PRACTICAL ISSUES AT THE REALIZATION OF ROBOT CONTROL

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OUTLINE

- Digital realization
- Velocity estimation
- Other
- Exercise

Digital realization

- Until now it was assumed that analog controller is implemented for realization of the controller.
- For digital relization of controllers a discrete equivalent of controller is necessary.
- How discrete linear controllers are obtained?
- Two methods:
  - o Discrete controller design
  - o Transformation of continous controller to discrete form

Digital realization

- **In robotics:**
  - Discrete controller design based on discretizing robot arm dynamics -> result are extremely complex discrete robot dynamics models and it is very hard to derive digital controller for them.
  - Transformation of the continous controller into discrete form = discretization of the controller.

Digital realization

Discretization of controller; z transformation:

$$X(z) = \sum_{n=-\infty}^{\infty} x(n) z^{-n}$$

Example: Discrete PID controller:

$$K(z) = K_p \left[1 + \frac{T}{T_{ID}} \frac{z+1}{z-1} + \frac{T_{Dd}}{T} \frac{z-1}{z+1} \right]$$

T is sampling time

In most of the cases this cannot be applied in the robot controllers. Why?

Digital realization

Transformation of continuous robot controller to digital (discrete) is based on approximation:

- $q_k \equiv q(kT) \in R^n$,
- $\dot{q}_k \equiv \dot{q}(kT) \in R^n$,
- $M(q_k) = M\big(q(kT)\big)$,
- $N(q_k, \dot{q}_k) = N\big(q(kT), \dot{q}(kT)\big)$.

For continuous CT with PD feedback:

$$\tau_c(t) = M(q)\big(\ddot{q}_D + K_v\dot{e} + K_p e\big) + N(q, \dot{q})$$

Is digital version:

$$\tau_c(k) = M(q_k)\big(\ddot{q}_k^d + K_v\dot{e}_k + K_p e_k\big) + N(q_k, \dot{q}_k)$$

Digital realization

$$\boxed{\tau_k = M(q_k)\left(\ddot{q}_k^d + K_v \dot{e}_k + K_p e_k\right) + N(q_k, \dot{q}_k)}$$

- This is CT-like controller:
  - $M(q_k) = \widehat{M}(q)$;
  - $N(q_k, \dot{q}_k) = \widehat{N}(q, \dot{q}\ )$.
- Robot sampling times 0.1 ms – few ms. Too high sampling rate means lost observability of the sampled system and results in periodic oscillations in the tracking errors.
- Multirate sampling: Outer feedback loop is sampled faster than inner nonlinear feedforward.

Velocity estimation

- Until now we have assumed that position and velocity of robot‘s joints are measured. This is mostly not the case.
- The velocity can be computed from the measured position by using Euler approximation:

$$\dot{q}_k = \frac{q_k - q_{k-1}}{T}$$

- This amplifies measurement noise, therefore additional filter needs to be added:

$$v_k = \gamma v_{k-1} + \frac{q_k - q_{k-1}}{T}$$

γ is design parameter, for small values high frequencies are filtered. Also other approaches such as alfa-beta tracker (special form of Kalman filter) can be used. Note that velocity is used also in calculation of feedforward inner part in CT.

Other

- Torque saturation; non-linear saturation function needs to be included in the controller.
  - o Do not give unrealistic reference to the controller.
  - o Do not set parameters to close to unstability.
- Anti-windup compensation of integral control action is recommended.
  - o If torque saturation is not implemented this is even more frequent problem.

REPORT REQUIRED

Exercise: Sampling time

A 2 DOF planar elbow robot has link masses *1 kg* and lengths *1 m*. The desired trajectory is given with:

$$\theta_{1,d} = k_1 sin(2\pi t/T)$$
$$\theta_{2,d} = k_2 cos(2\pi t/T)$$

Where $k_{1,2} = 0.1\, rad$, $T = 2s$. $K_{p1,2} = 100$; $\xi = 1$.

In simulation calculate CT-PD controller controller with sample time $T_s = 1\, ms$ and model with variable step integration method(default ODE45). In this way more realistic simulation results are obtained (why?).

Explore the effect of higher sampling time (10 ms, 50 ms, 70 ms, 100 ms, 200 ms) to the controller's performance.