Trajectory Generation for a Linearly Actuated Delta Quadruped Robot

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Overview

- Use nonlinear trajectory optimization to generate a walking trajectory for a soft, quadruped, delta-actuated walking robot
- Verify the walking trajectory by simulating it, utilizing the inverse kinematics of the delta robot

System Setup

We use DIRCOL to generate our trajectory:

Dynamics

$$\begin{bmatrix} m_b I & & & & \\ & m_f I & & & \\ & & m_f I & & \\ & & & m_f I & \\ & & & & m_f I \end{bmatrix} \begin{bmatrix} \dot{v}_b \\ \dot{v}_{f_1} \\ \dot{v}_{f_2} \\ \dot{v}_{f_3} \\ \dot{v}_{f_4} \end{bmatrix} = \begin{bmatrix} -\vec{m}_b g \\ -\vec{m}_{f_1} g \\ -\vec{m}_{f_2} g \\ -\vec{m}_{f_3} g \\ -\vec{m}_{f_4} g \end{bmatrix} + \begin{bmatrix} -I & -I & -I & -I \\ I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & I & 0 \\ 0 & 0 & 0 & I \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & I & 0 \\ 0 & 0 & 0 & I \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix}$$

State $x = \begin{bmatrix} p^{(b)} & p^{(1)} & p^{(2)} & p^{(3)} & p^{(4)} & v^{(b)} & v^{(1)} & v^{(2)} & v^{(3)} & v^{(4)} \end{bmatrix}^T$

Control $u = \begin{bmatrix} F^{(1)} & F^{(2)} & F^{(3)} & F^{(4)} \end{bmatrix}^T$

Contact Forces $\begin{bmatrix} \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 \end{bmatrix}^T$

Costs $$J(x_{1:N}) = \sum_{i=1}^{N} \left[\frac{1}{2} ||(x_i - x_g)||_2^2 \right]$$

Constraints

1. Dynamics constraint
2. Body torque equality constraint
3. Foot velocity inequality constraint
4. Foot position inequality constraint
5. Body height constraint
6. Grounded foot velocity constraint
7. Grounded foot z-height constraint
8. Floating foot ground force constraint
9. Grounded foot ground force constraint

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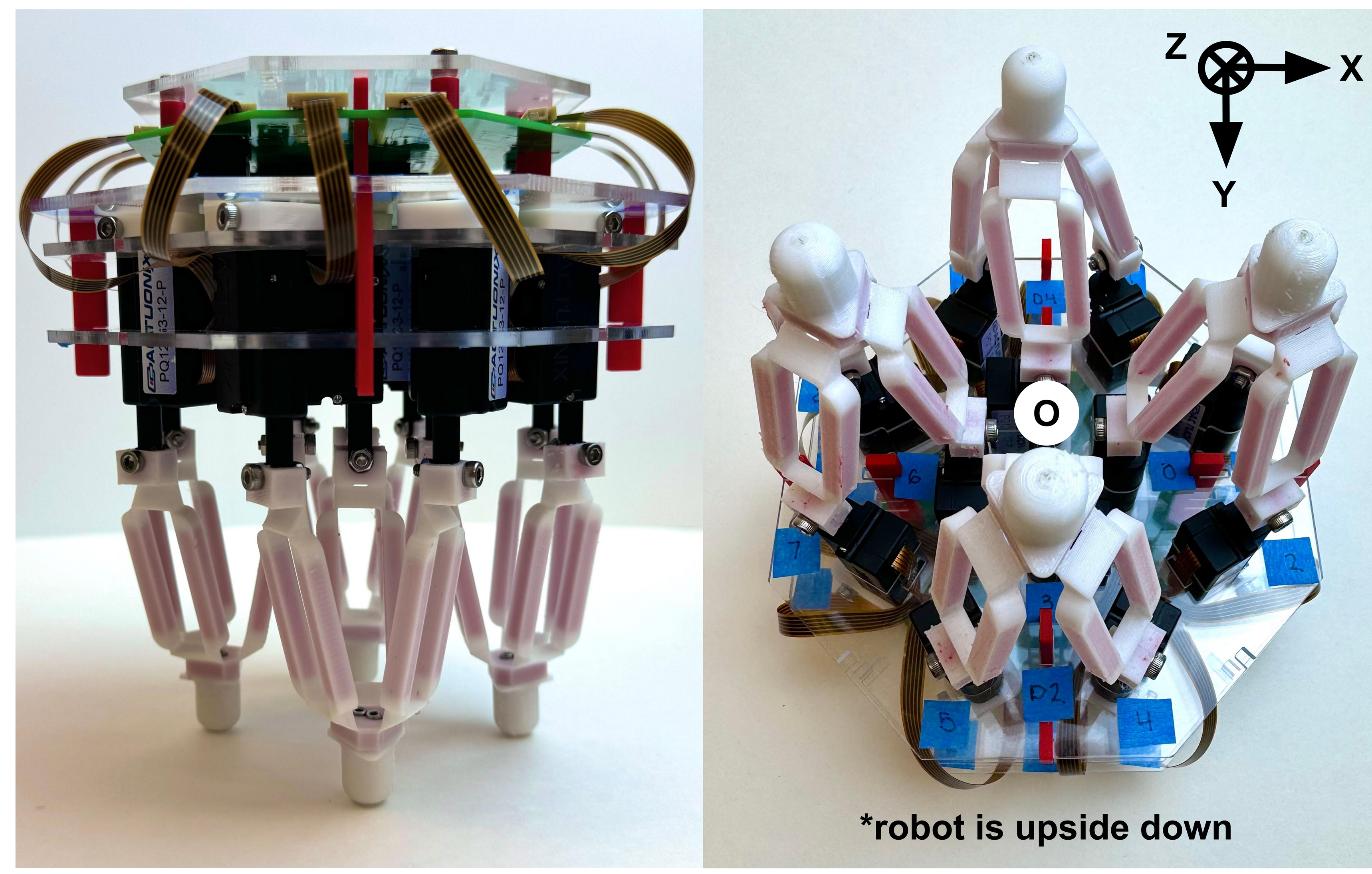
Delta Walker

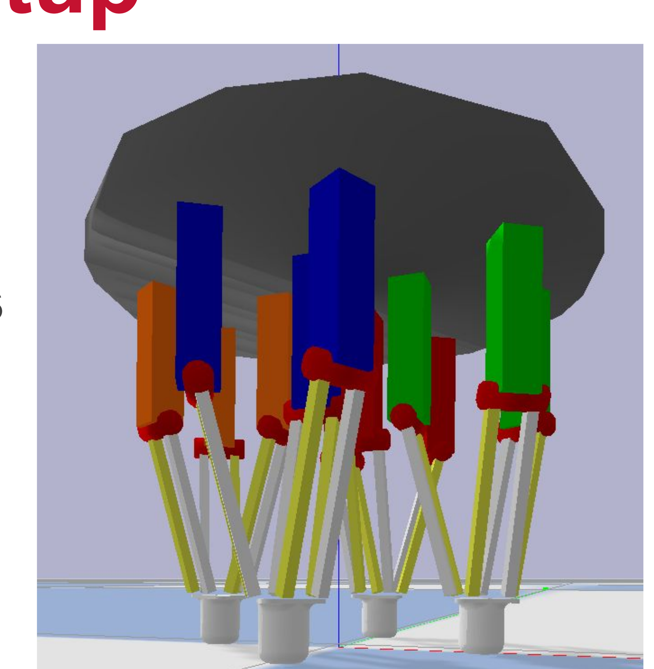


- 4 soft, 3D printed prismatic delta robots arranged in a diamond shape about the origin
- Each linear actuator has a 2 cm range of motion
- Robot frame origin is at the center of the robot in the XY plane and aligned with the actuator base in the Z plane
- The end effectors locations in the robot frame are in the negative Z axis

Trajectory Conversion

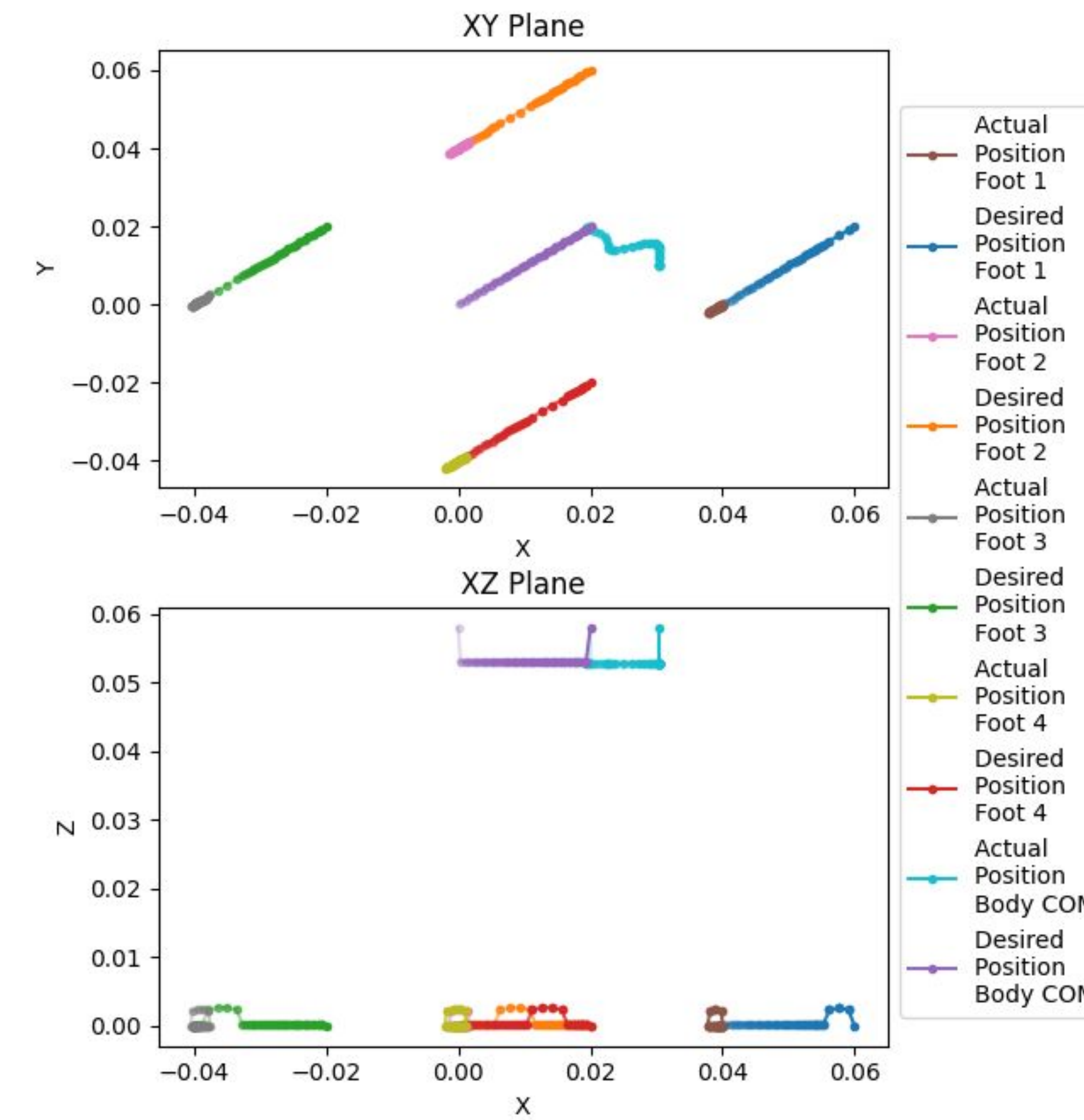
Desired COM and Feet Positions in World Frame → Delta Inverse Kinematics → Motor Actuation Amounts for Each Foot

Simulation Setup



- Simulate the robot movement though Pybullet with a URDF model of the robot
- Command motor actuation amounts using Pybullet's built in P Control function
- Use velocity and force bounds on the simulator to ensure realistic speeds are being used

Results



Limitations

There is a large Sim2Real gap preventing the real robot behavior from matching with the simulated results. Also, there is some simulation error that does not match with the forward kinematics results.

Conclusion

We were able to find a trajectory for the robot to follow. However, the robot moves very little. Currently, the generated trajectory is optimal to the solver, but constraints need to be tuned to produce a trajectory that is reasonable for the robot.

Future Work

- Continue to refine our system such that we can generate better walking trajectories
- Evaluate the walking trajectories on the system in simulation and the real world