UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama

Sidang Akademik 2003/2004

September/Oktober 2003

EEE 453 – REKABENTUK SISTEM KAWALAN

Masa : 3 Jam

ARAHAN KEPADA CALON:-

Sila pastikan kertas peperiksaan ini mengandungi **SEBELAS (11)** muka surat termasuk **3 Lampiran** bercetak dan **ENAM (6)** soalan sebelum anda memulakan peperiksaan ini.

Jawab **LIMA (5)** soalan.

Agihan markah diberikan di sut sebelah kanan soalan berkenaan.

Semua soalan hendaklah dijawab di dalam Bahasa Malaysia.

...2/-

1. Matrik **A**, **B**, **C** dan **D** persamaan dinamik suatu sistem kawalan diberikan seperti berikut:

__A__, __B__, __C__ and __D__ matrices of the dynamical state equation of a control system is given as follows:

$$\mathbf{A}=\begin{bmatrix}-1 & 1\\ 0 & -2\end{bmatrix};\quad \mathbf{B}=\begin{bmatrix}1\\1\end{bmatrix};\quad \mathbf{C}=\begin{bmatrix}0 & 1\end{bmatrix};\quad \mathbf{D}=[\,0\,]$$

(a) Lukiskan gambarajah keadaan bagi sistem tersebut berdasarkan kepada matrik-matrik di atas.

Draw the state diagram for the system based on the above matrices.

(20%)

(b) Tentukan kebolehkawalan dan kebolehcerapan keadaan sistem tersebut masing-masing menggunakan matrik kebolehkawalan dan kebolehcerapan.

Determine the state controllability and observability of the system using controllability matrix and observability matrix, respectively.

(20%)

(c) Tentukan persamaan ciri sistem tersebut. (20%)

Determine the characteristic equation of the system.

(d) Tentukan fungsi pindah sistem tersebut. (20%)

Determine the transfer function of the system.

(e) Jelmakan persamaan dinamik keadaan sistem tersebut kepada bentuk CCF menggunakan matrik jelmaan.

Transform the above state equation into CCF form.

(20%)

...3/-

2. Fungsi pindah suatu sistem kawalan diberikan seperti berikut:

Transfer function of a control system is given as follows:

$$G(s) = \frac{2s+6}{(s+a)(s+2)^2}$$

(a) Nyatakan persamaan dinamik keadaan sistem tersebut dalam bentuk:

Express the state dynamical equation of the system in the following form:

[i] CCF (15%)

[ii] OCF (15%)

(b) Apakah nilai a yang perlu dielak untuk memastikan sistem tersebut bolehcerap dan bolehkawal secara serentak.

What is the value of a that should be avoided such that the system will be controllable and observable simultaneously.

(10%)

(c) Setkan $a = 0$, nyatakan fungsi pindah sistem tersebut dalam bentuk pecahan separa, lukiskan gambarajah keadaan bagi penguraian selari dan tentukan matrik **A**, **B**, **C** dan **D**.

*Set $a = 0$, express the transfer of the system in partial fraction, draw the state diagram for parallel decomposition and determine the matrices **A**, **B**, **C** and **D**.*

(30%)

...4/-

(d) Tentukan persamaan peralihan keadaan sistem tersebut jika $x_1(t)=0;\ x_2(t)=1;$ $x_3(t)=1$ dan $u(t)=2$ berdasarkan persamaan keadaan bentuk DCF dalam bahagian (c).

Determine the state transition equation for the system if $x_1(t)=0;\ x_2(t)=1;$ $x_3(t)=1$ *and* $u(t)=2$, *based on the state dynamical equation in DCF form as in part (c).*

(30%)

3. Fungsi pindah suatu sistem kawalan diberikan oleh persamaan dinamik keadaan seperti berikut:

The transfer function of a control system is given by the following state dynamical equation:

$$\dot{\mathbf{x}}(t)=\begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ -6 & -11 & -6\end{bmatrix}\mathbf{x}(t)+\begin{bmatrix}0\\ 0\\ 1\end{bmatrix}u(t)$$

$$y(t)=\begin{bmatrix}1 & 1 & 1\end{bmatrix}\mathbf{x}(t)$$

Dengan memilih kedudukan kutub-kutub menggunakan kaedah ITAE;

By selecting the poles location based on ITAE method:

(a) Rekabentuk pengawal suapbalik keadaan dengan hukum kawalan $u(t)=-\mathbf{K}\mathbf{x}(t)$ dan memilih $\omega_0=1$ rad/s.

Design a state feedback controller based on control law $u(t)=-\mathbf{K}\mathbf{x}(t)$ *and select* $\omega_0=1$ *rad/s.*

(30%)

(b) Rekabentuk pemerhati tertib penuh dengan memilih $\omega_0=2$ rad/s.

Design a full order state observer by selecting $\omega_0=2$ *rad/s.*

(50%)

...5/-

(c) Tentukan fungsi pindah keseluruhan pengawal berdasarkan pengawal dan pemerhati dalam bahagian (a) dan (b).

Determine the overall controller transfer function based on the controller and observer in part (a) and (b).

(20%)

4. Suatu sistem diwakili oleh,

A system is represented by,

$$\mathbf{A} = \begin{bmatrix} 0 & 1 \\ 0 & -2 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}; \quad \mathbf{C} = \begin{bmatrix} 1 & 0 \end{bmatrix}; \quad \mathbf{D} = 0; \quad \mathbf{E} = 0$$

dan masukannya memenuhi persamaan $\ddot{r}(t) = \dot{r}(t) - 2r(t)$.

and the system input satisfies the equation $\ddot{r}(t) = \dot{r}(t) - 2r(t)$.

(a) Rekabentuk pengawal keadaan dengan menggunakan hukum kawalan kamiran yang mempunyai struktur seperti di dalam Rajah (1) dan meletakkan kutub pada s = -1, -1.5, -2, dan –2.5.

Design a state controller using integral control law that have the structure as in Figure (1) and place the poles at s = -1, -1.5, -2 and –2.5.

(80%)

(b) Tuliskan hukum kawalan sistem tersebut berdasarkan struktur yang diberikan dalam Rajah (1) dan menggunakan nilai-nilai parameter yang dikira dalam bahagian (a).

Write the control law of the system based on the structure in Figure (1) and use the parameters that were calculated in part (a).

(20%)

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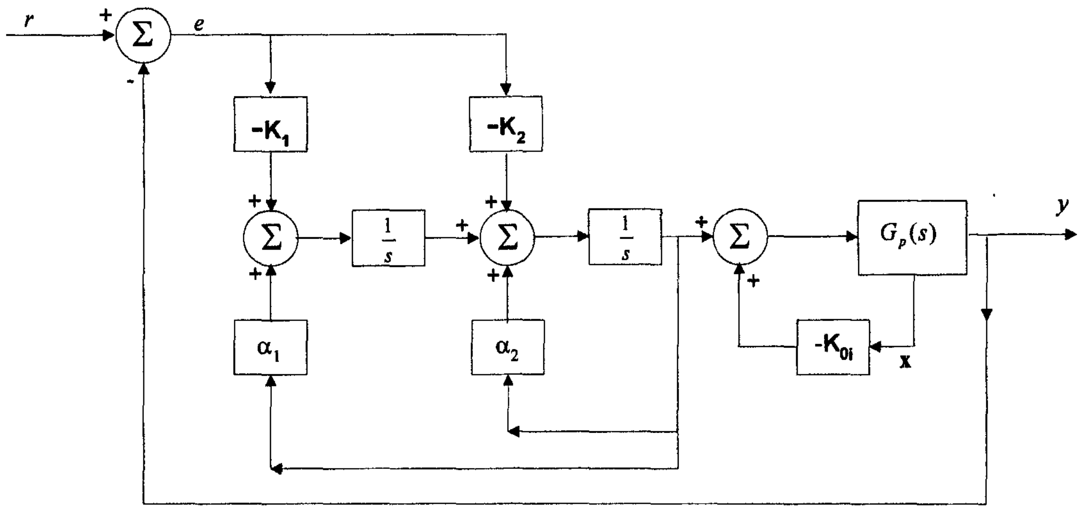

Rajah (1)
Figure (1)

5. Diberikan model suatu loji ialah:
The model of a plant is given as:

$$y(k)=\frac{bz^{-1}}{1+a_1z^{-1}+a_2z^{-2}}u(k)$$
$$y(k)=x(k)+n(k)$$

di sini $u(k)$ dan $y(k)$ adalah masing-masing masukan dan keluaran loji. $n(k)$ ialah satu jujukan bising putih diskret.

where $u(k)$ and $y(k)$ are the input and output of the plant, respectively. $n(k)$ is a discrete white noise sequence.

(a) Apakah jenis model di atas, terangkan bagaimana anda mengenali model tersebut?

Determine the type of the above model, explain how you recognize the model?

(10%)

(b) Menggunakan data dalam Jadual (1), tentukan nilai-nilai anggaran bagi:

Using the data in Table (1), determine the estimated values for:

[i] a_1, a_2 dan b dengan menggunakan kaedah algorithma kuasa dua terkecil piawai.

a_1, a_2 and b *using the standard least squares algorithm.*

(40%)

[ii] a_1, a_2 dan b dengan menggunakan algoritma kuasa dua terkecil jadi semula dengan pemberat eksponen. Setkan nilai awalan $P = 1000I$, $\lambda = 0.95$ dan nilai-nilai lain kepada 0.

a_1, a_2 and b *using exponentially weighted recursive least squares algorithm. Set initial value of* $P = 1000I$, $\lambda = 0.95$ *and others to 0.*

(50%)

Jadual (1)
Table (1)

k	1	2	3	4	5
$u(k)$	-0.43	-1.67	0.13	0.29	-1.15
$y(k)$	-0.01	-0.1	-1.66	-1.04	-0.24

6. Pertimbangkan suatu sistem yang diwakili oleh:

Consider a system that is represented by:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u$$
$$y = \mathbf{C}\mathbf{x} + \mathbf{D}u$$

dan

and

$$\mathbf{A} = \begin{bmatrix} 0 & 3 \\ 0 & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}; \mathbf{C} = [1 \quad 0]; \mathbf{D} = [0];$$

...8/-

(a) Nyatakan fungsi pindah sistem tersebut. (20%)

Determine the transfer function of the system.

(b) Andaikan satu sistem kawalan linear,

Assumed that the control law is linear,

$$u = -\mathbf{K}\mathbf{x} = -k_1x_1 - k_2x_2$$

dan keadaan awalan ialah:

and initial state is:

$$\mathbf{x}(0) = \begin{bmatrix} 1 \\ 0 \end{bmatrix}.$$

Jika indeks prestasi diberi sebagai:

If the performance index is given as:

$$J = \int_0^\infty \left(x^T \begin{bmatrix} 1 & 0 \\ 0 & 3 \end{bmatrix} x + 2u^2 \right) dt$$

[i] Rekabentuk suatu pengawal LQR menggunakan pendekatan pembolehubah keadaan yang boleh memberi nilai minima bagi J dengan kedudukan equilibrium $t \to \infty$.

Design a LQR controller using state variable approach that could give a minimum value for J with equilibrium position $t \to \infty$.

(70%)

[ii] Lukiskan gambarajah blok bagi sistem kawalan tersebut.

Draw the block diagram for the control system.

(10%)

- ooOoo -

Kutub-kutub kaedah ITAE bagi $\omega_0 = 1$

$s + 0.7 \pm j0.7$	tertib ke-2
$(s + 0.7)(s + 0.5 \pm j1.1)$	tertib ke-3

WRLS Algorithm

$$\hat{\beta}_{N+1} = \hat{\beta}_N + K_{N+1}\left[y_{N+1} - x_{N+1}^T\,\hat{\beta}_N\right]$$

$$K_{N+1} = \frac{P_N x_{N+1}}{\lambda + x_{N+1}^T P_N x_{N+1}}$$

$$P_{N+1} = \frac{P_N}{\lambda}\left\{I - \frac{x_{N+1}\, x_{N+1}^T\, P_N}{\lambda + x_{N+1}^T P_N\, x_{N+1}}\right\}$$

Persamaan matrik terturun Riccati:

$$\mathbf{A^TP + PA - PBR^{-1}B^TP + Q} = 0$$

dan $K=R^{-1}B^TP$

Laplace Transform Table

1	Unit-impulse function $\delta(t)$
$\frac{1}{s}$	Unit-step function $u_s(t)$
$\frac{1}{s^2}$	Unit-ramp function t
$\frac{n!}{s^{n+1}}$	t^n (n = positive integer)
$\frac{1}{s+\alpha}$	$e^{-\alpha t}$
$\frac{1}{(s+\alpha)^2}$	$te^{-\alpha t}$
$\frac{n!}{(s+\alpha)^{n+1}}$	$t^n e^{-\alpha t}$ (n = positive integer)
$\frac{1}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(e^{-\alpha t} - e^{-\beta t})$ $(\alpha \neq \beta)$
$\frac{s}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(\beta e^{-\beta t} - \alpha e^{-\alpha t})$ $(\alpha \neq \beta)$
$\frac{1}{s(s+\alpha)}$	$\frac{1}{\alpha}(1 - e^{-\alpha t})$
$\frac{1}{s(s+\alpha)^2}$	$\frac{1}{\alpha^2}(1 - e^{-\alpha t} - \alpha t e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)}$	$\frac{1}{\alpha^2}(\alpha t - 1 + e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)^2}$	$\frac{1}{\alpha^2}\left[t - \frac{1}{\alpha} + \left(t + \frac{2}{\alpha}\right)e^{-\alpha t}\right]$

Laplace Transform Table (continued)

$\dfrac{s}{(s+\alpha)^2}$	$(1-\alpha t)e^{-\alpha t}$
$\dfrac{\omega_n^2}{s^2+\omega_n^2}$	$\sin \omega_n t$
$\dfrac{s}{s^2+\omega_n^2}$	$\cos \omega_n t$
$\dfrac{\omega_n^2}{s(s^2+\omega_n^2)}$	$1-\cos \omega_n t$
$\dfrac{\omega_n^2(s+\alpha)}{s^2+\omega_n^2}$	$\omega_n\sqrt{\alpha^2+\omega_n^2}\sin(\omega_n t+\theta)$ where $\theta = \tan^{-1}(\omega_n/\alpha)$
$\dfrac{\omega_n}{(s+\alpha)(s^2+\omega_n^2)}$	$\dfrac{\omega_n}{\alpha^2+\omega_n^2}e^{-\alpha t}+\dfrac{1}{\sqrt{\alpha^2+\omega_n^2}}\sin(\omega_n t-\theta)$ where $\theta = \tan^{-1}(\omega_n/\alpha)$
$\dfrac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\dfrac{\omega_n}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin \omega_n\sqrt{1-\zeta^2}\,t \quad (\zeta<1)$
$\dfrac{\omega_n^2}{s(s^2+2\zeta\omega_n s+\omega_n^2)}$	$1-\dfrac{1}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t+\theta)$ where $\theta = \cos^{-1}\zeta \quad (\zeta<1)$
$\dfrac{s\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\dfrac{-\omega_n^2}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t-\theta)$ where $\theta = \cos^{-1}\zeta \quad (\zeta<1)$
$\dfrac{\omega_n^2(s+\alpha)}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\omega_n\sqrt{\dfrac{\alpha^2-2\alpha\zeta\omega_n+\omega_n^2}{1-\zeta^2}}\,e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t+\theta)$ where $\theta = \tan^{-1}\dfrac{\omega_n\sqrt{1-\zeta^2}}{\alpha-\zeta\omega_n} \quad (\zeta<1)$
$\dfrac{\omega_n^2}{s^2(s^2+2\zeta\omega_n s+\omega_n^2)}$	$t-\dfrac{2\zeta}{\omega_n}+\dfrac{1}{\omega_n^2\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t+\theta)$ where $\theta = \cos^{-1}(2\zeta^2-1) \quad (\zeta<1)$