First Semester Examination
2018/2019 Academic Session

December 2018 / January 2019

EEE350 – CONTROL SYSTEMS
(*Sistem Kawalan*)

Duration 3 hours
(Masa : 3 jam)

Please check that this examination paper consists of FOURTEEN (14) pages of printed material and ONE (1) page of Appendices before you begin the examination.

*Sila pastikan bahawa kertas peperiksaan ini mengandungi DUA BELAS (12**)** muka surat bercetak dan **SATU (1) muka surat Lampiran** sebelum anda memulakan peperiksaan ini.*

Instructions: This question paper consists of **SIX (6)** questions. Answer **FIVE (5**) questions : **THREE (3**) from Section A and **TWO (2)** from Section B. All questions carry the same marks.

[***Arahan:*** *Kertas soalan ini mengandungi **ENAM (6)** soalan. Jawab **LIMA (5)** soalan : **TIGA (3)** daripada Bahagian A dan **DUA (2)** daripada Bahagian B. Semua soalan membawa jumlah markah yang sama.]*

Answer to any question must start on a new page.

[Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru]

"In the event of any discrepancies, the English version shall be used".

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai]

PART A

BAHAGIAN A

1. (a) Determine the transfer function $\frac{E_o(s)}{E_i(s)}$ of the following electrical circuit shown in Figure 1.1 (assuming an ideal op-amp).

Tentukan fungsi pemindahan $\frac{E_o(s)}{E_i(s)}$ *litar elektrik yang ditunjukkan dalam Rajah 1.1 (dengan menganggap op-amp tersebut ideal).*

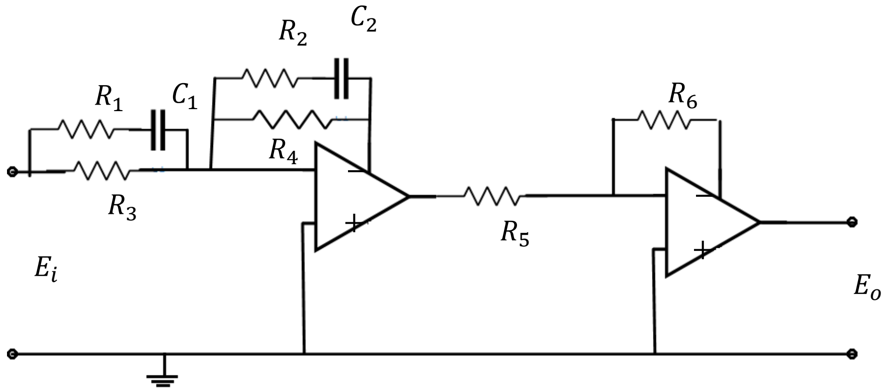


Figure 1.1. Op-amp electrical circuit

Rajah 1.1 Litar elektrik op-amp

(30 arks/*markah*)

(b) A laser printer uses a laser beam to print copy rapidly for a computer. The laser is positioned by a control input $r(t)$, so that we have

Pencetak laser menggunakan sinar laser untuk mencetak salinan dengan cepat bagi sesebuah komputer. Laser diletakkan oleh kawalan input r(t) supaya kita mempunyai

$$Y(s) = \frac{4(s+50)}{s^2+30s+200}\ R(s)$$

The input $r(t)$ represents the desired position of the laser beam.

input $r(t)$ *yang mewakili jawatan yang dicita pancaran laser.*

(i) If $r(t)$ is a unit step input, find the output $y(t)$?

Jika r(t) satu unit langkah masukan, carikan keluaran output $y(t)$ *?*

(30 arks/*markah*)

(ii) What is the steady state value of $y(t)$ as, $t \rightarrow \infty$?

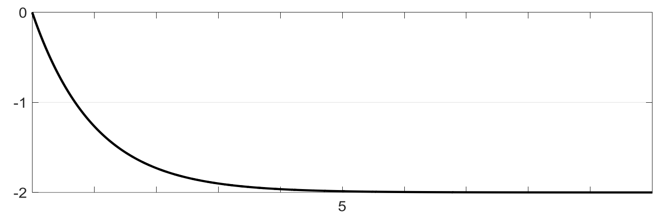
Apakah nilai keadaan stabil $y(t)$ as, $t \rightarrow \infty$?

(10 marks/*markah*)

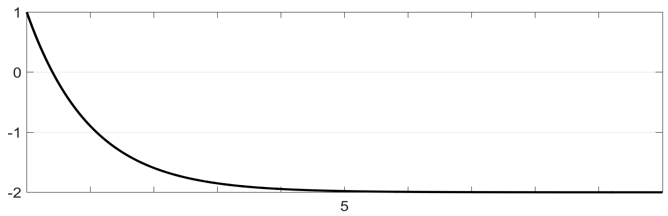
(c) The unit step response of a system with the transfer function $G(s) = \frac{1-2s}{1+s}$ is given by which of the following waveforms shown in Figure 1.2? Justify your choice.

Unit langkah tindak balas sistem dengan fungsi pemindahan $G(s) = \frac{1-2s}{1+s}$ *ditunjukkan dalam gelombang mana satu daripada Rajah 1.2?. Terangkan pilihan anda.*

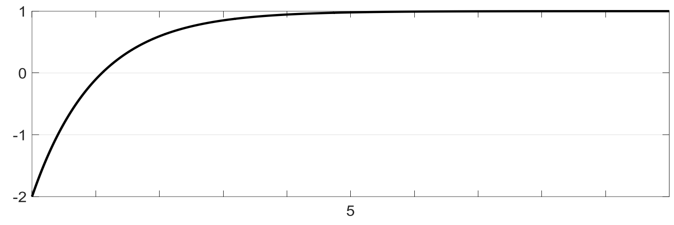
(30 marks/*markah*)



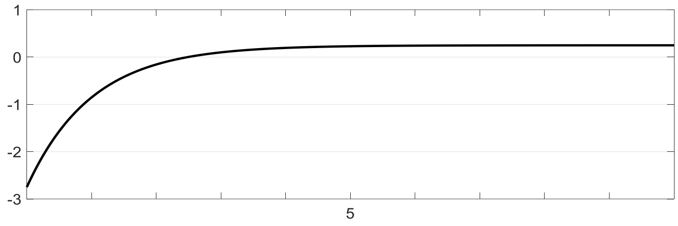
(a)



(b)



(c)



(d)

Figure 1.2. Waveform output

Rajah 1.2. Bentuk gelombang keluaran

2.

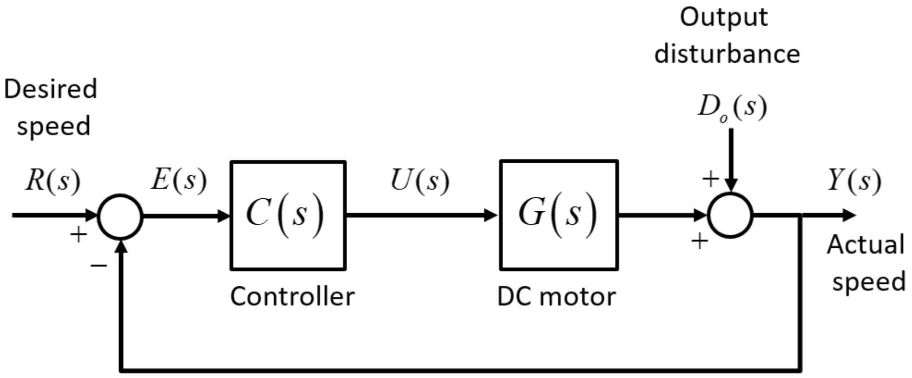


Figure 2.1: Feedback control of a DC motor

Rajah 2.1: Kawalan suap balik sebuah motor arus terus

Consider the feedback system of a DC motor as shown in Figure 2.1 where R, D_o and Y represent the desired speed, output disturbance and the actual speed of the DC motor respectively. The dynamics of the DC motor is represented by the transfer function

Pertimbangkan sistem suap balik sebuah motor arus terus seperti di dalam Rajah 2.1 di mana R, D_o dan Y masing-masing mewakili halaju yang dikehendaki, gangguan keluaran dan halaju sebenar. Dinamik motor arus terus tersebut diwakili oleh rangkap pindah

(a) Derive the transfer functions from $R(s)$ to $Y(s)$, and from $D_o(s)$ to $Y(s)$ in terms of the controller and the DC motor.

Ciptakan rangkap pindah dari $R(s)$ ke $Y(s)$, dan dari $D_o(s)$ ke $Y(s)$ dalam sebutan pengawal dan motor arus terus.

(20 arks/*markah*)

(b) Let

Biarkan

$$G(s) = \frac{3}{s+6}.$$

If the controller is structured as

Jika pengawal tersebut distruktur seperti

$$C(s) = K_p + \frac{K_i}{s}$$

where K_p and K_i are positive constants, find the transfer functions from $D_o(s)$ to $Y(s)$ and from $R(s)$ to $Y(s)$ in terms of K_p and K_i .

di mana K_p dan K_i adalah pemalar positif, carikan rangkap-rangkap pindah dari $D_o(s)$ ke $Y(s)$, dan dari $R(s)$ ke $Y(s)$ dalam sebutan K_p dan K_i .

(10 marks/*markah*)

(c) Prove that the controller above can guarantee zero steady-state error in the presence of both $R(s)$ and $D_o(s)$.

Buktikan pengawal di atas boleh menjamin ralat keadaan mantap sifar dengan kehadiran kedua-dua $R(s)$ dan $D_o(s)$.

(25 marks/*markah*)

(d) Find the damping ratio, ζ , in terms of K_p and K_i

Carikan nisbah rendaman ζ dalam sebutan K_p dan K_i .

(20 arks/*markah*)

(e) Let $K_i = 20$ and assume $D_o(s) = 0$. Find the values of K_p such that the peak overshoot of a step response is less than 10%.

Biarkan $K_i = 20$ dan andaikan $D_o(s) = 0$. Carikan nilai-nilai K_p supaya puncak tersasar untuk respon langkah kurang daripada 10%.

Use the approximations

Gunakan anggaran

$$M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$$ (peak overshoot / puncak tersasar)

(25 marks/*markah*)

3. (a) Given a unity feedback system that has the forward transfer function of $G(s) = \frac{K(s+2)}{s^2-4s+13}$

Diberi suatu sistem suap-balik unit yang mempunyai rangkap pindah ke hadapan $G(s) = \frac{K(s+2)}{s^2-4s+13}$

(i) Sketch the root locus

Lakarkan londar punca

(10 marks/*markah*)

(ii) Find the imaginary-axis crossing

Cari lintasan khayalan paksi

(10 marks/*markah*)

(iii) Find the gain, K, at the $j\omega$axis crossing

Cari gandaan, K, di persimpangan paksi

(10 marks/*markah*)

(iv) Find the break-in point.

Dapatkan titik pulang dalam.

(15 marks/*markah*)

(v) Find the angle of departure from the complex poles.

Cari sudut berlepas dari kutub kompleks.

(15 markah/*markah*)

(b) Given a unity feedback system that has the forward transfer function $G(s) = \frac{K(s+2)}{s^2+4s+13}$

Diberi suatu sistem suap-balik unit yang mempunyai rangkap pindah ke hadapan $G(s) = \frac{K(s+2)}{s^2+4s+13}$

(i) Calculate the angle of *G(s)* at the point $(-3 + j0)$by finding the algebraic sum of angles of the vectors drawn from the zeros and poles of *G(s)* to the given point.
Kirakan sudut G (s) pada titik $(-3 + j0)$ *dengan mencari jumlah sudut algebra sudut vektor diambil daripada sifar dan kutub G (s) ke titik yang diberikan.*

(10 marks/*markah*)

(ii) Determine if the point specified in (i) is on the root locus.
Tentukan sama ada titik yang dinyatakan dalam (i) adalah pada londar punca.

(15 marks/*markah*)

(iii) If the point specified in (i) is on the root locus, find the gain *K*, using the lenghts of the vectors.
Jika titik yang dinyatakan dalam (i) adalah pada londar punca, cari gandaan K, dengan menggunakan penjang vektor.

(15 marks/*markah*)

PART B

BAHAGIAN B

4. (a) Determine the transfer function $\frac{E_o(s)}{E_i(s)}$ of the following electrical circuit shown in Figure 4.1.
Tentukan fungsi pemindahan $\frac{E_o(s)}{E_i(s)}$ *litar elektrik berikut yang ditunjukkan dalam Rajah 4.1.*

(30 marks/markah)

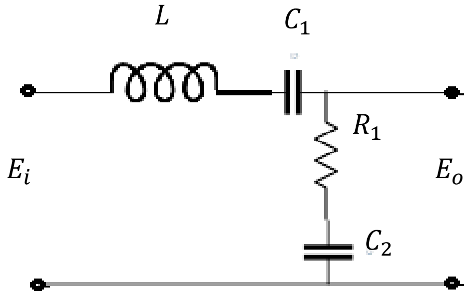


Figure 4.1. Op-amp electrical circuit

Rajah 4.1. Litar elektrik op-amp

(b) A system has a complex pole pair of $(-1 \pm j\ 2)$ and a real zero of (-3). The steady state output to a unit step input is 2. Find the transfer function of the system.

Sebuah sistem mempunyai sepasang kutub kompleks $(-1 \pm j\ 2)$ dan satu sifar sebenar (-3). Keadaan keluaran stabil ke satu unit langkah ialah 2. Carikan fungsi pemindahan sistem.

(30 marks/*markah*)

(c) Consider the optical scanner shown in Figure 4.2. This system is represented by the following differential equation

Mempertimbangkan pengimbas optik yang ditunjukkan dalam Rajah 4.2. Sistem ini telah diwakili oleh persamaan pembezaan berikut

$$J\frac{dy}{dt} + by = T_m$$

where J = 0.1, b =0.06 , and T_m is the motor input torque.

di mana J = 0.1, b = 0.06, dan T_m tork input dalam motor.

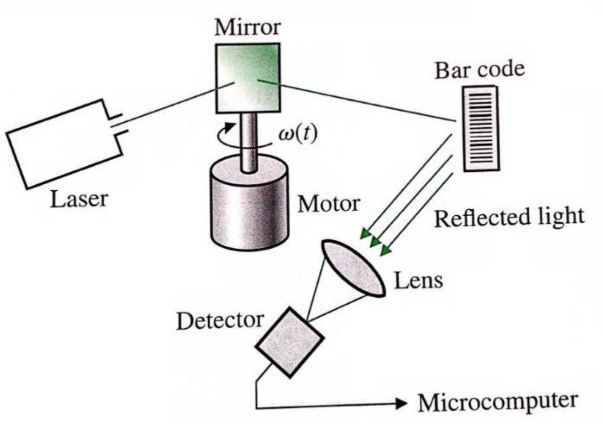


Figure 4.2. Optical scanner

Rajah 4.2. Pengimbas optic

Assume zero initial condition with input torque $T_m(s) = \frac{1}{s}$

Anggapkan keadaan awal sifar dengan tork masukan $T_m(s) = \frac{1}{s}$

(i) Find the Laplace Transforms Y(S) of the system.

Carikan di transformasi Laplace Y (s) sistem tersebut.

(20 marks/*markah*)

(ii) Determine the time domain function y(t) and the steady state response of the system as, $t \rightarrow \infty$.

Menentukan y(t) fungsi domain masa dan keadaan stabil tindak balas sistem jika , $t \rightarrow \infty$.

(20 marks/*markah*)

5. A closed-loop system is shown in Figure 5.1

Sebuah sistem gelung tertutup ditunjukkan dalam Rajah 5.1.

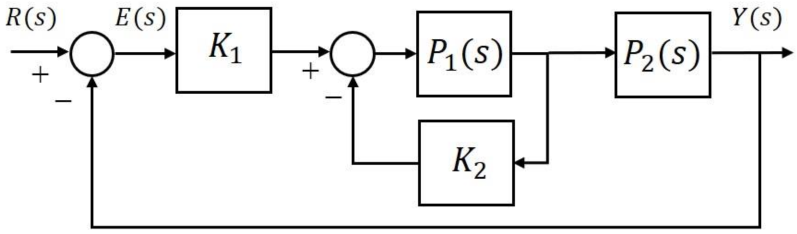


Figure 5.1: Closed-loop system

Rajah 5.1: Sistem gelung tertutup

(a) Derive the transfer function from $R(s)$ to $Y(s)$ in terms of K_1, K_2 , $P_1(s)$ and $P_2(s)$.

Ciptakan rangkap pindah dari $R(s)$ *kepada* $Y(s)$ *dalam sebutan* K_1, K_2 , $P_1(s)$ *and* $P_2(s)$.

(40 marks/*markah*)

(b) A closed-loop system subject to a step input disturbance, d_i is shown in Figure 5.2 where the controller is given by $C(s) = K$, and

Sebuah system gelung tertutup dengan gangguan langkah masukan, d_i, *ditunjukkan di dalam Rajah 5.2 di mana pengawal diberikan* $C(s) = K$ *, dan*

$$P(s) = \frac{1}{s(s+6)}$$

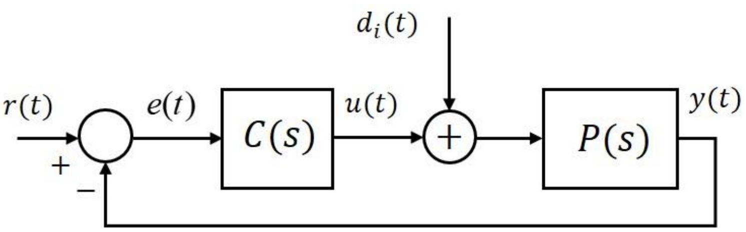


Figure 5.2: Closed-loop system with an input disturbance

Rajah 5.2: Sistem gelung tertutup dengan gangguan masukan

Suggest the values of K such that the step response of the closed-loop system satisfies the following specifications:
Cadangkan nilai-nilai K supaya sambutan langkah sistem gelung tertutup tersebut menepati spesifikasi-spesifikasi di bawah:

(i) The magnitude of the steady-state error with respect to the input disturbance is less than 10%.
Magnitude ralat keadaan mantap disebabkan oleh gangguan masukan kurang daripada 10%.

(ii) The damping ratio, ζ, for the closed-loop system is greater than 0.75.
Nisbah rendaman, ζ, untuk system gelung tertutup tersebut lebih daripada 0.75.

(60 marks/*markah*)

6. (a) Given a system with an open-loop transfer function of $G(s) = \frac{K(1-s)}{s+1}$
Diberi sistem dengan rangkap pindah gelung terbuka $G(s) = \frac{K(1-s)}{s+1}$

(i) Sketch a Nyquist locus for the system.
Lakarkan londar Nyquist untuk sistem.

(15 marks/*markah*)

(ii) Using Nyquist stability criterion, determine *K* for stabiliy of the system.
Dengan menggunakan kriteria kestabilan Nyquist, tentukan K untuk kestabilan.

(20 marks/*markah*)

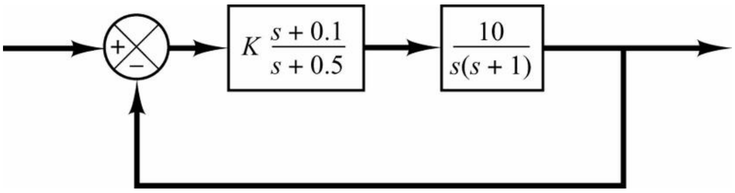


Figure 6.1

Rajah 6.1

(b) Consider the system shown in Figure 6.1 above.
Pertimbangkan sistem yang ditunjukkan di Rajah 6.1 atas.

(i) Draw a Bode diagram of the open-loop transfer function,
Lakar gambarajah Bode rangkap pindah gelung terbuka,

(15 marks/*markah*)

(ii) Determine the value of the gain *K* such that the phase margin is 50.
Tentukan nilai gandaan K supaya margin fasa ialah 50.

(15 marks/*markah*)

(iii) What is the gain margin of the system with this gain *K*
Apakah margin gandaan sistem tersebut dengan keuntungan K ini

(15 marks/*markah*)

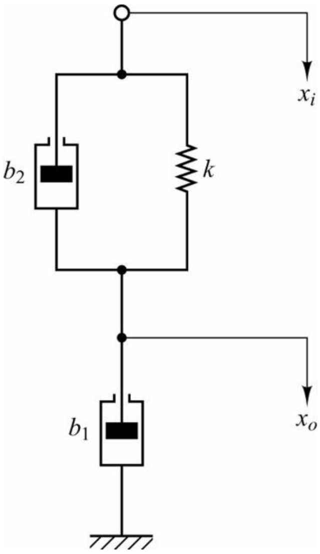


Figure 6.2
Rajah 6.2

(c) Consider the mechanical system shown in Figure 6.2. It consists of a spring and two dashpots.
Pertimbangkan sistem mekanikal yang ditunjukkan dalam Rajah 5a. Ia terdiri daripada satu spring dan dua peredam.

(i) Obtain the transfer function of the system. The displacement x_i is the input, and the displacement x_o is the output.
Dapatkan rangkap pindah sistem tersebut. Anjakan x_i adalah masukan, dan anjakan x_o adalah keluaran.

(10 marks/*markah*)

(ii) Is this system a mechanical lead network or lag network? Explain the reason of your answer.
Adakah sistem ini rangkaian mendulu atau rangkaian mengekor? Terangkan sebab jawapan anda.

(10 marks/*markah*)

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APPENDIX

LAMPIRAN

IMPORTANT LAPLACE TRANSFORM PAIRS	
$f(t)$	$F(s)$
Impulse function: $\delta(t)$	1
Step function: $u(t)$	$\frac{1}{s}$
e^{-at}	$\frac{1}{s+a}$
$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$
t^n	$\frac{n!}{s^{n+1}}$
$f^{(k)}(t)=\frac{d^k f(t)}{dt^k}$	$s^k F(s)-s^{k-1}f(0^-)-s^{k-2}f'(0^-)-\ldots-f^{(k-1)}(0^-)$
$\int_{-\infty}^{t} f(t)dt$	$\frac{F(s)}{s}+\frac{1}{s}\int_{-\infty}^{0} f(t)dt$
$e^{-at}\sin\omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$
$e^{-at}\cos\omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$
$\frac{\omega_n}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t\right);\ \ \zeta<1$	$\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$
$1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t+\phi\right);$ $\phi=\cos^{-1}\zeta;\ \ \zeta<1$	$\frac{\omega_n^2}{s\left(s^2+2\zeta\omega_n s+\omega_n^2\right)}$