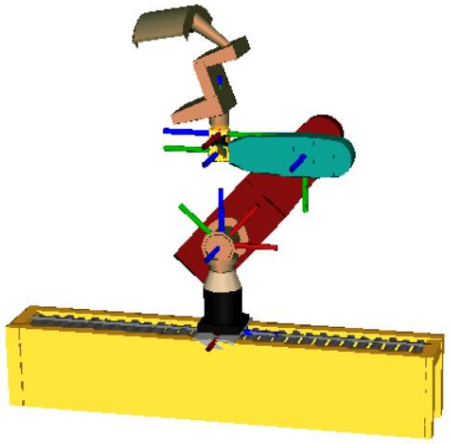
$$J0 = \begin{pmatrix} 0 & -3.9 & 0. & 0. & 0. & -1.2 & 0 \\ 0 & 0 & -3.9 & -2.4 & -1.4 & 0. & 0 \\ 1 & 0. & 0. & 0. & 0. & 0. & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$



- **Internal:**

linearly dependent columns

$$J0 = \begin{pmatrix} 0 & -4.\times10^{-16} & -1.\times10^{-17} & -1.\times10^{-17} & -1.\times10^{-17} & -1. & 0 \\ 0 & 0 & -3.\times10^{-16} & 0. & -9.\times10^{-17} & 7.\times10^{-17} & 0 \\ 1. & 0 & -3. & -1. & -1. & 0 & 0 \\ 0 & 0 & 1. & 1. & 1. & 0 & 0 \\ 0 & -1. & 0 & 0 & 0 & -6.\times10^{-17} & -1. \\ 0 & 0 & 0 & 0 & 0 & -1. & 6.\times10^{-17} \end{pmatrix}$$



Maximum Load

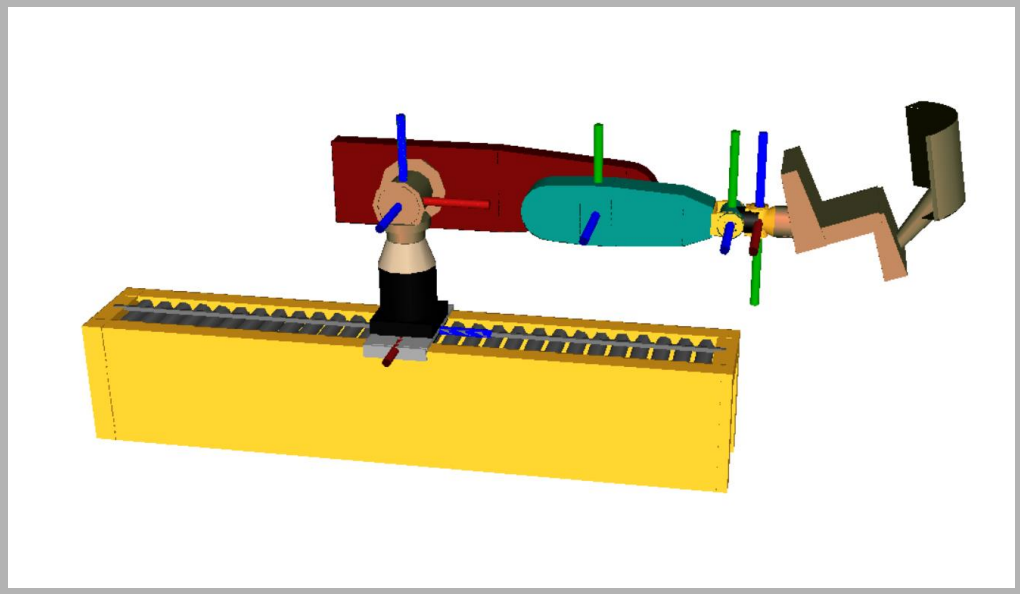
- **Maximum Task Force/Torque:**

  F_{MAX} = [0,1130,0]N,
  N_{MAX} = [0,0,0]

- **Workspace Pose:**

  ${}^0p_T$= [0,-1,4.9],

${}^0R_T$= [1,0,0;0,1,0;0,0,1]



- **Joint Position:**

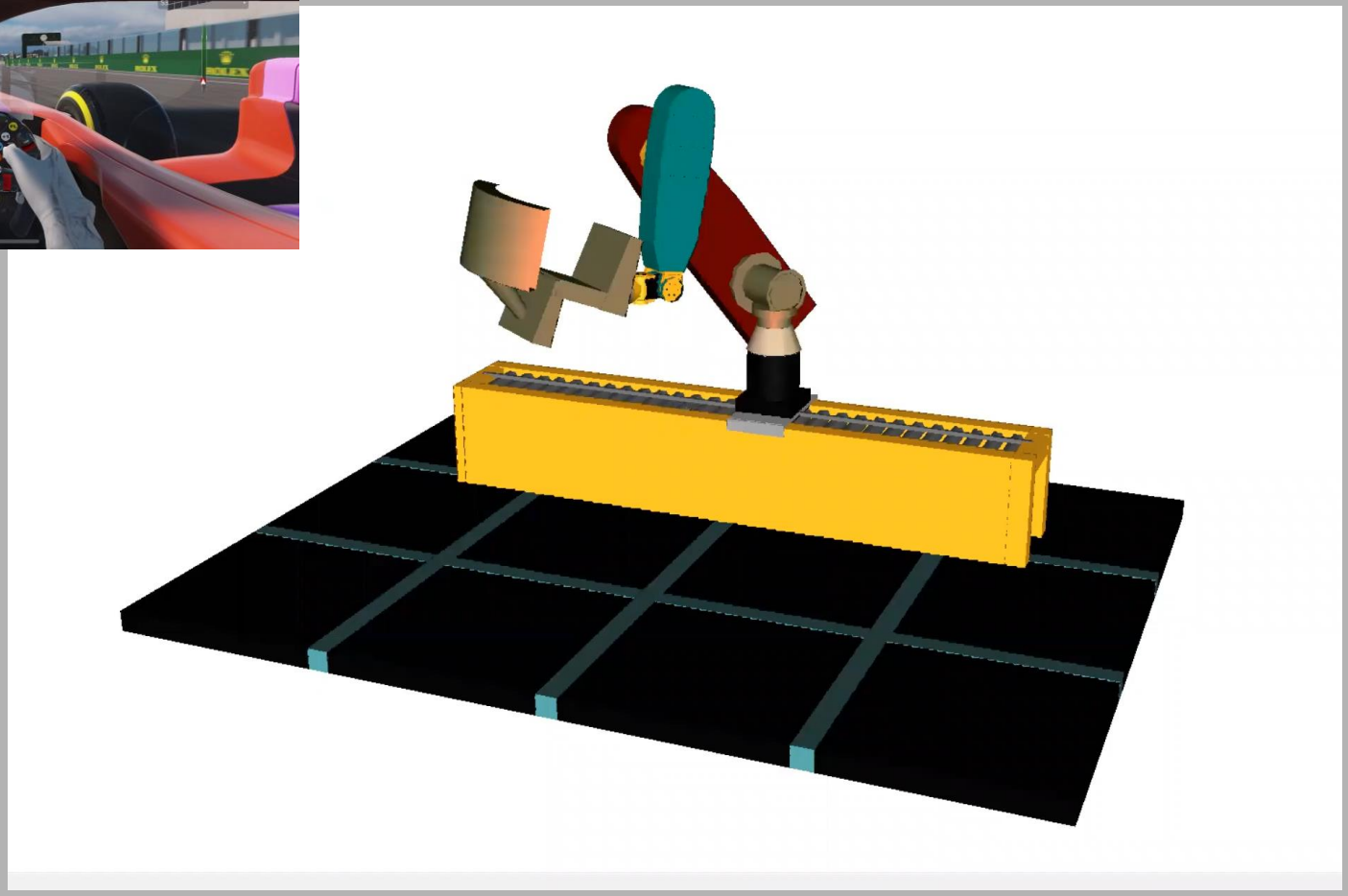
  q_T= [1,π/2,0,0,0,-π/2,0]

$\vartheta^T(\theta)$

τ = [0,0,4407,2712, 1582,0,0]

(Joint Torques)

Task (Animation)



Conclusions

- **Robot Design**
  - Few singularities due to joint Redundancy
  - SimulatorBot has large range of motion compared to the standard Stewart platforms
- **Future Work**
  - Link Sizing to reduce interference
  - Training astronauts to drive rovers
- **What I Learned**
  - Using inverse kinematics to lock joints when needed
  - Roboworks modelling helped in iterating some of the DH parameters and joint .