UNIVERSITI SAINS MALAYSIA

First Semester Examination

Academic Session 2003/2004

September/October 2003

EEE 550 – ADVANCED CONTROL SYSTEMS

Time : 3 Hours

INSTRUCTION TO CANDIDATE:-

Please ensure that this examination paper contains **SEVEN** (7) printed pages with **1 Appendix** and **SIX** **(6)** question before answering.

Answer **FIVE** **(5)** questions.

Distribution of marks for each question is given accordingly.

All questions must be answered in English.

...2/-

1. A plant for a control system is modelled by:

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

where $u(k)$ and $y(k)$ are the input and output of the plant, respectively. Using the data in Table 1 estimate:

(a) a and b using LMS algorithm, set $\gamma = 0.1$ (40%)

(b) a and b using exponential weighted recursive least squares algorithm. Set the initial values of $\mathbf{P} = 1000\mathbf{I}$, $\lambda = 0.95$ and others to 0.

(60%)

Table 1

k	1	2	3	4
$u(k)$	-1.67	0.13	0.29	-1.15
$y(k)$	-0.45	-1.97	-1.25	-0.55

2. Pulse transfer function for sampling time of 0.2s of a continuous plant is given as:

$$G(z) = \frac{0.1z + 0.03}{z^2 - 1.2z + 0.25}$$

The controller structure is selected to be as follows,

$$Ru(t) = Tu_c(t) - Sy(t)$$

where u, u_c and y are the control signal, command signal and output signal, respectively. If the model is selected such that $A_m = z^2 - 1.1z + 0.3$ and B_m to give unity steady-state output for unit step input, design a STR using minimum-degree pole placement algorithm without zero cancellation. Show all your design steps and state all your assumptions.

(100%)

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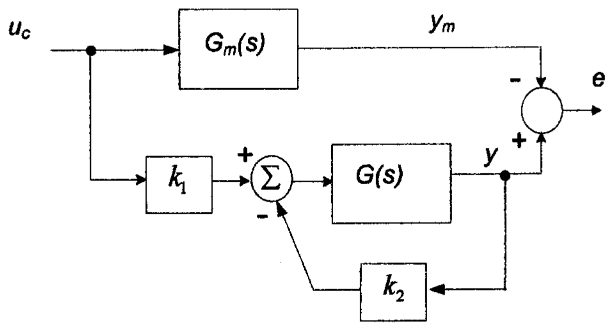
3. A Model Reference Adaptive System (MRAS) is selected to have the following structure:



It is desired to adjust k_1 and k_2 such that the output of the plant $G(s)$ will follow the output of the model $G_m(s)$. If transfer functions of the plant and model are given as:

$$G(s)=\frac{0.5}{s+1} \quad \text{and} \quad G_m(s)=\frac{2}{s+2},$$

(a) Calculate the actual value of k_1 and k_2. (25%)

(b) Design a MRAS controller to update k_1 and k_2 based on MIT Rule by assigning $\gamma = 0.1$. Show all your design steps and state all your assumptions. (50%)

(c) Draw the complete block diagram of the MRAS based on your design in (b). (25%)

4. (a) By using a suitable diagram, discuss the principle of tuning a controller based on model identification. (20%)

(b) There are two rules proposed by Ziegler-Nichols for tuning PID (Proportional-Integral-Derivative) controller parameters.

[i] Discuss the conditions under which each rule is applicable/inapplicable. (10%)

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[ii] By using suitable time-response diagrams, explain how to determine the three controller parameters using each rule.

(20%)

(c) Consider the system shown in Figure 4(a).

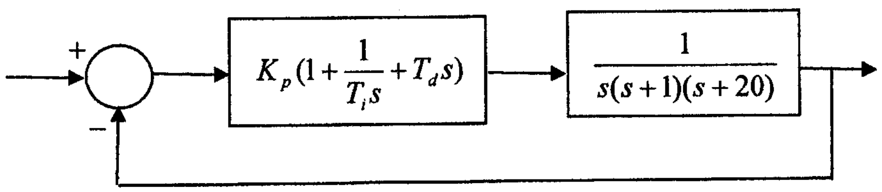

Figure 4(a)

Using a suitable Ziegler-Nichols tuning rule, determine

[i] the values of K_p, T_i, and T_d. (30%)

[ii] the location of the double zeros of the controller. (10%)

[iii] the closed-loop transfer function of the overall system. (10%)

5. (a) [i] By using a suitable diagram, discuss the principle of gain scheduling in a control system. (20%)

[ii] What is the main problem in the design of systems with gain scheduling.

(10%)

[iii] Discuss two approaches which are useful in the design of gain-scheduling controllers. Give an example for each approach.

(20%)

(b) Consider the following state-space representation of a system,

$$\dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{Bu} \quad \text{or} \quad \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 3 & 0 & 2 \\ -12 & -7 & -6 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 6 \end{bmatrix} u$$

$$y = \boldsymbol{Cx} \quad \text{or} \quad y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

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[i] Define a set of new state variables and find a transformation matrix to obtain a diagonal Canonical form of the state matrix, ***A***.

(20%)

[ii] Find the new state equation and output equation of the system.

(20%)

[iii] Discuss the properties of the new state matrix.

(10%)

6. (a) Consider a tank in which the cross section A varies with height h. The model is

$$V = \int_0^h A(\tau) d\tau \qquad \frac{dV}{dt} = A(h)\frac{dh}{dt} = q_i - a\sqrt{2gh}$$

where V is the volume, q_i is the input flow, and a is the cross section of the output pipe. Define q_i as the input and h as the output of the system. A PI controller is used to control the system. Given the transfer function of the linearised model at an operating point q_{in}^o and h^o as

$$G(s) = \frac{\frac{1}{A(h^o)}}{s + \frac{q_{in}^o}{2A(h^o)h^o}}$$

[i] obtain the closed-loop transfer function of the system (with the PI controller).

(10%)

[ii] determine the values of K_p and T_i in terms of q_{in}^o, h^o, A, ω_n (natural frequency), and ζ (damping ratio)

(20%)

[iii] discuss how gain scheduling could be applied in the above system

(10%)

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(b) [i] Use a suitable diagram to illustrate problem of computational delay, and discuss its significance in practical implementation of a digital controller.

(10%)

[ii] Propose a method to tackle the problem of computational delay.

(20%)

(c) A plant with transfer function $G_p(s)$ is to be controlled by using a PID controller. Two practical configurations for implementing the PID controller are PI-D-controlled and I-PD-controlled approaches.

Referring to *EITHER ONE* of the approaches,

[i] draw a block diagram to illustrate the overall system (with controller, disturbance, and noise).

(10%)

[ii] obtain the output (in the s-domain) of the system (with controller, disturbance, and noise).

(10%)

[iii] discuss the practical issues that could be overcome by using the approach.

(10%)

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LS

$$\hat{\theta}=(\varphi^T\varphi)^{-1}\varphi^T Y$$

WRLS

$$K(t)=P(t-1)\varphi(t)\left[\lambda+\varphi^T(t)P(t-1)\varphi(t)\right]^{-1}$$
$$P(t)=\left[I-K(t)\varphi^T(t)\right]P(t-1)/\lambda$$
$$\hat{\theta}(t)=\hat{\theta}(t-1)+K(t)\left[y(t)-\varphi^T(t)\hat{\theta}(t-1)\right]$$

LMS

$$\hat{\theta}(t)=\hat{\theta}(t-1)+\gamma\varphi(k)\left[y(k)-\varphi^T(k)\hat{\theta}(k-1)\right]$$

Minimum-degree pole placement algorithm without zero cancellation,

$$\deg A_0=\deg A-\deg B^+-1$$
$$B^+=1$$
$$B^-=B=b_0q+b_1$$
$$B_m=\beta B;\ \beta=\frac{A_m(1)}{B(1)}$$
$$T=\beta A_0$$

Diophantine Equation:

$$AR+BS=A_mA_0$$
$$(q^2+a_1q+a_2)(q+r_1)+(b_0q+b_1)(s_0q+s_1)=(q^2+a_{m1}q+a_{m2})(q+a_0)$$