UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2002/2003

Februari/Mac 2003

EEE 354 – SISTEM KAWALAN DIGIT

Masa : 3 jam

ARAHAN KEPADA CALON:

Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEMBILAN (9)** muka surat berserta Lampiran (3 muka surat) bercetak dan **ENAM (6)** soalan sebelum anda memulakan peperiksaan ini.

Jawab **LIMA (5)** soalan.

Agihan markah bagi soalan diberikan disut sebelah kanan soalan berkenaan.

Jawab semua soalan di dalam Bahasa Malaysia.

...2/-

1. Persamaan kebezaan yang memperihalkan suatu sistem kawalan diberikan seperti berikut:

The difference equation describing a control system is given as follows:

$$y(k) = 1.2y(k-1) - 0.36y(k-2) + r(k) - 0.8r(k-1) + 0.15r(k-2)$$

$r(k)$ adalah unit langkah dan semua nilai awalan $y(k)$ adalah kosong.

$r(k)$ is a unit step and all the initial values of $y(k)$ are zeros.

(a) Tentukan fungsi pindah sistem tersebut.

Determine the transfer function of the system.

(25%)

(b) Lukiskan graf aliran keadaan sistem kawalan tersebut dalam bentuk berkanun boleh kawal (CCF).

Draw the state flow graph of the system in controllable canonical form (CCF).

(20%)

(c) Berdasarkan graf aliran keadaan dalam (b), terbitkan persamaan keadaan diskret bagi sistem tersebut dalam bentuk berkanun boleh kawal (CCF).

Based on the state flow graph in (b), derive the discrete state equation of the system in controllable canonical form.

(20%)

...3/-

(d) Berdasarkan fungsi pindah dalam (a), untuk T = 1s tentukan y(kT) menggunakan:
Based on the transfer function in (a), for T = 1s determine y(kT) using:

(i) Jelmaan-Z songsang dan kirakan 5 sebutan pertama.
Inverse Z-transform and calculate the first 5 terms.

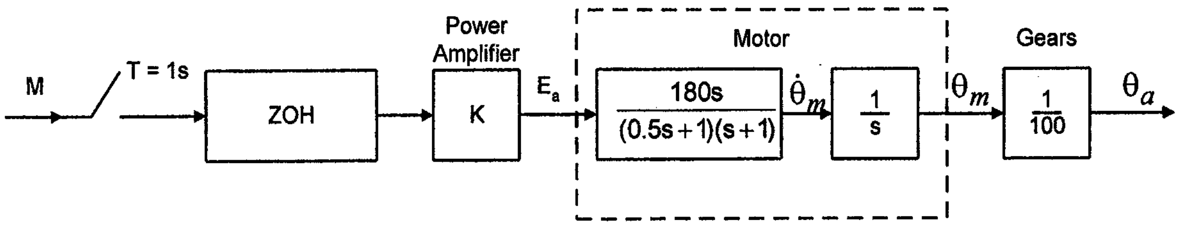
(25%)

(ii) Persamaan kebezaan di atas dan kirakan 5 sebutan pertama.
The above difference equation and calculate the first 5 terms.

(10%)

2. Gambarajah blok suatu penyambung lengan robot ditunjukkan dalam Rajah 1. Isyarat M(*s*) ialah masukan pensampel, $E_a(s)$ ialah voltan masukan motor, $\theta_m(s)$ ialah sudut shaf motor dan keluaran $\theta_a(s)$ ialah sudut lengan tersebut.

The block diagram of a joint of a robotic arm is shown in Figure 1. The signal M(s) is the sampler input, $E_a(s)$ is the motor input voltage, $\theta_m(s)$ is the motor shaft angle and the output $\theta_a(s)$ is the angle of the arm.



Rajah 1
Figure 1

(a) Tentukan fungsi pindah dedenyut sistem tersebut.

Determine the pulse transfer function of the system.

(35%)

(b) Tentukan sambutan sistem tersebut untuk masukan unit langkah pada kala pensampelan.

Determine the system response for unit step input at the sampling interval.

(35%)

(c) Kirakan sambutan keadaan mantap sistem tersebut berdasarkan sambutan dalam (b).

Calculate the steady state response of the system based on the response in (b).

(10%)

(d) Kirakan sambutan keadaan mantap sistem tersebut berdasarkan teorem nilai akhir dan semak sama ada teorem nilai akhir akan memberi jawapan yang betul dalam hal ini.

Calculate the steady state response of the system using final value theorem and check whether final value theorem will give a correct answer in this case.

(20%)

3. Gambarajah blok suatu sistem kawalan satu bilik besar ditunjukkan dalam rajah berikut. Satu masukan gangguan, U(s), adalah disebabkan oleh pembukaan pintu bilik tersebut.

The block diagram of a control system for a large room is shown in the following figure. A disturbance input, U(s), is due to the door opening of the room.

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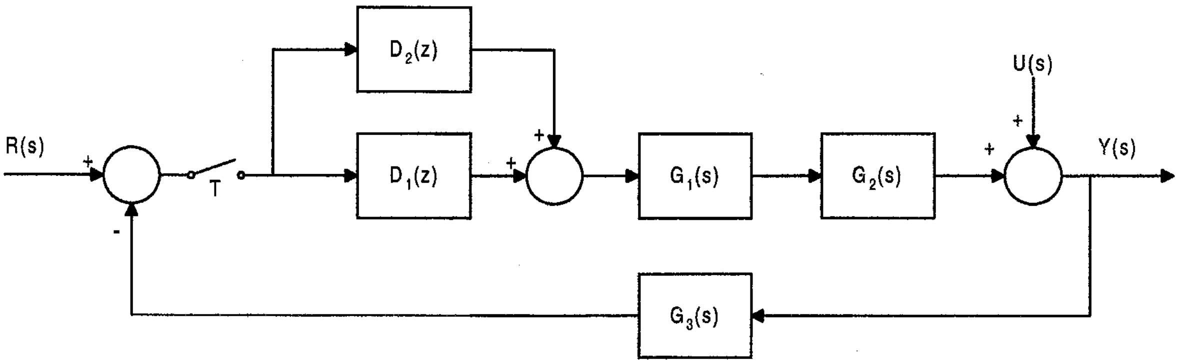


Rajah 2

Figure 2

(a) Terbitkan fungsi pindah sistem di atas dengan menyatakan Y(z) dalam sebutan R(z) dan U(z). Gunakan OFG, SFG dan formula untung Mason dalam terbitan anda.

Derive the transfer function of the above system by expressing Y(z) in term of R(z) and U(z). Use OFG, SFG and Mason's gain formula in your derivation.

(50%)

(b) Jika fungsi pindah kepada blok-blok tersebut adalah seperti berikut:
If the transfer functions of the blocks are as follows:

$$G_1(s) = \text{ZOH},\ G_2(s) = \frac{2s+1}{(s+1)(s+10)},\ G_3(s) = 0.5,\ D_1(z) = 5 \text{ and } D_2(z) = \frac{0.5z}{z-1}$$

...6/-

Tentukan fungsi pindah sebenar sistem tersebut berdasarkan fungsi pindah yang didapati dalam bahagian (a), untuk T = 1s.

Determine the actual transfer function of the system based on the transfer function obtained in part (a), for T = 1s.

(40%)

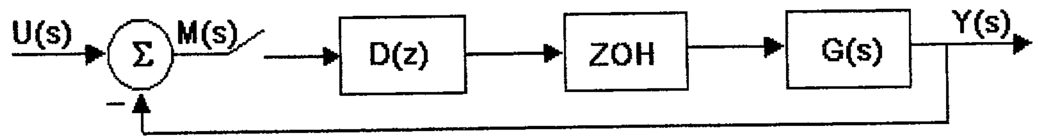
(c) Tentukan persamaan ciri sistem tersebut.

Determine the characteristic equation of the system.

(10%)

4. Gambarajah blok kepada satu sistem kawalan suhu bagi pengimpal paip ditunjukkan dalam Rajah 3.

The block diagram of a temperature control system for a pipe-wielding is shown in Figure 3.



Rajah 3

Figure 3

Fungsi pindah dedenyut sistem tersebut diberikan sebagai:

The pulse transfer function of the system is given as:

$$G(z)=\frac{0.21z+0.19}{z^2-1.78z+0.78},\ D(z)=1;\ \text{for T = 0.1s}$$

...7/-

(a) Tentukan fungsi pindah gelung tertutup sistem tersebut.
Determine the closed loop transfer function of the system.

(20%)

(b) Berdasarkan persamaan ciri sistem gelung tertutup tersebut, tentukan faktor lemati, frekuensi tabii dan pemalar masa sistem tersebut.

Based on the characteristic equation of the closed loop system, determine the damping factor, natural frequency and time constant of the system.

(35%)

(c) Jika D(z) ialah satu pengawal PI iaitu,
If D(z) is a PI controller that is,

$$D(z) = 2 + \frac{0.5z}{z-1}$$

kirakan ralat keadaan mantap sistem untuk masukan-masukan berikut:
calculate the steady state error of the system for the following inputs:

(45%)

(i) Unit langkah
Unit step

(ii) Unit rampa
Unit ramp

(iii) Unit parabola
Unit parabolic

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5. Fungsi pindah dedenyut suatu sistem kawalan suapbalik unit diberikan seperti berikut:
The pulse transfer function of a unity feedback control system is given as follows:

$$G(z) = \frac{K(0.18z - 0.17)}{z(z - 0.77)}, \qquad T = 0.4s$$

(a) Tentukan persamaan ciri sistem gelung tertutup dalam domain-z dan domain-w sebagai suatu fungsi K.

Determine the characteristic equation of the closed loop system in z-domain and w-domain as a function of K.

(25%)

(b) Tentukan julat K supaya sistem tersebut akan kekal stabil menggunakan kriteria Routh-Hurwitz.

Determine the range of K such that the system will remain stable using Routh-Hurwitz criterion.

(25%)

(c) Semak jawapan anda dalam (b) menggunakan ujian kestabilan Jury.
Check your answer in (b) using Jury's stability test.

(25%)

(d) Lakarkan Londar Punca untuk sistem tersebut dalam domain-z.
Sketch the Root Locus of the system in z-domain.

(25%)

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6. Rajah 3 mewakili gambarajah blok satu model anggaran kepada satu sistem kawalan gelung tertutup penghawa dingin. Fungsi pindah dedenyut sistem tersebut boleh dinyatakan sebagai:

Figure 3 represents the block diagram of an approximate model for an air-condition closed loop control system. The pulse transfer function of the system can be expressed as:

$$G(z) = \frac{0.0048z + 0.0046}{(z-1)(z-0.9048)}; \quad T = 0.1\text{s}$$

Sambutan frekuensi kepada *G(z)* tersebut diberikan di dalam Jadual 1. Sambutan sistem tersebut perlu diperbaiki supaya ralat keadaan mantap sistem boleh dikurangkan dari 0.5 kepada 0.25 dan sut fasa perlu tingkatkan kepada 65°. Rekabentuk:

The frequency response of G(z) is given in Table 1. The system response has to be improved such that the system steady state error can be reduce from 0.5 to 0.25 and phase margin has to be increased to 65°. Design:

(a) Satu pengawal duluan fasa untuk memenuhi spesifikasi di atas.
A phase lead controller for the above specifications.

(60%)

(b) Satu pengawal PI untuk spesikasi di atas.

A PI controller for the above specifications. (40%)

(Nota: Nyatakan semua jawaban akhir anda dalam bahagian (a) dan (b) dalam domain-z)
(Note: Express all your final answers in part (a) and (b) in z-domain)

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ω_w	ω	$\|G(j\omega_w)\|$	$\|G(j\omega_w)\|$dB	$\angle G(j\omega_w)$	$\left\|\frac{G(j\omega_w)}{1+G(j\omega_w)}\right\|_{dB}$
0.1000	0.1000	9.95041	19.95682	−95.99702	0.04760
0.2000	0.2000	4.90299	13.80922	−101.88250	0.18813
0.3000	0.3000	3.19289	10.08369	−107.55740	0.41372
0.4000	0.3999	2.32139	7.31496	−112.94450	0.70734
0.5000	0.4999	1.78911	5.05276	−117.99240	1.03622
0.6000	0.5998	1.42948	3.10358	−122.67450	1.34277
0.7000	0.6997	1.17073	1.36911	−126.98560	1.53758
0.8000	0.7996	0.97655	−0.20612	−130.93550	1.50754
0.9000	0.8994	0.82641	−1.65609	−134.54460	1.15424
1.0000	0.9992	0.70770	−3.00307	−137.83850	0.44876
2.0000	1.9934	0.22457	−12.97286	−159.06920	−10.97265
3.0000	2.9778	0.10651	−19.45228	−169.96690	−18.49177
4.0000	3.9479	0.06179	−24.18212	−177.09400	−23.62893
5.0000	4.8996	0.04040	−27.87273	−182.49680	−27.51491
6.0000	5.8291	0.02858	−30.87771	−186.95820	−30.62776
7.0000	6.7335	0.02139	−33.39674	−190.83250	−33.21241
8.0000	7.6101	0.01669	−35.55328	−194.30040	−35.41178
9.0000	8.4571	0.01344	−37.42904	−197.46320	−37.31700
10.0000	9.2730	0.01112	−39.08097	−200.38180	−38.99006
20.0000	15.7080	0.00353	−49.04776	−221.18530	−49.02468
30.0000	19.6560	0.00200	−53.97535	−232.97050	−53.96489
40.0000	22.1430	0.00140	−57.09782	−240.09520	−57.09178
50.0000	23.8060	0.00108	−59.35686	−244.66820	−59.35286
60.0000	24.9810	0.00088	−61.12365	−247.74910	−61.12076
70.0000	25.8500	0.00074	−52.57513	−249.89890	−62.57292
80.0000	26.5160	0.00065	−63.80777	−251.43480	−63.80599
90.0000	27.0430	0.00057	−64.87953	−252.54670	−64.57804
100.0000	27.4680	0.00051	−65.82789	−253.35480	−65.82662

Jadual 1
Table 1

Laplace transform $E(s)$	Time function $e(t)$	z-Transform $E(z)$	Modified z-transform $E(z, m)$
$\frac{1}{s}$	$u(t)$	$\frac{z}{z-1}$	$\frac{1}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$	$\frac{mT}{z-1}+\frac{T}{(z-1)^2}$
$\frac{1}{s^3}$	$\frac{t^2}{2}$	$\frac{T^2z(z+1)}{2(z-1)^3}$	$\frac{T^2}{2}\left[\frac{m^2}{z-1}+\frac{2m+1}{(z-1)^2}+\frac{2}{(z-1)^3}\right]$
$\frac{(k-1)!}{s^k}$	t^{k-1}	$\lim_{a\to 0}(-1)^{k-1}\frac{\partial^{k-1}}{\partial a^{k-1}}\left[\frac{z}{z-\epsilon^{-aT}}\right]$	$\lim_{a\to 0}(-1)^{k-1}\frac{\partial^{k-1}}{\partial a^{k-1}}\left[\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}\right]$
$\frac{1}{s+a}$	ϵ^{-at}	$\frac{z}{z-\epsilon^{-aT}}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{1}{(s+a)^2}$	$t\epsilon^{-at}$	$\frac{Tz\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}$	$\frac{T\epsilon^{-amT}[\epsilon^{-aT}+m(z-\epsilon^{-aT})]}{(z-\epsilon^{-aT})^2}$
$\frac{(k-1)!}{(s+a)^k}$	$t^k\epsilon^{-at}$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{z}{z-\epsilon^{-aT}}\right]$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}\right]$
$\frac{a}{s(s+a)}$	$1-\epsilon^{-at}$	$\frac{z(1-\epsilon^{-aT})}{(z-1)(z-\epsilon^{-aT})}$	$\frac{1}{z-1}-\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{a}{s^2(s+a)}$	$t-\frac{1-\epsilon^{-at}}{a}$	$\frac{z[(aT-1+\epsilon^{-aT})z+(1-\epsilon^{-aT}-aT\epsilon^{-aT})]}{a(z-1)^2(z-\epsilon^{-aT})}$	$\frac{T}{(z-1)^2}+\frac{amT-1}{a(z-1)}+\frac{\epsilon^{-amT}}{a(z-\epsilon^{-aT})}$
$\frac{a^2}{s(s+a)^2}$	$1-(1+at)\epsilon^{-at}$	$\frac{z}{z-1}-\frac{z}{z-\epsilon^{-aT}}-\frac{aT\epsilon^{-aT}z}{(z-\epsilon^{-aT})^2}$	$\frac{1}{z-1}-\left[\frac{1+amT}{z-\epsilon^{-aT}}+\frac{aT\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}\right]\epsilon^{-amT}$
$\frac{b-a}{(s+a)(s+b)}$	$\epsilon^{-at}-\epsilon^{-bt}$	$\frac{(\epsilon^{-aT}-\epsilon^{-bT})z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}-\frac{\epsilon^{-bmT}}{z-\epsilon^{-bT}}$
$\frac{a}{s^2+a^2}$	$\sin(at)$	$\frac{z\sin(aT)}{z^2-2z\cos(aT)+1}$	$\frac{z\sin(amT)+\sin(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{s}{s^2+a^2}$	$\cos(at)$	$\frac{z(z-\cos(aT))}{z^2-2z\cos aT+1}$	$\frac{z\cos(amT)-\cos(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{1}{(s+a)^2+b^2}$	$\frac{1}{b}\epsilon^{-at}\sin bt$	$\frac{1}{b}\left[\frac{z\epsilon^{-aT}\sin bT}{z^2-2z\epsilon^{-aT}\cos(bT)+\epsilon^{-2aT}}\right]$	$\frac{1}{b}\left[\frac{\epsilon^{-amT}[z\sin bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}\right]$
$\frac{s+a}{(s+a)^2+b^2}$	$\epsilon^{-at}\cos bt$	$\frac{z^2-z\epsilon^{-aT}\cos bT}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$	$\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{a^2+b^2}{s[(s+a)^2+b^2]}$	$1-\epsilon^{-at}\left(\cos bt+\frac{a}{b}\sin bt\right)$	$\frac{z(Az+B)}{(z-1)(z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT})}$ $A=1-\epsilon^{-aT}\left(\cos bT+\frac{a}{b}\sin bT\right)$ $B=\epsilon^{-2aT}+\epsilon^{-aT}\left(\frac{a}{b}\sin bT-\cos bT\right)$	$\frac{1}{z-1}$ $-\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$ $\frac{+\frac{a}{b}\{\epsilon^{-amT}[z\sin bmT-\epsilon^{-aT}\sin(1-m)bT]\}}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab}+\frac{\epsilon^{-at}}{a(a-b)}$ $+\frac{\epsilon^{-bt}}{b(b-a)}$	$\frac{(Az+B)z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})(z-1)}$	$A=\frac{b(1-\epsilon^{-aT})-a(1-\epsilon^{-bT})}{ab(b-a)}$ $B=\frac{a\epsilon^{-aT}(1-\epsilon^{-bT})-b\epsilon^{-bT}(1-\epsilon^{-aT})}{ab(b-a)}$