B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER - 2024

Subject: **INTRODUCTION TO MODERN CONTROL THEORY(HONS.)**

Time: Three hours **Full Marks: 100**

Answer any **FIVE** *questions. Different parts of the same question should be answered together.*
Assume any relevant data if necessary.

[1] For the process, shown in Fig.P1, consisting of 2 interconnected tanks – R_0, R_1 and R_2 are the linearized pipe resistances, h_1 and h_2 are the water levels in the 2 tanks and A_1 and A_2 are the tank cross-sectional areas. The input to the system is the flow rate q into tank 1 and output of the system is the height of water in tank 2 *i.e.* h_2. For $A_1 = 1, A_2 = 0.5$, $R_0 = 0.25, R_1 = 0.5, R_2 = 2$, [20]

(a) Write down the governing differential equations.
(b) Construct the block diagram.
(c) Obtain the state space model, clearly specifying **A, B** and **C**.
(d) Check the stability of the system.
(e) Obtain the transfer function matrix.
(f) Obtain the system response for $q = 1$.

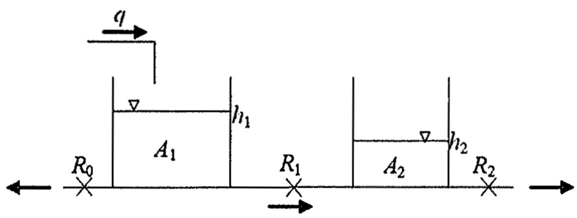

Fig.P1

[2] (a) For a state-space system given by $\dot{\mathbf{X}} = \begin{bmatrix} -6 & 2 \\ 4 & -5 \end{bmatrix}\mathbf{X} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}\mathbf{U}; \mathbf{Y} = [0 \quad 1]\mathbf{X}$, design the state feedback controller and observer so that the controller eigenvalues are placed at –4 and –9 whereas the observer eigenvalues are placed at –12 and –15.

(b) What is meant by *observability* and *stabilazability*? [14+6=20]

[3] A control system with 2 inputs r_1 and r_2 and 2 outputs y_1 and y_2 is shown in Fig.P3 below. Construct a state space model for the system. [20]

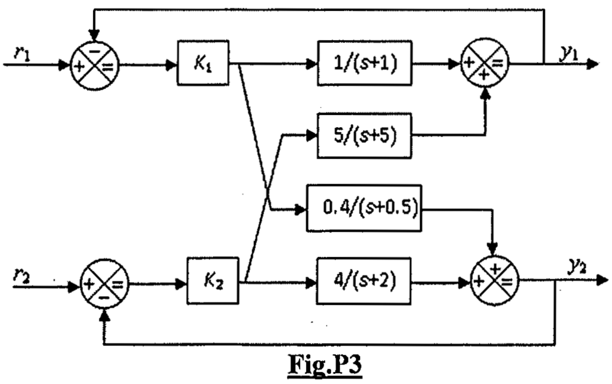

Fig.P3

[4] (a) Model a 4-way 3-position proportional valve with a 3-layer feed forward neural network. The inputs are the valve pressure drop and the command voltage while the output is the valve flow rate. Sketch the network with a single hidden layer comprising of 3 hidden neurons having tan sigmoid activation functions. The output layer has linear activation functions. Obtain the learning equations for w_{23} (weight between 2nd input and 3rd hidden neuron) and v_{11} (weight between 1st hidden and output neuron) using the backpropagation training algorithm for a given set of 100 training data.

(b) What is the role of *momentum factor* in the learning process? [15+5=20]

[5] (a) For an under-damped second order system, obtain the phase-plane equation and the isocline equation. Sketch the isoclines.

(b) Explain the terms globally asymptotically stable, locally asymptotically stable, and stable for a dynamic system with **X** as the state vector

(c) State *Lyapunov's* Stability Theorem.

(d) A spring-mass-damper system for which the damping force is proportional to the third power of the velocity is described by the differential equation

$$\ddot{y} + 0.5\dot{y}^3 + y = 0$$

Comment on the stability of the system. [8+3+3+6=20]

[6] (a) Consider: $\dot{x}_1 = 2x_2$

$\dot{x}_2 = -4x_1 - 9x_2 + 5u$

If the system lumped uncertainty can be expressed as $|e(\mathbf{X}, \mathbf{U}, \mathbf{V}, t)| \leq 3$ and a sliding surface is defined as, $\sigma = 4x_1 + x_2$, then obtain the sliding mode control u in terms of x_1 and x_2.

(b) Consider a state model $\dot{\mathbf{X}} = \mathbf{AX} + \mathbf{BU} + \Delta\mathbf{AX} + \Delta\mathbf{BU} + \mathbf{GV}$ where $\Delta\mathbf{A}$ and $\Delta\mathbf{B}$ are the uncertainties associated with the state matrix **A** and the input matrix **B**; **V** are the external disturbances. With suitable assumptions, identify the *lumped uncertainty* **e(X,U,V,*t*)**. **[14+6=20]**

[7] (a) A dynamic system can be modelled as a spring-mass-dashpot system with force as input and displacement as output. What can be 2 possible inputs and the output of a fuzzy logic controller for this dynamic system? Design the membership functions for these input-output(s) assuming suitable ranges. State some realistic rules for the controller. The force ranges between ±1000N, the displacement ranges between ±0.1m and the rate of force ranges between ±20N/s. Show the membership functions in a graph paper corresponding to the rules.

(b) What is the advantage of fuzzy controllers over crisp controllers. [16+4=20]

[8] Write short notes on any FOUR (4) of the following:

(i) Companion form of the state matrix;

(ii) Sliding mode and reaching mode;

(iii) Feedforward neural network;

(iv) Features in system responses indicating presence of nonlinearity;

(v) Linearization techniques. [4×5=20]