UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2007/2008

April 2008

EEE 354 – SISTEM KAWALAN DIGIT

Masa: 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN muka surat dan TIGA muka surat LAMPIRAN yang bercetak sebelum anda memulakan peperiksaan ini.

Kertas soalan ini mengandungi ENAM soalan.

Jawab LIMA soalan.

Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru.

Agihan markah bagi setiap soalan diberikan di sudut sebelah kanan soalan berkenaan.

Jawab semua soalan dalam bahasa Malaysia atau bahasa Inggeris atau kombinasi kedua-duanya.

...2/-

1. Persamaan kebezaan untuk suatu sistem kawalan diberikan seperti di bawah:
The difference equation for a control system is given below:

$$y(k+3) - 2.2y(k+2) + 1.57y(k+1) - 0.36y(k) = u(k)$$
$$y(2) = y(1) = y(0) = 0$$
$$u(k) = 1 \text{ for } k \geq 0$$

(a) Lukiskan gambarajah simulasi untuk persamaan kebezaan yang mewakili sistem tersebut.

Draw the simulation diagram for the difference equation that represents the system.

(20%)

(b) Tentukan fungsi pindah sistem berdasarkan persamaan kebezaan tersebut.

Determine the transfer function of the system based on the difference equation.

(20%)

(c) Tentukan persamaan keadaan ruang diskret sistem tersebut berdasarkan fungsi pindah dalam (b).

Determine the discrete state space equation of the system based on the transfer function in (b).

(20%)

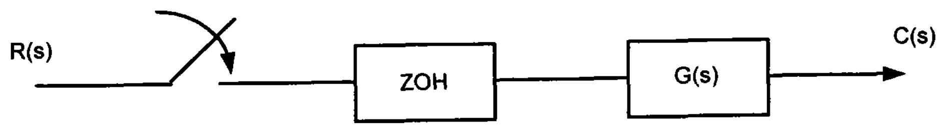
(d) Tentukan y(kT) menggunakan:
Determine y(kT) using:

(i) Kaedah jujukan. Kirakan y(kT) untuk k = 3,4,5.
Sequential method. Calculate y(kT) for k = 3,4,5.

(ii) Kaedah siri kuasa dan jelmaan z. Kirakan y(kT) untuk k = 3,4,5.
Power series and z transform method. Calculate y(kT) for k = 3,4,5.

(40%)

2. Suatu sistem kawalan terbuka boleh diwakili oleh gambarajah berikut:
An open loop control system can be represented by the following diagram:



Rajah 1
Figure 1

Jika,
If, $G(s) = \frac{4}{(s+1)}$

(a) Tentukan fungsi pindah dedenyut bagi sistem tersebut untuk T = 1 saat.
Determine the pulse transfer function of the system for T = 1 sec.

(20%)

(b) Tentukan sambutan masa sistem tersebut pada kala pensampelan bagi:
Determine the system time response at the sampling interval for:

(i) Masukan unit langkah.
Unit step input.

(ii) Masukan unit rampa.
Unit ramp input. (30%)

(c) Kirakan sambutan keadaan mantap sistem tersebut menggunakan teorem nilai akhir jelmaan z dan juga berdasarkan sambutan masa dalam (b)(i).

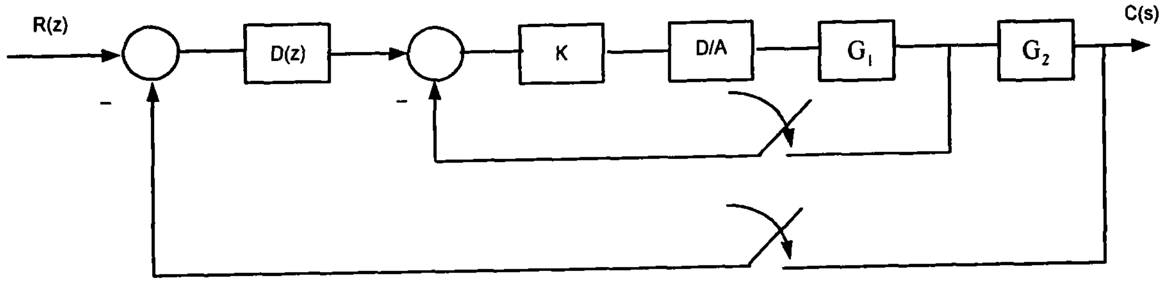
Calculate the steady state reponse of the system using final value theorem of z transform and also based on the time domain response in part (b)(i).

(30%)

(d) Ulangi (a) menggunakan jelmaan z terubahsuai jika,
Repeat (a) using modified z transform if,

$$G(s) = \frac{e^{-0.3s}}{(s+1)}$$ (20%)

3. Rajah 2 menunjukkan gambarajah blok bagi suatu sistem kawalan.
Figure 2 represents the block diagram of a control system.



Rajah 2
Figure 2

(a) Dapatkan fungsi pindah sistem tersebut. Anda boleh menggunakan OFG, SFG dan formula untung Mason di mana bersesuaian dalam terbitan anda.

Obtain the transfer function of the system. You may use OFG, SFG and Mason's Gain formula where appropriate in your derivation.

(45%)

(b) Jika,
If,

$$G_1(s) = \frac{5}{(s+1)},\ G_2(s) = \frac{1}{(s+2)},\ D(z) = 1,\ K = 1$$

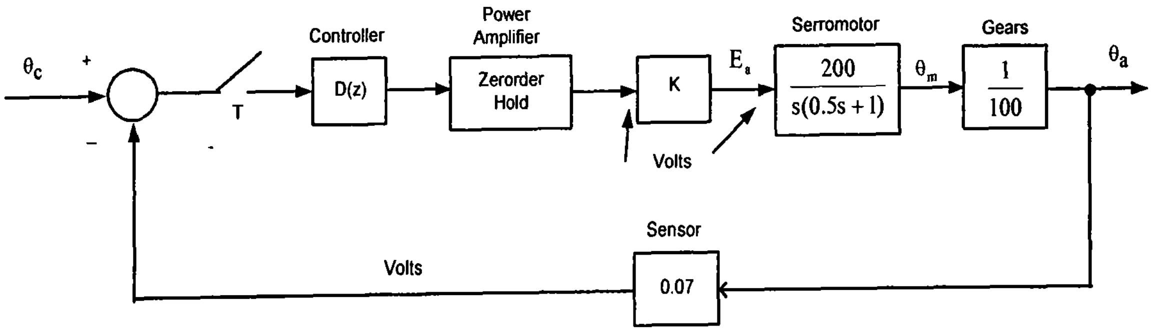
Tentukan fungsi pindah sebenar sistem tersebut berdasarkan fungsi pindah yang diperolehi dalam bahagian (a), untuk T = 1 saat.

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

(55%)

4. Pertimbangkan sebuah sistem kawalan sendi lengan robot seperti di Rajah 1. Diberi T=0.1s dan D(z)=1.

Consider the robot arm joint control system of Figure 1. Let T=0.1s and D(z)=1.



Rajah 1
Figure 1

Juga diberi
Also given,

$$Z\left[\frac{1-e^{-TS}}{s}\frac{4}{s(s+2)}\right]=\frac{0.01873z+0.01752}{(z-1)(z-0.8187)}$$

(a) Tuliskan persamaan ciri sistem gelung tertutup.
Write the closed loop system characteristic equation.

(15%)

(b) Gunakan kriteria Routh-Hurwitz bagi menentukan julat K untuk kestabilan.
Use the Routh-Hurwitz criterion to determine the range of K for stability.

(15%)

(c) Ulangi bahagian (b) dengan menggunakan uji Jury.
Repeat part (b) by using Jury's test.

(15%)

(d) Tentukan kedudukan punca persamaan ciri dalam kedua-dua satah iaitu satah-w dan satah-z bagi nilai K>0 pada tahap sistem stabil berjidar.

Determine the location of all roots of the characteristic equation in both w-plane and the z-plane for the value of K>0 for which the system is marginally stable.

(20%)

(e) Tentukan frekuensi satah-s dan frekuensi satah-w pada keadaan sistem akan berayun apabila dalam keadaan stabil berjidar, menggunakan jawapan dari bahagian (d).

Determine both the s-plane frequency and the w-plane frequency at which the system will oscillate when marginally stable, using the results of part (d).

(20%)

(f) Tunjukkan yang frekuensi-frekuensi dalam bahagian (e) memenuhi:
Show that the frequencies in part (e) satisfy:

$$\omega_w = \frac{2}{T} \tan \frac{\omega T}{2}$$

(15%)

5. Diberi sebuah sistem digital yang rangkap pindahnya gelung buka seperti di bawah:

Given a digital control system with the following open-loop transfer function:

$$G(z) = \frac{0.368z + 0.264}{(z-1)(z-0.368)}$$

Andaikan masa pensampelan ialah T=1.0s.

Assume the sampling time is T=1.0s.

(a) Tentukan jidar fasa dan jidar gandaan bagi system G(z).

Determine the phase margin and gain margin for system G(z).

(60%)

(b) Adakah ia stabil?

Is it stable? (10%)

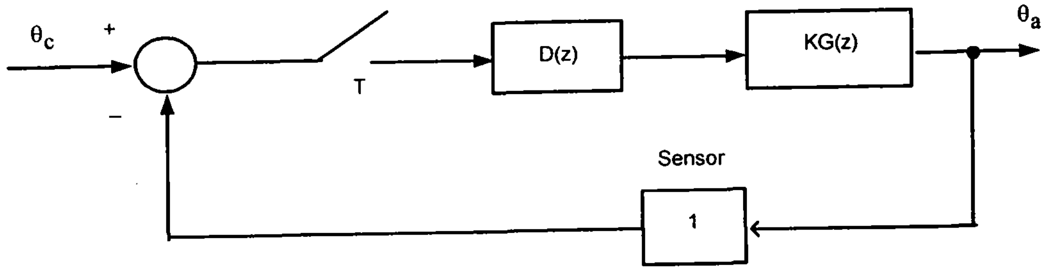
(c) Tentukan frekuensi ω pada keadaan sistem yang stabil berjidar akan berayun.

Determine frequency ω at which the marginally stable system will oscillate.

(30%)

6. Sebuah sistem kawalan yang mengawal lengan robot ditunjukkan dalam Rajah 2,

A control system that controls a robot arm is shown in Figure 2,



Rajah 2
Figure 2

Andaikan,
Assume,

$$G(z) = \frac{0.368z + 0.264}{(z-1)(z-0.368)}$$

(Rujuk kepada jawapan anda dalam soalan 5 untuk membantu anda)
(Refer to your answer in question 5 to help you)

(a) Rekabentuk sebuah pemampas-mengekor dengan gandaan dc 10 yang menghasilkan jidar fasa sistem sebanyak 45°.

Design a phase-lag controller with the dc gain of 10 that yields a system phase margin of 45°.

(100%)

ooo0ooo

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	$\frac{Tz}{(z-1)^2}$	$\frac{mT}{z-1}+\frac{T}{(z-1)^2}$
$\frac{1}{s^3}$	$\frac{t^2}{2}$	$\frac{T^2 z(z+1)}{2(z-1)^3}$	$\frac{T^2}{2}\left[\frac{m^2}{z-1}+\frac{2m+1}{(z-1)^2}+\frac{2}{(z-1)^3}\right]$
$\frac{(k-1)!}{s^k}$	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}	$\frac{z}{z-\epsilon^{-aT}}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{1}{(s+a)^2}$	$t\epsilon^{-at}$	$\frac{Tz\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}$	$\frac{T\epsilon^{-amT}[\epsilon^{-aT}+m(z-\epsilon^{-aT})]}{(z-\epsilon^{-aT})^2}$
$\frac{(k-1)!}{(s+a)^k}$	$t^k\epsilon^{-at}$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{z}{z-\epsilon^{-aT}}\right]$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}\right]$
$\frac{a}{s(s+a)}$	$1-\epsilon^{-at}$	$\frac{z(1-\epsilon^{-aT})}{(z-1)(z-\epsilon^{-aT})}$	$\frac{1}{z-1}-\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{a}{s^2(s+a)}$	$t-\frac{1-\epsilon^{-at}}{a}$	$\frac{z[(aT-1+\epsilon^{-aT})z+(1-\epsilon^{-aT}-aT\epsilon^{-aT})]}{a(z-1)^2(z-\epsilon^{-aT})}$	$\frac{T}{(z-1)^2}+\frac{amT-1}{a(z-1)}+\frac{\epsilon^{-amT}}{a(z-\epsilon^{-aT})}$
$\frac{a^2}{s(s+a)^2}$	$1-(1+at)\epsilon^{-at}$	$\frac{z}{z-1}-\frac{z}{z-\epsilon^{-aT}}-\frac{aT\epsilon^{-aT}z}{(z-\epsilon^{-aT})^2}$	$\frac{1}{z-1}-\left[\frac{1+amT}{z-\epsilon^{-aT}}+\frac{aT\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}\right]\epsilon^{-amT}$
$\frac{b-a}{(s+a)(s+b)}$	$\epsilon^{-at}-\epsilon^{-bt}$	$\frac{(\epsilon^{-aT}-\epsilon^{-bT})z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}-\frac{\epsilon^{-bmT}}{z-\epsilon^{-bT}}$
$\frac{a}{s^2+a^2}$	$\sin(at)$	$\frac{z\sin(aT)}{z^2-2z\cos(aT)+1}$	$\frac{z\sin(amT)+\sin(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{s}{s^2+a^2}$	$\cos(at)$	$\frac{z(z-\cos(aT))}{z^2-2z\cos aT+1}$	$\frac{z\cos(amT)-\cos(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{1}{(s+a)^2+b^2}$	$\frac{1}{b}\epsilon^{-at}\sin bt$	$\frac{1}{b}\left[\frac{z\epsilon^{-aT}\sin bT}{z^2-2z\epsilon^{-aT}\cos(bT)+\epsilon^{-2aT}}\right]$	$\frac{1}{b}\left[\frac{\epsilon^{-amT}[z\sin bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}\right]$
$\frac{s+a}{(s+a)^2+b^2}$	$\epsilon^{-at}\cos bt$	$\frac{z^2-z\epsilon^{-aT}\cos bT}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$	$\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{a^2+b^2}{s[(s+a)^2+b^2]}$	$1-\epsilon^{-at}\left(\cos bt+\frac{a}{b}\sin bt\right)$	$\frac{z(Az+B)}{(z-1)(z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT})}$ $A=1-\epsilon^{-aT}\left(\cos bT+\frac{a}{b}\sin bT\right)$ $B=\epsilon^{-2aT}+\epsilon^{-aT}\left(\frac{a}{b}\sin bT-\cos bT\right)$	$\frac{1}{z-1}-\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]+\frac{a}{b}(\epsilon^{-amT}[z\sin bmT-\epsilon^{-aT}\sin(1-m)bT])}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab}+\frac{\epsilon^{-at}}{a(a-b)}+\frac{\epsilon^{-bt}}{b(b-a)}$	$\frac{(Az+B)z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})(z-1)}$	$A=\frac{b(1-\epsilon^{-aT})-a(1-\epsilon^{-bT})}{ab(b-a)}$ $B=\frac{a\epsilon^{-aT}(1-\epsilon^{-bT})-b\epsilon^{-bT}(1-\epsilon^{-aT})}{ab(b-a)}$

TABLE OF z TRANSFORMS

	$X(s)$	$x(t)$	$x(kT)$ or $x(k)$	$X(z)$
1.	—	—	Kronecker delta $\delta_0(k)$ $1, \quad k = 0$ $0, \quad k \neq 0$	1
2.	—	—	$\delta_0(n-k)$ $1, \quad n = k$ $0, \quad n \neq k$	z^{-k}
3.	$\dfrac{1}{s}$	$1(t)$	$1(k)$	$\dfrac{1}{1-z^{-1}}$
4.	$\dfrac{1}{s+a}$	e^{-at}	e^{-akT}	$\dfrac{1}{1-e^{-aT}z^{-1}}$
5.	$\dfrac{1}{s^2}$	t	kT	$\dfrac{Tz^{-1}}{(1-z^{-1})^2}$
6.	$\dfrac{2}{s^3}$	t^2	$(kT)^2$	$\dfrac{T^2z^{-1}(1+z^{-1})}{(1-z^{-1})^3}$
7.	$\dfrac{6}{s^4}$	t^3	$(kT)^3$	$\dfrac{T^3z^{-1}(1+4z^{-1}+z^{-2})}{(1-z^{-1})^4}$
8.	$\dfrac{a}{s(s+a)}$	$1-e^{-at}$	$1-e^{-akT}$	$\dfrac{(1-e^{-aT})z^{-1}}{(1-z^{-1})(1-e^{-aT}z^{-1})}$
9.	$\dfrac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$e^{-akT}-e^{-bkT}$	$\dfrac{(e^{-aT}-e^{-bT})z^{-1}}{(1-e^{-aT}z^{-1})(1-e^{-bT}z^{-1})}$
10.	$\dfrac{1}{(s+a)^2}$	te^{-at}	kTe^{-akT}	$\dfrac{Te^{-aT}z^{-1}}{(1-e^{-aT}z^{-1})^2}$
11.	$\dfrac{s}{(s+a)^2}$	$(1-at)e^{-at}$	$(1-akT)e^{-akT}$	$\dfrac{1-(1+aT)e^{-aT}z^{-1}}{(1-e^{-aT}z^{-1})^2}$

(continued)

	$X(s)$	$x(t)$	$x(kT)$ or $x(k)$	$X(z)$
12.	$\frac{2}{(s+a)^3}$	$t^2 e^{-at}$	$(kT)^2 e^{-akT}$	$\frac{T^2 e^{-aT}(1+e^{-aT}z^{-1})z^{-1}}{(1-e^{-aT}z^{-1})^3}$
13.	$\frac{a^2}{s^2(s+a)}$	$at-1+e^{-at}$	$akT-1+e^{-akT}$	$\frac{[(aT-1+e^{-aT})+(1-e^{-aT}-aTe^{-aT})z^{-1}]z^{-1}}{(1-z^{-1})^2(1-e^{-aT}z^{-1})}$
14.	$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$	$\sin \omega kT$	$\frac{z^{-1}\sin \omega T}{1-2z^{-1}\cos \omega T+z^{-2}}$
15.	$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	$\cos \omega kT$	$\frac{1-z^{-1}\cos \omega T}{1-2z^{-1}\cos \omega T+z^{-2}}$
16.	$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin \omega t$	$e^{-akT}\sin \omega kT$	$\frac{e^{-aT}z^{-1}\sin \omega T}{1-2e^{-aT}z^{-1}\cos \omega T+e^{-2aT}z^{-2}}$
17.	$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	$e^{-akT}\cos \omega kT$	$\frac{1-e^{-aT}z^{-1}\cos \omega T}{1-2e^{-aT}z^{-1}\cos \omega T+e^{-2aT}z^{-2}}$
18.			a^k	$\frac{1}{1-az^{-1}}$
19.			a^{k-1} $k=1,2,3,\ldots$	$\frac{z^{-1}}{1-az^{-1}}$
20.			ka^{k-1}	$\frac{z^{-1}}{(1-az^{-1})^2}$
21.			k^2a^{k-1}	$\frac{z^{-1}(1+az^{-1})}{(1-az^{-1})^3}$
22.			k^3a^{k-1}	$\frac{z^{-1}(1+4az^{-1}+a^2z^{-2})}{(1-az^{-1})^4}$
23.			k^4a^{k-1}	$\frac{z^{-1}(1+11az^{-1}+11a^2z^{-2}+a^3z^{-3})}{(1-az^{-1})^5}$
24.			$a^k\cos k\pi$	$\frac{1}{1+az^{-1}}$
25.			$\frac{k(k-1)}{2!}$	$\frac{z^{-2}}{(1-z^{-1})^3}$
26.			$\frac{k(k-1)\cdots(k-m+2)}{(m-1)!}$	$\frac{z^{-m+1}}{(1-z^{-1})^m}$
27.			$\frac{k(k-1)}{2!}a^{k-2}$	$\frac{z^{-2}}{(1-az^{-1})^3}$
28.			$\frac{k(k-1)\cdots(k-m+2)}{(m-1)!}a^{k-m+1}$	$\frac{z^{-m+1}}{(1-az^{-1})^m}$

$x(t)=0$, for $t<0$.
$x(kT)=x(k)=0$, for $k<0$.
Unless otherwise noted, $k=0,1,2,3,\ldots$.