EE 301P: Control Systems Laboratory
Lab Exercise 9

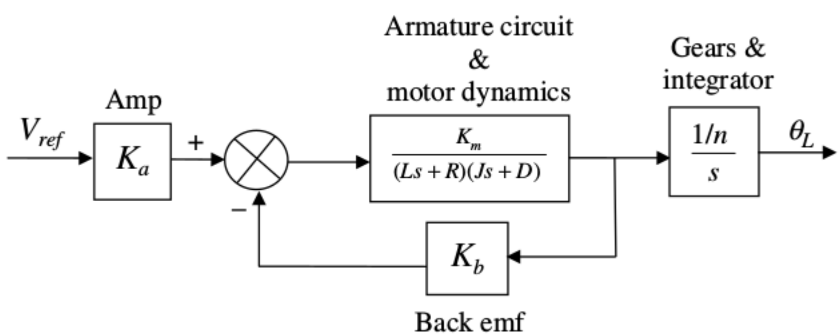
Lab session: November 10, 2023 *Report due*: November 17, 2023

1 Objective

To use MATLAB to design the gain of a controller via root locus method.

2 Pre-lab exercise

The open-loop system dynamics model for the NASA eight-axis Advanced Research Manipulator II (ARM II) electromechanical shoulder joint/link, actuated by an armature-controlled DC servomotor is shown below. The parameter values are given in the adjacent table.



K_a	12
L	0.006 H
R	1.4Ω
K_b	0.00867
n	200
K_m	4.375
J_L	1
D_L	0.5
J_m	0.00844
D_m	0.00013
J	$J_m + J_L/n^2$
D	$D_m + D_L/n^2$.

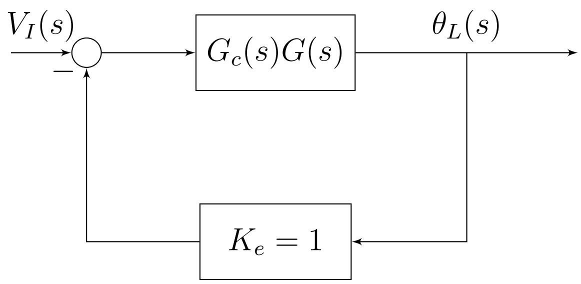
a) Obtain the equivalent open-loop transfer function $G(s) = \frac{\theta_L(s)}{V_{ref}(s)}$.

b) The loop is to be closed by cascading a controller, $G_c = K_D s + K_P$, with $G(s)$ in the forward path forming an equivalent forward-transfer function, $G_e(s) = G_c(s)G(s)$. Parameters of the controller can be used to design a desired transient performance. The input to the closed-loop system is a voltage, $V_I(s)$, representing the desired angular displacement of the robotic joint with a ratio of 1 volt equals 1 radian. The output of the closed-loop system is the actual angular displacement of the joint, $\theta_L(s)$. An encoder in the feedback path, K_e, converts the actual joint displacement to a voltage with a ratio of 1 radian equals 1 volt. Draw the closed-loop system showing all the transfer functions.

c) Find the closed-loop transfer function.

3 Lab exercise

a) Upon the deploying the aforementioned proportional derivative controller the system takes the following form



Assume that $K_P = 4K_D$. Sketch the root locus. Verify using `rlocus` function in MATLAB's Control Systems Toolbox.

b) Find the value of gain required to ensure that the closed-loop pole of the system is placed at $-115 \pm j50$. Verify the gain value by finding the point on the root locus shown in MATLAB figure (obtained in (a)).

c) For this value of gain, find the damping ratio, natural frequency of the system. Verify this value by finding the point on the root locus shown in MATLAB figure (obtained in (a)). [Hint: Use second order approximation: factorize $s^3 + as^2 + bs + c$ as $(s + p)(s^2 + 2\zeta\omega_n s + \omega_n^2)$].

d) For the value of ζ obtained in (c), find the peak overshoot in step response. Verify this by plotting the step response of the system using MATLAB or Simulink.

[Optional: do for bonus 2 marks]
From the type of the system, what can you say about the steady-state error and the static error constants? Validate your understanding using MATLAB or Simulink.

References

[1] J.J Craig, Introduction to robotics: mechanics and control, Prentice Hall, 2005.