Theory and Practice of Humanoid Walking Control

2020 Fall semester

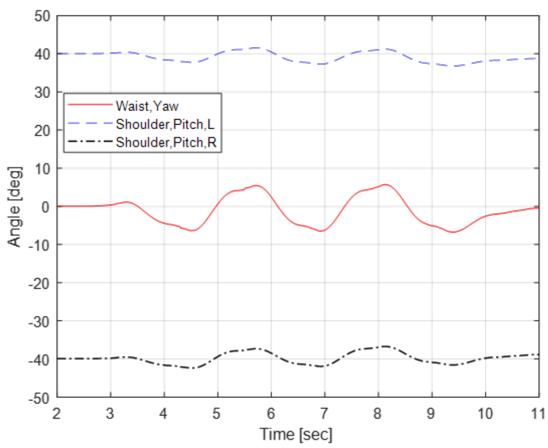
Homework # 10

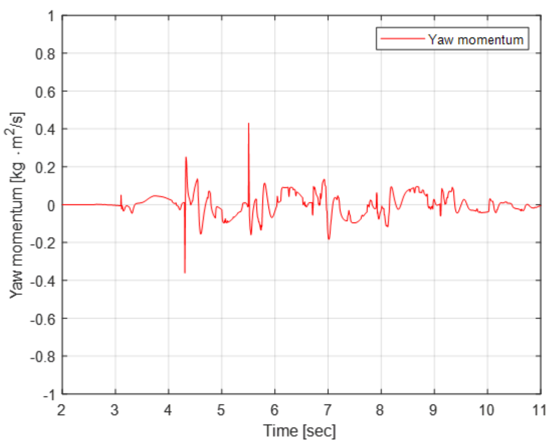
Problem 10 Centroidal dynamics

※ The first supporting foot is the left foot.

※ References:

1) Centroidal dynamics of a humanoid robot, David E. Orin, Ambarish Goswami, Sung-Hee Lee, Autonomous Robots, 35:161-176, 2013





- ✓ Design a centroidal momentum controller using QP.
  1) Convert the given objective function to quadratic form
     - Objective function : $\min_{\dot{q}_{sel}} \frac{1}{2}\left\|h^{yaw,d} - h_{sel}^{yaw}\right\|^2 + \frac{1}{2}\|\dot{q}_{sel}\|^2$ / s.t. ${}^{pel}J_{leg}\dot{q}_{leg} = {}^{pel}\dot{x}_{foot}^{d}$
     - General quadratic form : $\min_{X} \frac{1}{2}X^TQX + X^Tg$ / s.t. $AX = b$
  2) Reorganize the matrix and constraints into forms for using QPOASES, referring to the reference materials.
     - Set all the vector elements of lbx_input to -10[rad/s] and all the vector elements of ubx_input to 10[rad/s]. (Range of $\dot{q}_{sel}$)
  3) Command the joint angle using the solution (qOpt) calculated by QP.
- ✓ Run it after programming
  1) rosrun dyros_jet_gui dyros_jet_gui → X: 1.0m, Step length : 0.2m → START walking button click!!
  2) Plot the measured yaw momentum with and without momentum control.
  3) Plot the calculated 15 joint angles (QP solution) with and without momentum control.
  4) Record the walking simulation video.

* Hint

Simulation time → walking_tick_ (1tick : 0.005sec)

1 step time (1.2sec) → t_total_

Start time of each step → t_start_

End time of each step → t_last_

First DSP and last DSP time in one step → t_double1_ (0.15 sec), t_double2_ (0.15 sec)

The total number of steps to reach the target point. (It is automatically calculated when you click the start walking button.) → total_step_num_

Current number of steps → current_step_num_

Initial X, Y, Z CoM position w.r.t the support foot → xi_, yi_, zc_

Real pelvis position w.r.t the supporting foot frame → pelv_support_current_.translation()(n), n = 0, 1, 2 (X, Y, Z respectively.)

Initial pelvis height w.r.t the supporting foot frame → pelv_support_start_.translation()(2)

Real CoM position w.r.t the supporting foot frame → com_support_current_(n), n = 0, 1, 2 (X, Y, Z respectively.)

Foot step position w.r.t the current support foot frame

→ foot_step_support_frame_(n,0), foot_step_support_frame_(n,1)

→ The first element n of the variable means sequence, and the second elements 0 and 1 mean the positions of X and Y, respectively.

Measured joint angle → current_motor_q_leg_ (Vector12d)

Jacobian matrix from the pelvis frame to the left ankle frame → current_leg_jacobian_l_ // (6x6)

Jacobian matrix from the pelvis frame to the right ankle frame → current_leg_jacobian_r_ // (6x6)

Desired velocity of the left foot w.r.t the pelvis frame → lfoot_desired_vel_ // (6x1)

Desired velocity of the right foot w.r.t the pelvis frame → rfoot_desired_vel_ // (6x1)

Centroidal momentum matrix → Augmented_Centroidal_Momentum_Matrix_ // (6x28)

Centroidal momentum matrix for leg joint → Augmented_Centroidal_Momentum_Matrix_.block<1,12>(5,0) // (1x12)

Centroidal momentum matrix for waist yaw → Augmented_Centroidal_Momentum_Matrix_.block<1,1>(5,12) // 1x1

Centroidal momentum matrix for left shoulder pitch
→Augmented_Centroidal_Momentum_Matrix_.block<1,1>(5,14) // 1x1

Centroidal momentum matrix for right shoulder pitch
→Augmented_Centroidal_Momentum_Matrix_.block<1,1>(5,21) // 1x1

- Objective function : $\min_{\dot{q}_{sel}} \frac{1}{2}\left\|h^{yaw,d} - h^{yaw}_{sel}\right\|^2 + \frac{1}{2}\|\dot{q}_{sel}\|^2$ / s.t. ${}^{pel}J_{leg}\dot{q}_{leg} = {}^{pel}\dot{x}^{d}_{foot}$
- General quadratic form : $\min_{x} \frac{1}{2}X^TQX + X^Tg$ / s.t. $AX = b$

leg wrt pel

$$\min_{\dot{q}_{sel}} \frac{1}{2}\left\| \cancel{h^{yaw,d}}_{0} - h^{yaw}_{sel} \right\|^2 + \frac{1}{2}\|\dot{q}_{sel}\|^2$$

$$h^{yaw}_{sel} \rightarrow A^{yaw}_{sel}\dot{q}_{sel}$$

quadratic

$$\min_{\dot{q}_{sel}} \frac{1}{2}\left\| -A^{yaw}_{sel}\dot{q}_{sel} \right\| + \frac{1}{2}\|\dot{q}_{sel}\|^2$$

$$= \min_{\dot{q}_{sel}} \frac{1}{2}\left(\dot{q}^T_{sel}A^T_{sel}A_{sel}\dot{q}_{sel}\right) + \frac{1}{2}\dot{q}^T_{sel}\dot{q}_{sel}$$

$$= \frac{1}{2}\dot{q}^T_{sel}\left(A^T_{sel}A_{sel} + I_{15\times15}\right)\dot{q}_{sel} \Leftrightarrow \min_{x} \frac{1}{2}x^TQx + x^Tg \quad g = 0$$

then;

$$A_{sel} = \left[A_{leg,l} \quad A_{leg,r} \quad A_{waist,yaw} \quad A_{shouldr,pitch,l} \quad A_{shoulder,pitch,r}\right]$$

$$X \rightarrow \dot{q}_{sel} = \begin{bmatrix} \dot{q}_{leg,l} \\ \dot{q}_{leg,r} \\ \dot{q}_{waist,yaw} \\ \dot{q}_{shoulder,pitch,l} \\ \dot{q}_{shoulder,pitch,r} \end{bmatrix}_{15\times1}$$

to be 12×15

$$A = {}^{pel}_{leg}J = \begin{bmatrix} {}^{pel}_{leg}J^{left}_{6\times6} & 0_{6\times6} & 0_{6\times3} \\ 0_{6\times6} & {}^{pel}_{leg}J^{rigth}_{6\times6} & 0_{6\times3} \end{bmatrix}_{12\times15}$$

$$Ax = b$$

$$b = \begin{bmatrix} {}^{pel}\dot{x}^{d}_{foot,left\ 6\times1} \\ {}^{pel}\dot{x}^{d}_{foot,right\ 6\times1} \end{bmatrix}_{12\times1}$$

$$Q = A^T_{sel}A_{sel} + I_{15\times15}$$