UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2006/2007

October/November 2006

EEE 550 – ADVANCED CONTROL SYSTEMS

Duration: 3 hours

Please check that this examination paper consists of NINE pages of printed material before you begin the examination.

This paper contains SIX questions.

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

Answer to any question must start on a new page.

Distribution of marks for each question is given accordingly

All questions must be answered in English.

1. (a) Describe what are the Least Square Method (LS) and Recursive Least Square (RLS) methods utilised in an adaptive control system.

(20%)

(b) The following input and output data has been obtained from an experiment, as shown in Table 1.

Table 1

t	$u(t)$	$y(t)$
1	0.75	0.0
2	0.0	0.75
3	0.75	-0.5
4	0.75	1.5
5	0.0	0.275

Use least squares to fit a model with the structure:

$$A(q^{-1})y(t) = B(q^{-1})\, u(t\text{-}1) + \varepsilon(t)$$

$$with \quad A(q^{-1}) = 1 + a\, q^{-1};\ B(q^{-1}) = b$$

(20%)

(c) Consider the FIR model

$$y(t) = b_0 u(t) + b_1 u(t-1) + e(t) \quad t = 1, 2, ...$$

Where $\{e(t)\}$ is a sequence of independent normal random variables with zero mean and standard deviation σ.

(i) Determine the regressor vector and parameter vector of the linear regression model.

(ii) Write the normal equation for the least-square estimation of the parameters b_o and b_1.

(iii) Assume that the input signal is a step, that is

$$u(t) = \begin{cases} 0, & t = 0 \\ 1, & t > 0. \end{cases}$$

Determine the least-square estimate of the parameters b_o and b_1.

(iv) Analyse the covariance of the estimate when the number of estimates goes to infinity.

(60%)

2. (a) Describe what is a Self Tuning Regulator (STR) in relation to its use in adaptive control application.

(20%)

(b) Consider the system

$$G(s) = G_1(s)G_2(s)$$

where

$$G_1(s) = \frac{a}{s+b}$$
$$G_2(s) = \frac{c}{s+d}$$

Here *a* and *b* are unknown parameters and *c* and *d* are known. This could for example represent a system where the plant is known, but where certain sensor dynamics are unknown. The system is to be controlled in such a way that the closed loop system is given by:

$$G_m(s) = \frac{\omega^2}{s^2 + 2\omega\zeta + \omega^2}$$

(i) Construct a discrete time *indirect* self tuning regulator without zero cancellation.

(ii) Construct a discrete time *direct* self tuning regulator without zero cancellation.

(40%)

(c) Consider the second order system:

$$\dot{x_1} = -x_2 + \theta x_1^2$$
$$\dot{x_2} = u$$

Assume that the parameter θ is known. Design a controller that stabilises the system using the backstepping method.

(40%)

3. (a) What is a Model Reference Adaptive System (MRAS) or Model Reference Adaptive Control (MRAC)? Use relevant diagram to illustrate this control approach.

(20%)

(b) Let us consider a linear process with the transfer function $kG(s)$, where $G(s)$ is known and k is an unknown parameter. Find a feed-forward controller that gives a system with the transfer function $G_m(s) = k_o G(s)$, where k_o is a given constant. Use the controller structure

$$u = \theta u_c$$

where u is the control signal and u_c the command signal. Use the MIT rule to update the parameter θ, and draw a block diagram of the resulting adaptive system.

(30%)

(c) Consider the process;

$$G(s) = \frac{1}{s(s+a)}.$$

Where a is an unknown parameter.

(i) Determine a controller that can give the closed-loop system

$$G_m(s) = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}.$$

(Assume for this point that a is known)

(ii) Determine a model-reference adaptive contoller based on the MIT rule.

(50%)

4. (a) There are two methods suggested by Ziegler and Nichols for tuning PID (Proportional-Integral-Derivative) controllers.

Choose ONE method and explain the tuning procedure in detail.

Tabulate the tuning rule of K_p (proportional gain), T_i (integral time), and T_d (derivative time) for all three (P, PI, and PID) controllers.

For the PID controller, state the transfer function and explain the pole and zero positions of the resulting controller. Also, discuss the property of the PID controller.

(40%)

(b) Figure Q4 shows the block diagram of a plant with a PID controller. The Ziegler and Nichols method is to be used for tuning the PID controller.

(i) Determine the value of K_p so that the system will exhibit sustained ocsillation?

(ii) What are the frequency and period of the sustained ocsillation?

(iii) Suggest the suitable values for K_p, T_i, and T_d, and state the pole and zero positions of the PID controller.

(iv) Suppose the input is a unit step, obtain the closed-loop transfer function of the system.

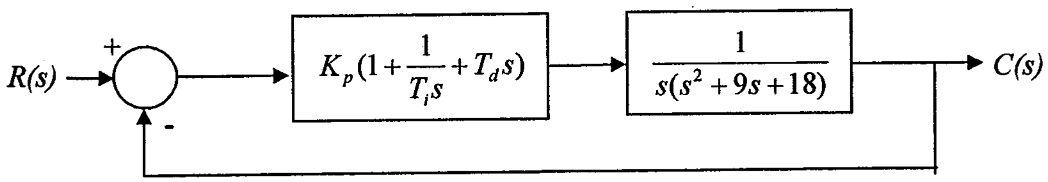

Figure Q4

(60%)

5. (a) By using a suitable diagram, explain the principle of gain scheduling in control. Discuss two advantages and two disadvantages of gain scheduling controllers.

(20%)

(b) In combustion control of a boiler, it is important to adjust the oxygen content of the flue gases. The flow of combustion air depends on the burn rate in the boiler. The measurement signal is the oxygen content in the exhaust stack, and the control signal is the trim position. There is a significant time delay between the input to the burner and the oxygen sensor in the exhaust stack.

What is the difficulty that would be faced by a conventional controller in combustion control as described above?

Suggest an adaptive feedforward and gain scheduling approach for the above combustion control problem. Use a suitable block diagram to explain your answer.

(30%)

(c) Figure Q5 shows a flow control loop with a PI controller and a nonlinear valve. Suppose the static characteristic of the valve is

$v = f(u) = u^4 \qquad u \geq 0$

By using a crude approximation approach, discuss how to compensate for the nonlinearity of the valve in the system. Suggest a crude model for the approach that you have explained. Draw suitable diagrams to explain your answer.

(50%)

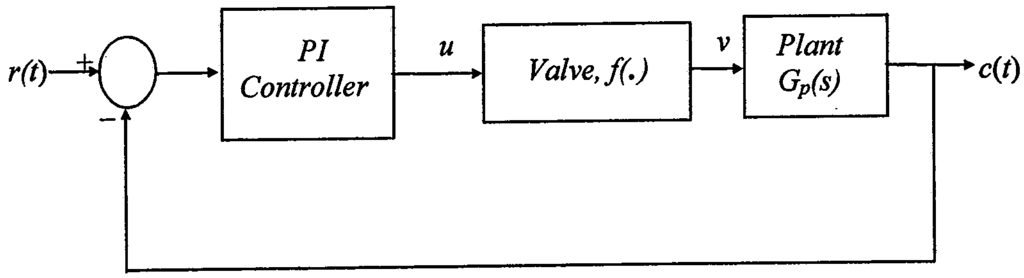

Figure Q5

6. (a) (i) Discuss three main procedures in a general fuzzy logic controller.

(ii) What are the advantages and disadvantages of fuzzy logic control as compared with conventional control approaches? Give an example to clarify your answer.

(iii) Describe three fuzzy set operators. Give an example to clarify how each fuzzy set operator works.

(40%)

(b) A fuzzy logic controller is to be designed for the inverted pendulum problem as shown in Figure Q6. The objective of the controller is to control the pole in the upright position by moving the cart. The inputs to the controller are the angle of the pole from the vertical line and the angular velocity. The output of the controller is the velocity of the cart.

Assume the pole angle is between -30 and 30 degrees, and the cart velocity is between -2.0 and 2.0 m/s.

(i) Suggest suitable fuzzy membership functions for the inputs and output of the fuzzy controller

(ii) Design a rule matrix for the fuzzy controller