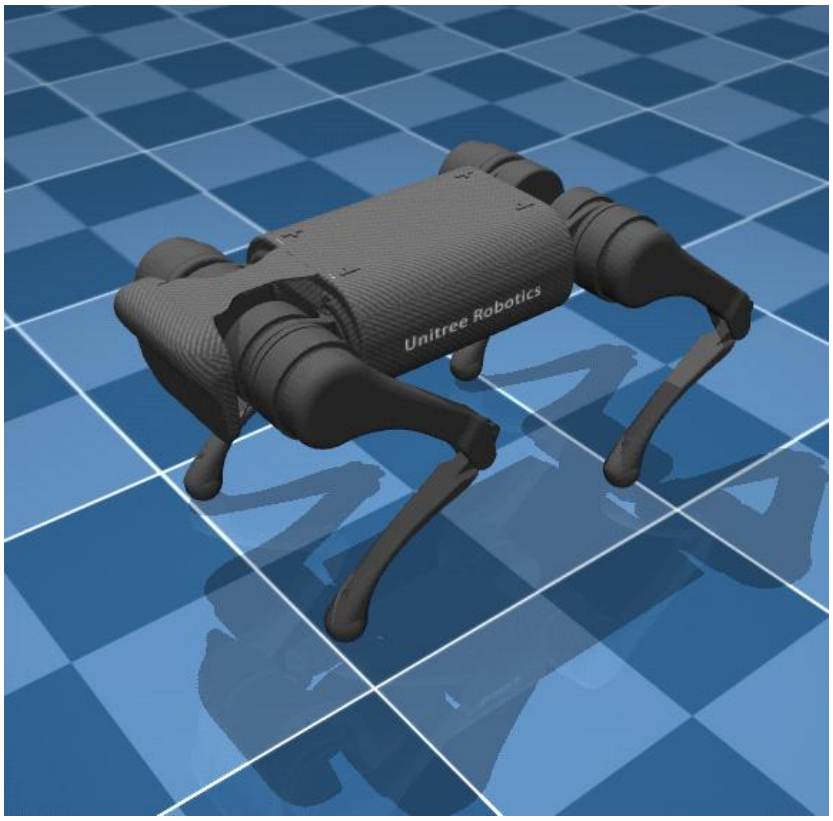
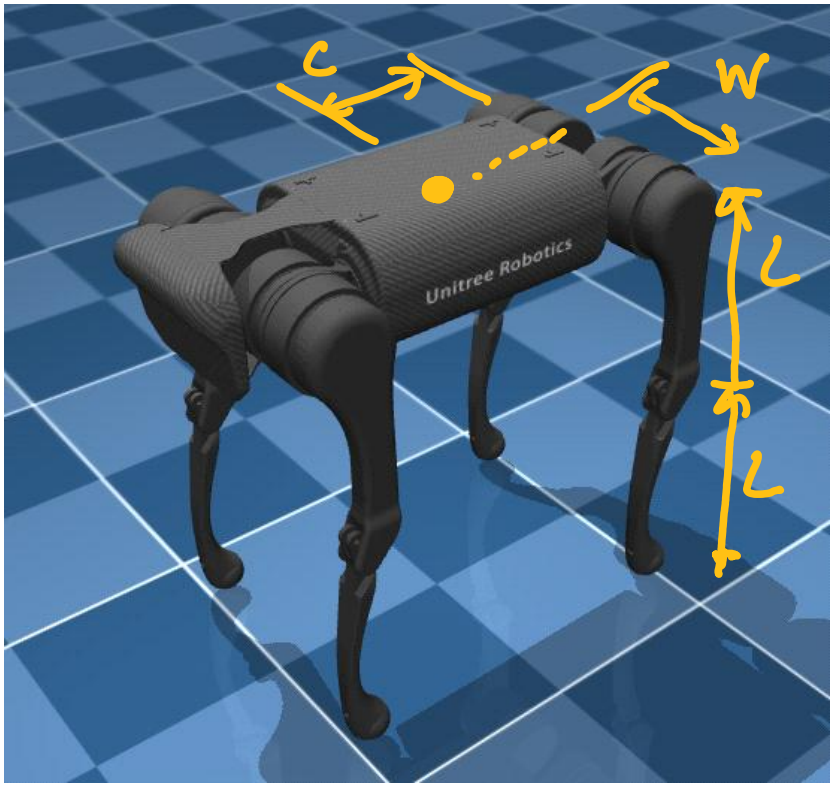
Unitree A1 (load key)



Unitree A1 (zero position)

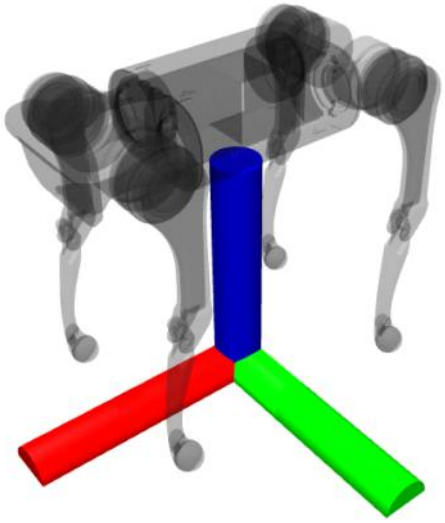


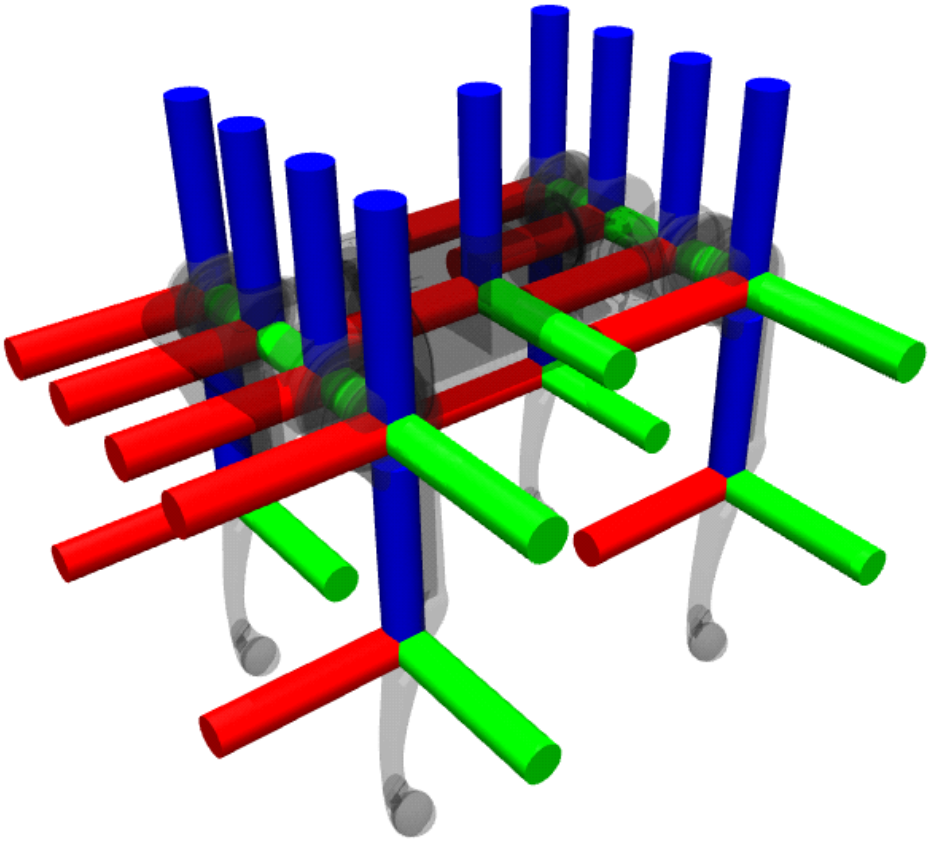
$L = 0.2$

$W = 0.047$

$c = 0.183$

Unitree A1 (frames)

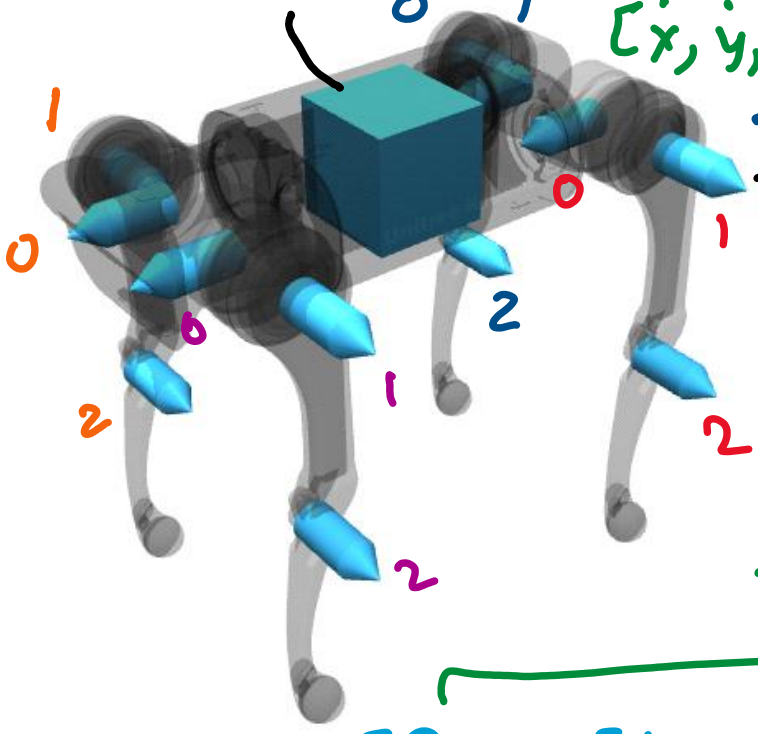




Unitree A1 (joints)

7 dofs

free joint $[x, y, z, q_0, q_x, q_y, q_z]$ *
$[\dot{x}, \dot{y}, \dot{z}, \omega_{bx}, \omega_{by}, \omega_{bz}]$
6 velocity



— revolute
$\theta, \dot{\theta}$ X12

xml defined this way

FR FL RR RL

→ qpos = 7 free $\theta_0, \theta_1, \theta_2, \theta_0, \theta_1, \theta_2, \theta_0, \theta_1, \theta_2, \theta_0, \theta_1, \theta_2$
(3 3 3 3)

→ qvel = 6 free $\dot{\theta}_0, \dot{\theta}_1, \dot{\theta}_2, \ldots$

0 FR - front right
1 FL - front left
2 RR - Rear Right
3 RL - Rear left

leg_no = 0, 1, 2, 3
FR, FL, RR, RL

Trot gait: 0,3
1,2.

Unitree A1 Trotting Code Flow

1) Kinematic Control

- State Machine()
- Cartesian_Traj()
- Joint_Traj()
- Mj_forward

X, Y, Z logs
IK ✓

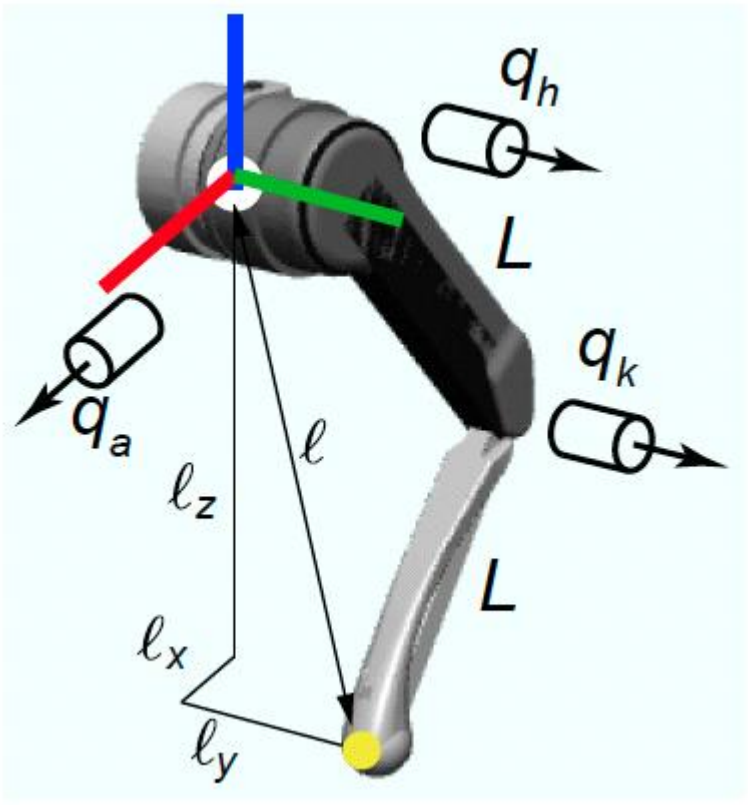
2) Dynamic Control

- State Machine()
- Cartesian_Traj()
- Joint_Traj()
  - Joint_Control()
  - Mj_step • dynamics

3) High Level Control

- State Machine()
- Cartesian_Traj()
- Joint_Traj()
- Joint_Control()
- High_Level_Control() ~~ set xdot_ref (x), ydot_ref (y), psidot_ref (ψ)
- Mj_step

Unitree A1 (Analytic Inverse Kinematics)

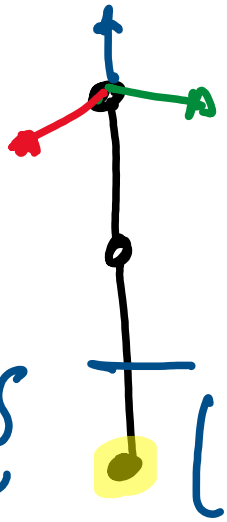


HW5

yellow dot is below the white dot when

$q_a = q_h = q_k = 0$

inverse_kinematic_analytic()



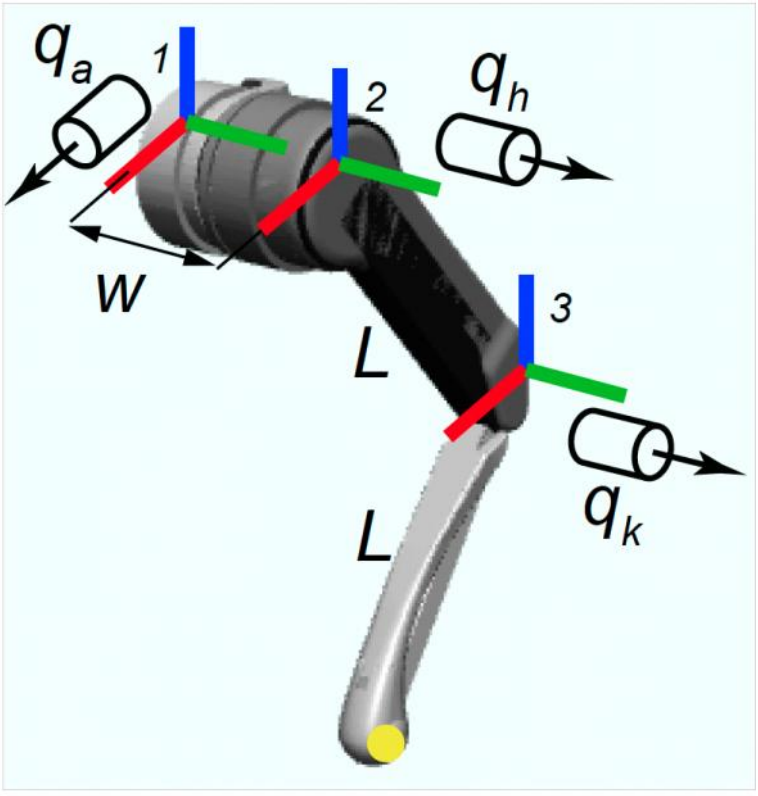
$q_a = q_h = q_k = 0$

hd $\{ (0, 0, l_{z_0})$

user defined

-ive value

Unitree A1 Leg (Kinematics/Jacobian)



HW7

$w \neq 0$

forward_kinematics_leg()

jac_end_eff_leg()

State machine (4 legs)

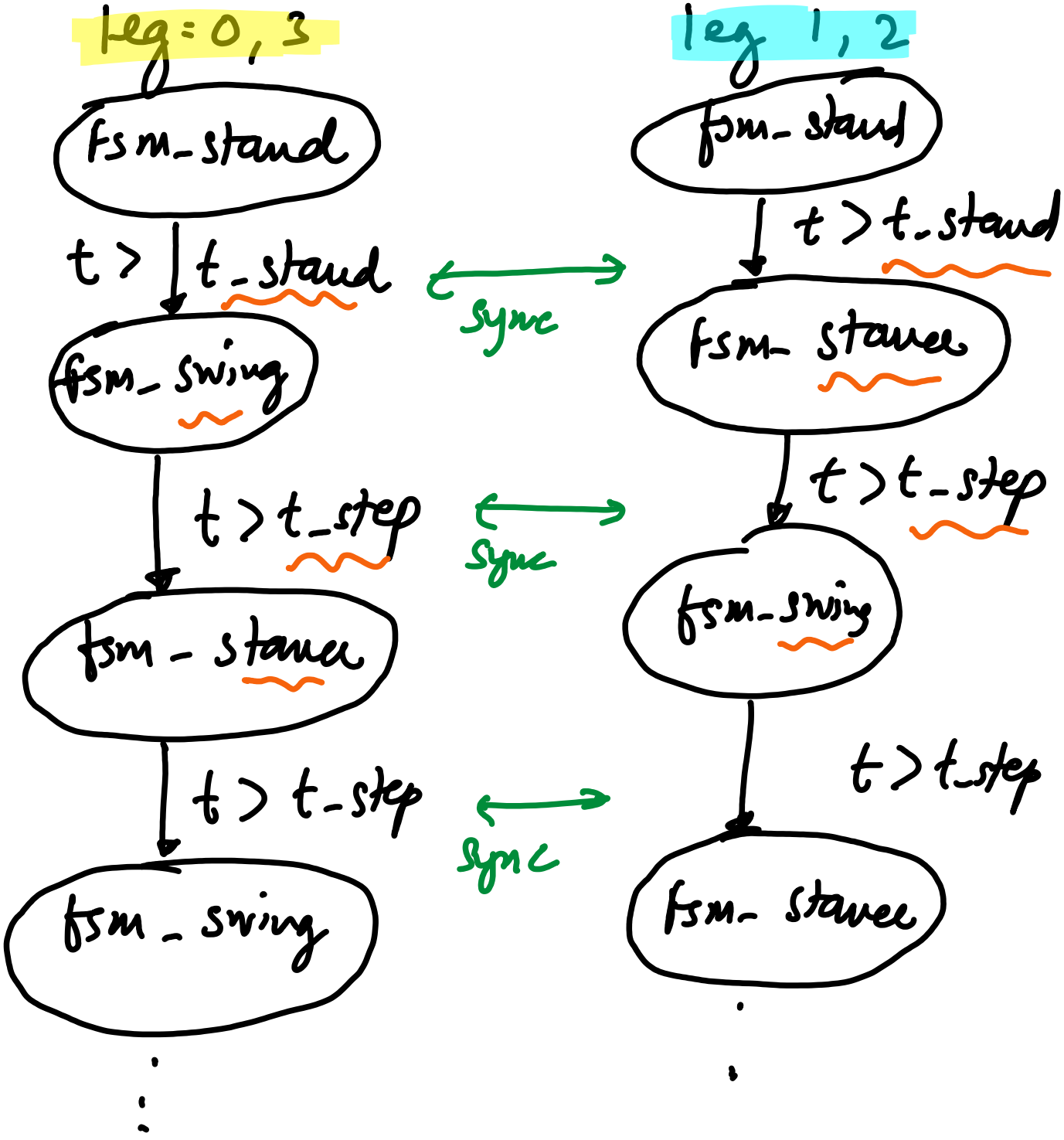
4 finite state machine (one for each leg)

fsm [leg_no] leg_no = 0, 1, 2, 3
FR, FL, RR, RL

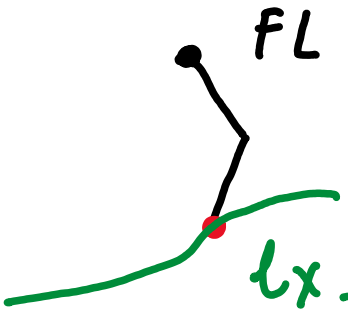
fsm_stand → state where all legs are on the ground.

fsm [0:3) = fsm_stand {initialization}

fsm_swing :- leg is in the air
fsm_stance - less than 4 legs are on the ground

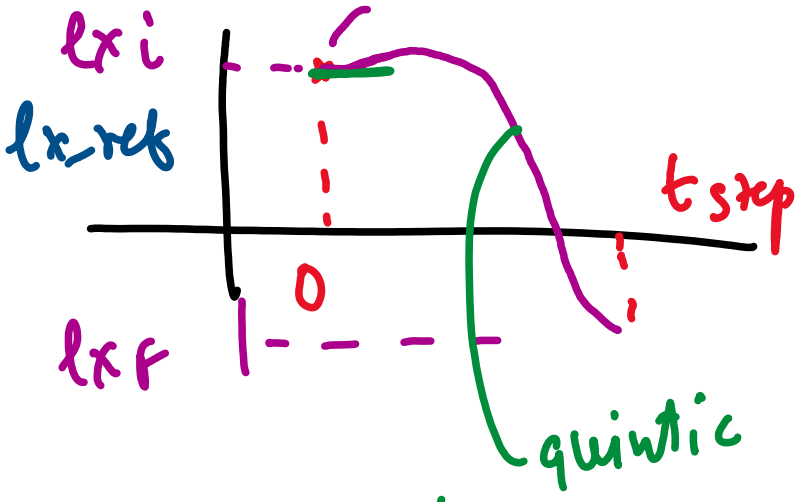

leg = 0, 3
fsm_stand
t > t_stand
fsm_swing
t > t_step
fsm_stance
t > t_step
fsm_swing
leg 1, 2
fsm_stand
t > t_stand
fsm_stance
t > t_step
fsm_swing
t > t_step
fsm_stance
Sync
Sync
Sync

cartesian_traj



$l_{x\_ref}, l_{y\_ref}, l_{z\_ref}$

quintic_poly



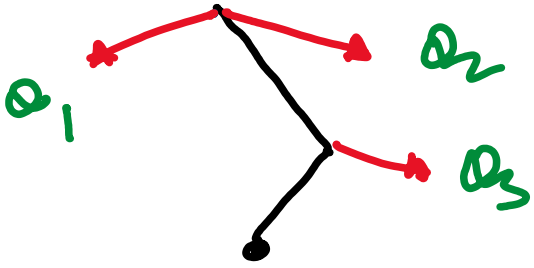
2

3 l_{y_ref}

1 l_{z_ref}

init / final vel / acc = 0

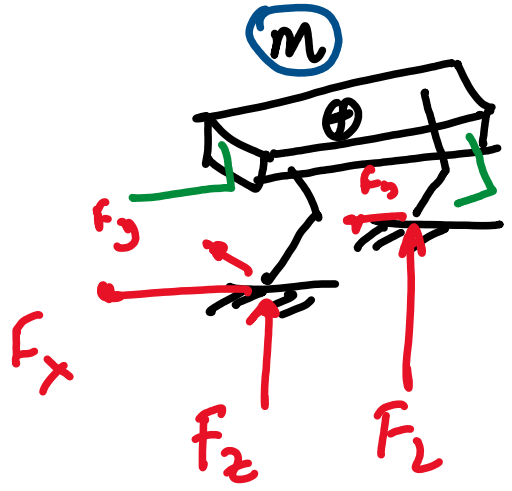
joint_traj()



l_{x_ref}, l_{y_ref}, l_{z_ref}

analytic_solution

① Simple gravity compensation in stance



feet are massless

$m = m_{trunk} + 4\, m_{leg}$

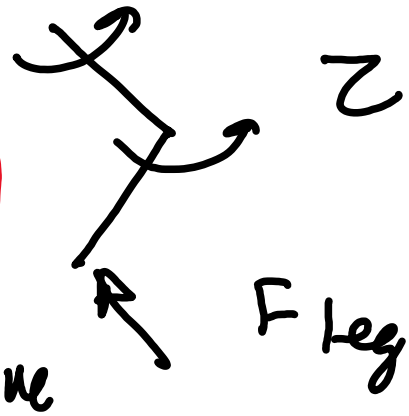
all mass is lumped in the trunk

$$\Sigma F_z = 0 \qquad F_2 + F_1 = mg$$

$$F_z = 0.5\, mg$$

$$\Sigma F_x = \Sigma F_y = 0$$

Force due to gravity $F_{leg} = [0, 0, 0.5mg]$

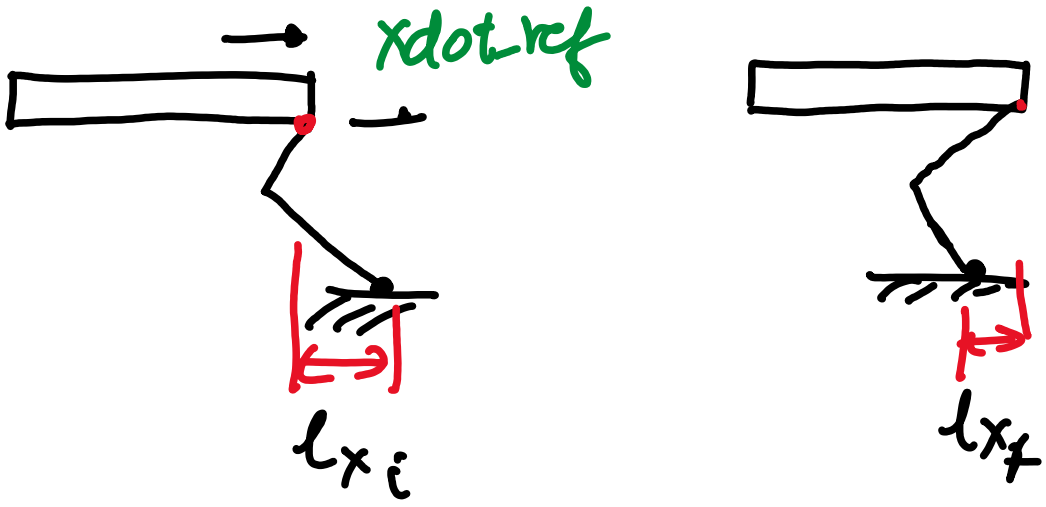


$$\tau = -J^T F_{leg}$$

↑ gravity torque


gravity torque
leg

state_machine (lx_i, lx_f)



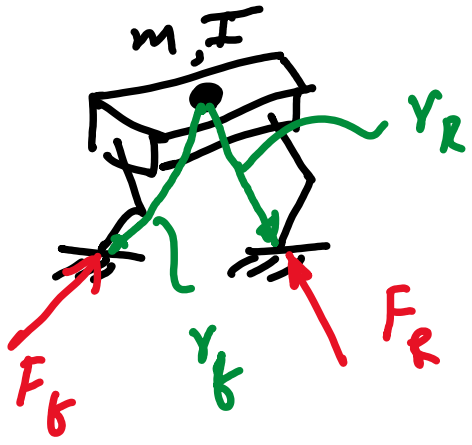
$$l_{x_i} = 0.5\,(\dot{x}_{ref})\,(t\_step)$$

$$l_{x_f} = -0.5\,(\dot{x}_{ref})\,(t\_step)$$

cartesian_traj

$l_{x\,ref},\ l_{\dot{x}\,ref}$ = quintic_poly.

② Stance Leg control for trotting



$$f_f + f_R - m\begin{bmatrix}0\\0\\g\end{bmatrix} = m\begin{bmatrix}\ddot{x}\\\ddot{y}\\\ddot{z}\end{bmatrix}$$

$$r_f \times f_f + r_R \times f_R = I\begin{bmatrix}\dot{\omega}_x\\\dot{\omega}_y\\\dot{\omega}_z\end{bmatrix} + \omega \times (I\omega) \quad (0)$$

$$m\begin{bmatrix}\ddot{x}\\\ddot{y}\\\ddot{z}\end{bmatrix} = \begin{bmatrix}f_{x0}\\f_{y0}\\f_{z0}\end{bmatrix} = \begin{bmatrix}k_x(\dot{x}_{dot\_ref} - \dot{x})\\k_y(\dot{y}_{dot\_ref} - \dot{y})\\k_z(-\dot{z}) - k_z(z - z_{ref})\end{bmatrix}$$

$$I\begin{bmatrix}\dot{\omega}_x\\\dot{\omega}_y\\\dot{\omega}_z\end{bmatrix} = \begin{bmatrix}M_{x0}\\M_{y0}\\M_{z0}\end{bmatrix} = \begin{bmatrix}-k_1\phi - k_2\omega_x\\-k_3\theta - k_4\omega_y\\k_\psi(\dot{\psi}_{dot\_ref} - \omega_z)\end{bmatrix}$$

b 6×1

$b_{6\times 1}$

$$F_{f}_{3\times1} + F_{R}_{3\times1} = \begin{bmatrix} I_{3\times3} & I_{3\times3} \\ S_{r_f}{}_{3\times3} & S_{r_R} \end{bmatrix}_{3\times1} \begin{bmatrix} F_f \\ F_R \end{bmatrix}_{6\times1}$$

$$r_f \times F_f + r_R \times F_R$$

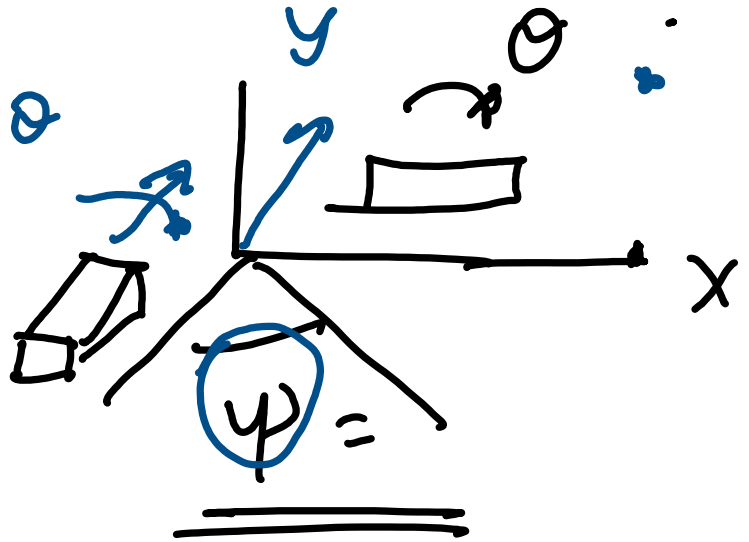
$$(S_{r_f}) F_f + (S_{r_R}) F_R$$

$$A_{6\times1} \quad F$$

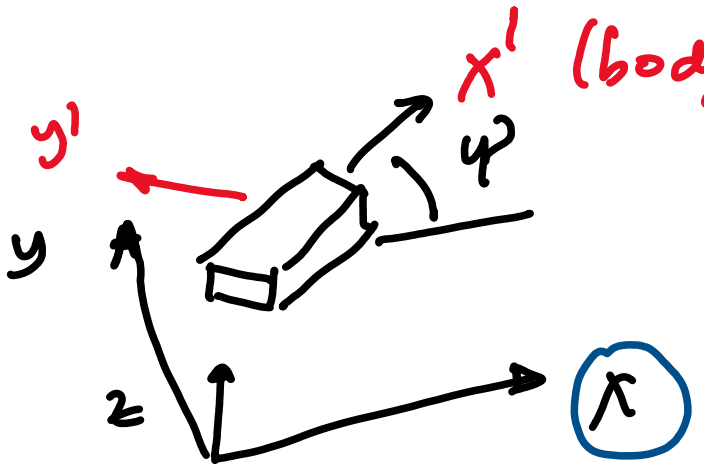
$$A_{6\times6} \; F_{6\times1} = b_{6\times1} = \begin{bmatrix} F_{x0} \\ F_{y0} \\ F_{z0} + \text{neg} \\ M_{x0} \\ M_{y0} \\ M_{z0} \end{bmatrix}$$

$F = A^{\dagger} b$ ← use pseudo-inverse

↑ forces from the stance leg.



θ



R = rotation matrix of the trunk

$R_z(\psi)$

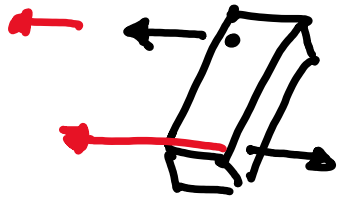
$R_b = R_z^T R$

euler_b = mat2euler

V_body = R_z^T · V_world

data.qvel

Turning ($\dot{\psi}$)



← sideway
+
← turn