EE406 Assignment 2

Due: 15/12/2022

Late submissions lose 10% per day.

Cut-off: 17/12/2024 (submissions not accepted after cut-off).

Marks: 10% of module.

Your individual parameters are on page 4.

Use of AI for MATLAB code:

You may be interviewed to confirm you understand your submitted code. If your interview shows you do not understand your code, you will receive zero for questions 1, 2 & 4.

Q1) [30 marks]

In figure 1, the plant is $G_p(s) = \frac{b_2 s + b_3}{s^3 + a_1 s^2 + a_2 s + a_3}$ and the sample period is T.

$D(z) = \frac{(TK_p + 0.5T^2K_i + K_d)z^2 + (0.5T^2K_i - TK_p - 2K_d)z + K_d}{Tz^2 - Tz}$ is a PID controller.

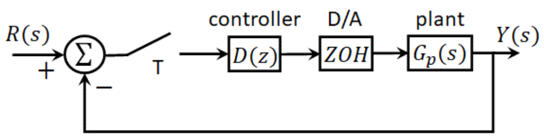

Figure 1 Sampled-data control system

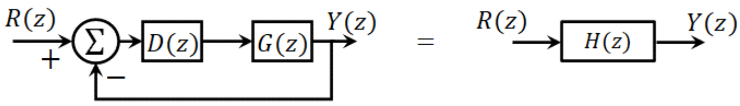

Figure 2 Discrete-time control system

Use MATLAB to simulate the discrete-time control system unit step response for n sample periods. Use the following PID controller gains. Make three figures with subplots like those on slides 17-19 of notes 4. Use `plot()` to plot the system input and `stem()` to plot the system output. For each figure, in subplots 1, 2, & 3 set the y-axis limits to [0 2] and do not set y-axis limits for subplot 4. You may find the sample code on slide 15 useful.

Controller	K_p	K_i	K_d	Make figure like
P	1	0	0	slide 17
	2	0	0	
	3	0	0	
	30	0	0	
PI	3	0	0	slide 18
	3	2	0	
	3	4	0	
	3	30	0	
PID	3	2	0	slide 19
	3	2	0.25	
	3	2	0.5	
	3	2	30	

Use your figures to discuss the effects of increasing K_p, K_i and K_d. Please type this discussion below the relevant figure. In your discussions, use the language of control e.g. transient and steady state response, steady state error and damping.

Q2) [10 marks]

$G(z) = \frac{b_1 z^2 + b_2 z + b_3}{z^3 + a_1 z^2 + a_2 z + a_3}$ with sample period T

(a) In MATLAB:

make $G(z)$

find the poles of $G(z)$

find the DC gain of $G(z)$

(b) On paper:

Sketch the unit impulse response and explain your sketch i.e. why do you expect the unit impulse response to be like your sketch?

Sketch the unit step response and explain your sketch i.e. why do you expect the unit step response to be like your sketch?

Note. You may find slide 37 of notes 4 useful. For both sketches, use time on the x-axis. Number the y-axis for the unit step response.

Q3) [30 marks]

Hand-written exercises:

$G(z) = \frac{b_1 z^2 + b_2 z + b_3}{z^3 + a_1 z^2 + a_2 z + a_3} = \frac{b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3}}{1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3}}$

(a) Find the controllable canonical form state space model for $G(z)$. Do **not** write it directly from the transfer function. Include a sketch of the simulation diagram.

(b) Find the observable canonical form state space model for $G(z)$. Do **not** write it directly from the transfer function. Include a sketch of the simulation diagram.

(c) Write the modal canonical form state matrix, A_w, for the model for $G(z)$. You can use the eigenvalues calculated by MATLAB in part (d)

MATLAB exercise:

(d) Use MATLAB's `eig()` and `roots()` commands to show that the eigenvalues for the state matrices of parts (a), (b) and (c) are the same as the poles of $G(z)$

(e) What do you conclude from part (d)?

Q4) [30 marks]

Use the plant transfer function, $G(z)$ from Q3, with sample period $T = 1$ second to design a reference tracking state feedback controller with eigenvalues at:

(a) $\lambda = 0.6, 0.6, 0.6$

(b) $\lambda = -0.6, -0.6, -0.6$

(c) $\lambda = 0.4, 0.4, 0.4$

(d) $\lambda = -0.4, -0.4, -0.4$

In each case, simulate the control system unit step response for 20 sample periods. The system initial condition should be zero. Create one figure, with four subplots showing the four step responses. Each subplot should display a stem plot of system output vs sample number, k, and a regular plot of system input vs sample number, k. Title each plot with the eigenvalues e.g. for subplot 1, 'eigenvalues at 0.6, 0.6, 0.6'. Ensure the x-axis of subplot 4 is labelled.

You may need the following MATLAB commands: `tf(), ssdata(), ones(), size(), acker(), ss(), dcgain(), lsim(), subplot(), stem(), plot(), hold(), title(), xlabel()`
You should find the code examples in notes 6 and tutorial 6 useful.

Discuss your results. Please type this discussion directly below the figure. You discussion should:

(1) describe the steady state response e.g. state the steady state gain and the stability

(2) describe the transient response eg. damping

(3) state whether (1) and (2) are good, bad or indifferent characteristics for a control system

(4) explain why the control system is producing (1) and (2)

Which of the control systems, (a), (b), (c) or (d) do you think is better if controlling the:

i. suspension of a car? Explain your answer.

ii. altitude of an aircraft? Explain your answer.

Please do **not** use screen captures for:

- code – use copy/paste.
- figures – use Copy Figure on the figure Edit menu.

<u>What to submit</u>

Submit **one PDF** file on Moodle containing scanned copies of your handwritten answers and code, figures and typed discussion for MATLAB questions. Ensure you state question numbers. Please include relevant code with each question, rather than putting all code at the end of your submission.

	Q1							Q2							Q3 & Q4					
STUDENT ID	**b_2**	**b_3**	**a_1**	**a_2**	**a_3**	**n**	**T**	**b_1**	**b_2**	**b_3**	**a_1**	**a_2**	**a_3**	**T**	**b_1**	**b_2**	**b_3**	**a_1**	**a_2**	**a_3**
22437852	11	16	6.3	13	8.4	49	0.09	-1.9665	3.933	29.4975	0.7	0.0525	-0.0045	1	2	7	3	12	-43	-630
20353843	2.2	2.7	4.5	5.3	1.9	21	0.43	-0.0127	0.0127	1.144	-0.36	-0.066	-0.002	1	2	0	-8	2	-69	-270
22309956	0.3	1.1	6.8	12	2.1	63	0.56	-0.6331	3.7985	25.3232	0.58	-0.082	0.0014	2	2	7	-15	5	-94	-560
22363533	1.5	3.5	4.7	6.7	2.5	42	0.28	-0.4993	3.9947	9.9867	0.745	-0.05275	-0.007	2	2	2	-12	9	-66	-560
21365316	6.9	23	8.3	20	14	63	0.09	-0.3727	1.118	14.9066	0.455	-0.15925	0.00858	2	2	10	0	11	-30	-432
22504436	3.7	18	9	23	13	56	0.16	-0.1712	0	1.5411	-0.92	0.0165	0.00135	2	2	16	0	6	-49	-294
22721451	4.7	23	8.4	20	14	35	0.25	-0.0381	0.3425	0.3805	-0.92	0.0165	0.00135	3	2	12	-32	10	-19	-280
18409336	2.7	9.4	6.1	11	6.5	35	0.14	-0.4792	4.3125	4.7917	0.67	0.065	-0.01	4	2	5	-12	10	-32	-384
22498946	9.4	39	11	32	21	28	0.28	-0.3675	-1.1025	14.7	0.625	0.04	-0.01125	4	2	1	-6	2	-84	-360
20405256	13	7.7	5.6	9.3	4.7	49	0.14	-0.2991	-0.5982	23.9272	0.595	-0.2565	0.0162	4	2	12	0	5	-100	-500
22416504	3.5	17	7.4	17	11	28	0.2	-0.078	0.4678	2.105	-0.895	0.062	0.0112	4	2	9	-5	10	-49	-490
22453894	2.2	6.3	7	11	3.9	49	0.2	-0.0143	-0.0428	0.9975	-0.65	-0.04	0.0035	4	2	-2	-4	5	-62	-336
22333606	21	58	9.8	30	30	49	0.07	-3.7228	11.1684	0	0.675	-0.19375	0.00788	5	2	6	0	10	-49	-490
22426906	5.7	24	9	23	13	56	0.21	-1.2808	11.5268	0	-0.235	-0.11675	-0.00788	5	2	9	-5	2	-85	-350
22386186	4.1	4.1	5.6	6.7	2.3	49	0.2	-0.705	4.23	28.2	0.575	0.02	-0.00875	5	2	4	-16	5	-78	-432
21252830	1.3	3.1	6.3	8.2	1.9	70	0.33	-0.44	1.32	30.8	0.825	0.1475	0.0075	5	2	9	-5	8	-36	-288
22407882	2.7	9.4	6.1	11	6.5	35	0.14	-1.3353	-5.341	16.023	-0.185	-0.13725	-0.01013	6	2	3	-2	9	-82	-720
20363191	1.1	3.1	5.9	10	5.2	49	0.16	-0.3219	0.3219	9.6568	0.92	0.0145	-0.00315	6	2	2	-12	6	-36	-216
22775725	23	18	10	32	34	35	0.08	3.4976	-31.4783	48.9662	1.015	0.093	-0.00945	6	2	6	-20	15	0	-500
18478834	3	8.6	6.8	11	5.1	35	0.22	-0.2162	1.9458	0	-0.51	-0.063	0.0054	7	2	9	4	12	-27	-486
22381933	28	31	8.3	21	16	56	0.08	-0.1092	0.7644	1.9656	-1.09	0.25	-0.0144	7	2	3	-2	6	-36	-216
21455956	5.5	13	6.1	12	7.1	42	0.2	0.1725	-2.07	3.45	-0.65	-0.05	0.0105	7	2	13	-7	7	-24	-180
20426842	2.1	7.7	5.7	9.8	4.4	35	0.28	-0.2527	0	4.0435	-0.745	-0.046	0.0016	8	2	7	3	7	-64	-448
21349661	20	14	9.7	30	28	49	0.09	-0.2235	1.3411	6.0351	0.54	-0.1105	0.00105	8	2	11	5	9	-49	-441
22728669	5.7	24	9	23	13	56	0.16	-0.0893	-0.1785	3.1238	0.495	-0.0655	-0.0015	8	2	4	-16	7	-70	-400
18474612	4.7	23	8.4	20	14	35	0.16	-7.7157	0	30.8629	0.445	-0.087	0.0036	9	2	0	-8	9	-25	-225
22398666	2.6	6.5	6	8.7	3.6	70	0.13	-0.1823	0.3645	14.5818	0.965	0.13875	0.0054	9	2	3	-9	10	-47	-504
22437852	9.4	39	11	32	21	28	0.34	-0.0115	-0.0461	0.5184	-0.94	0.176	-0.0056	9	2	11	-6	10	-100	-1000
20353843	2.2	6.3	7	11	3.9	49	0.29	3.87	-27.09	38.7	0.575	-0.0225	-0.0045	9	2	1	-6	6	-37	-210
22309956	20	37	8.8	25	24	42	0.08	-0.3676	0.3676	11.029	0.745	-0.15525	-0.01418	10	2	13	6	11	-20	-300
22363533	5.5	13	6.1	12	7.1	42	0.13	-0.1488	0.893	4.0186	0.68	-0.094	0.0016	10	2	15	7	7	-36	-252
21365316	6.9	23	8.3	20	14	63	0.09	-0.3727	1.118	14.9066	0.455	-0.15925	0.00858	2	2	10	0	11	-30	-432

	Q1							Q2							Q3 & Q4					
STUDENT ID	b_2	b_3	a_1	a_2	a_3	**n**	**T**	b_1	b_2	b_3	a_1	a_2	a_3	**T**	b_1	b_2	b_3	a_1	a_2	a_3
21386026	2.1	7.7	5.7	9.8	4.4	35	0.28	-0.2527	0	4.0435	-0.745	-0.046	0.0016	8	2	7	3	7	-64	-448
22420996	20	14	9.7	30	28	49	0.09	-0.2235	1.3411	6.0351	0.54	-0.1105	0.00105	8	2	11	5	9	-49	-441
22392706	5.7	24	9	23	13	56	0.16	-0.0893	-0.1785	3.1238	0.495	-0.0655	-0.0015	8	2	4	-16	7	-70	-400
23745651	4.7	23	8.4	20	14	35	0.16	-7.7157	0	30.8629	0.445	-0.087	0.0036	9	2	0	-8	9	-25	-225
22700079	2.6	6.5	6	8.7	3.6	70	0.13	-0.1823	0.3645	14.5818	0.965	0.13875	0.0054	9	2	3	-9	10	-47	-504
22374443	9.4	39	11	32	21	28	0.34	-0.0115	-0.0461	0.5184	-0.94	0.176	-0.0056	9	2	11	-6	10	-100	-1000
22454406	2.2	6.3	7	11	3.9	49	0.29	3.87	-27.09	38.7	0.575	-0.0225	-0.0045	9	2	1	-6	6	-37	-210
25256063	20	37	8.8	25	24	42	0.08	-0.3676	0.3676	11.029	0.745	-0.15525	-0.01418	10	2	13	6	11	-20	-300
21300653	12	23	8.4	20	15	70	0.07	-0.2304	-0.6912	2.304	-0.44	-0.104	0.0048	10	2	8	-10	4	-91	-490
25256066	5.5	13	6.1	12	7.1	42	0.13	-0.1488	0.893	4.0186	0.68	-0.094	0.0016	10	2	15	7	7	-36	-252
25256067	13	7.7	5.6	9.3	4.7	49	0.14	-0.2991	-0.5982	23.9272	0.595	-0.2565	0.0162	4	2	12	0	5	-100	-500
22439376	3.5	17	7.4	17	11	28	0.2	-0.078	0.4678	2.105	-0.895	0.062	0.0112	4	2	9	-5	10	-49	-490