Automatic Control - Laboratory 5
Motion control - Advanced control techniques
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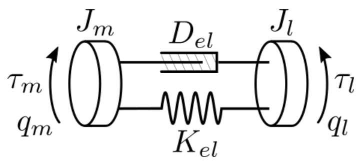


Consider a servomechanism characterized by the following parameters (SI units):

- motor moment of inertia, $J_m = 1.5 \cdot 10^{-4}$;
- transmission ration, $n = 100$;
- viscous friction coefficient, $D_m = 0.0034$;
- load moment of inertia, $J_l = 2.7$;
- transmission stiffness constant, $K_{el} = 3.05$;
- transmission damping, $D_{el} = 0.0022$.

Assuming as state variables motor position and velocity, and load position and velocity, and as output variable motor side position, the state-space model of the servomechanism is described by the following matrices

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{K_{el}}{J_m} & -\frac{D_m + D_{el}}{J_m} & \frac{K_{el}}{J_m} & \frac{D_{el}}{J_m} \\ 0 & 0 & 0 & 1 \\ \frac{K_{el}}{J_{lr}} & \frac{D_{el}}{J_{lr}} & -\frac{K_{el}}{J_{lr}} & -\frac{D_{el}}{J_{lr}} \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ \frac{1}{J_m} \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$$

where $J_{lr} = J_l/n^2$.

This laboratory aims at designing a digital motor side P/PI control architecture, and verify the performance improvement that can be achieved introducing in the standard architecture a digital implementation of the Torque Disturbance Observer.

1. Consider again the P/PI control system designed during the previous laboratory, and characterised by the following parameters

   $$K_{P_v} = 0.03 \quad T_{I_v} = 0.094 \quad (\omega_{c_v} = 70\, rad/s)$$
   $$K_{P_p} = 27$$

   The derivative action used to compute velocity from position is approximated by the following transfer function

   $$R_D(s) = \frac{s}{1 + \frac{s}{N}}$$

   where $N = 1000$.

2. Using a sample time of $1\, ms$ and Tustin transformation, compute the transfer functions $R_v^*(z)$, of the PI velocity regulator, and $R_D^*(z)$ of the digital control system (Matlab function `c2d` can be used to convert a system from continuous time to discrete time).

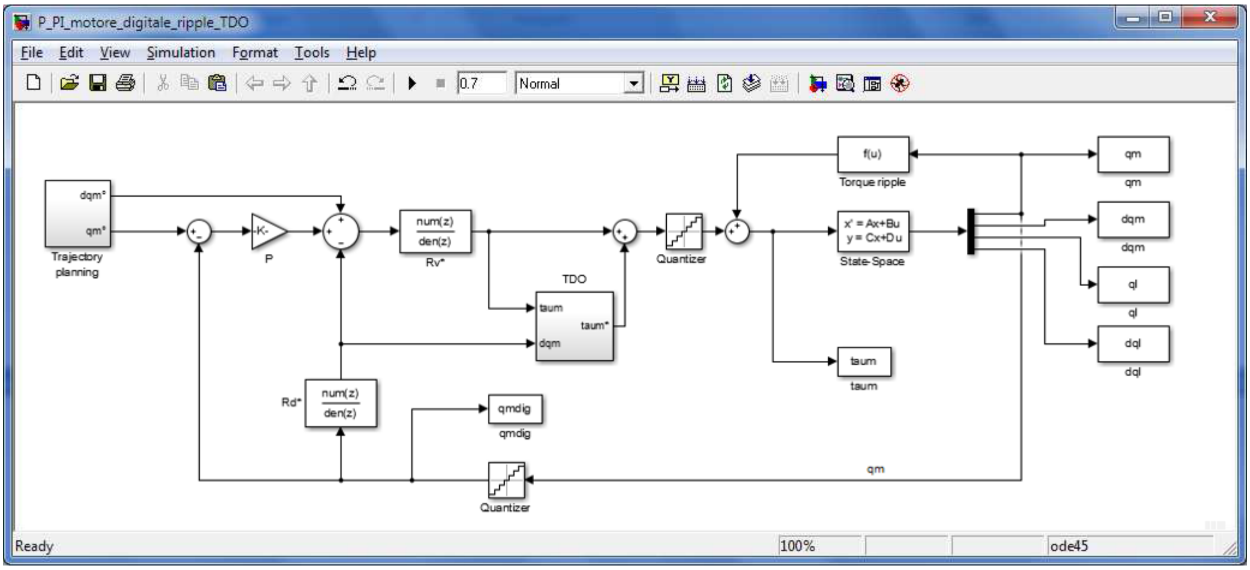
3. Compare the frequency responses of the continuous time and digital PI regulator.

4. Compute the phase decrement introduced in the velocity loop by the conversion of the PI regulator to a digital system.

5. Assume that the position measurement is acquired by the digital system through an A/D converter characterised by a 16-bit resolution. Compute the quantisation of the position measurement (i.e., the minimum variation of the motor position the digital system is able to measure).

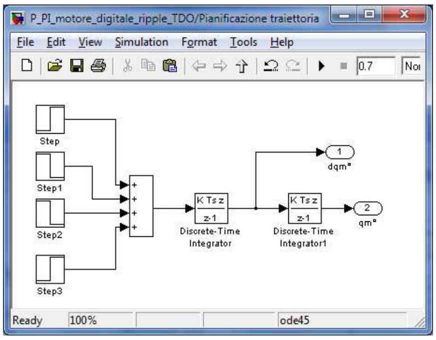
6. Assume that the D/A converter applied to the regulator output is characterised by a 12-bit resolution, the maximum current is $10\, A$ and the torque constant K_t is $1.6\, Nm/A$. Compute the output resolution in terms of motor torque generated by the control system.

7. Using the following Simulink diagram

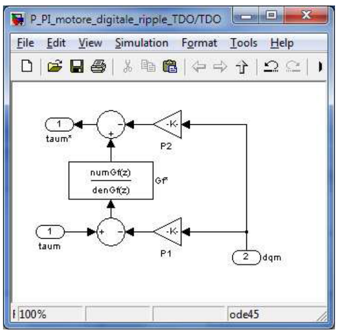


where

- trajectory planning block generates a symmetric trapezoidal velocity profile (the trapezoidal profile can be generated integrating a sum of positive and negative steps conveniently delayed, as depicted in the figure below) characterised by a maximum acceleration of $1000\,rad/s^2$, an acceleration and deceleration time of $0.2\,s$, a constant velocity interval of $0.1\,s$.



- torque ripple block is a user-defined function that generates a periodic torque ripple (frequency equal to 3), depending on motor position, whose amplitude is 3% of the maximum motor torque.
- TDO block is a digital implementation of a torque disturbance observer (see the figure below, where $G_f(z)$ is a digital first order low-pass filter).



simulate the motion control system without considering the torque disturbance and TDO, and analyse its performance. Introduce the torque disturbance and assess the decrease of performance of the velocity loop analysing motor and load velocity. Finally, include the torque disturbance observer and compare the results of the motion control system for different values of T_f.
Is the TDO able to increase control performance?