B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER EXAM 2019

Subject: **Elective III – Introduction to Modern Control Theory**

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.

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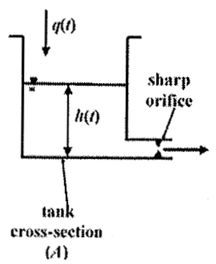
[1](a) For an over-damped 2nd order system, obtain the phase-plane equation and isocline equation. Sketch the isoclines.
(b) Give examples of 4 typical nonlinearities encountered in electrohydraulic actuation systems.
(c) What is meant by an *isocline*? What is the *isocline equation* for a second order system? [10+4+6]

[2] (a) For a system with plant transfer function $G(s) = 4/(s^3+9s^2+23s+15)$, obtain a state space model. Hence design a state feedback control $u = -k'x$ to place the closed-loop eigenvalues at -3, -4 and -5.
(b) Determine the output response of the system to the initial conditions and a unit step input.

$$\dot{\mathbf{x}} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}\mathbf{x} + \begin{bmatrix} 0 \\ 2 \end{bmatrix}u \text{ ; } \mathbf{y} = \begin{bmatrix} 3 & 1 \end{bmatrix}\mathbf{x} \text{ ; } \mathbf{x}_0 = \begin{bmatrix} 2 \\ 3 \end{bmatrix}$$ [10+10]

[3] (a) Show how a *dynamic observer* can be constructed for a state-model $\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}; \mathbf{y} = \mathbf{Cx}$.
(b) Distinguish between a *full-order observer* and a *reduced-order observer*.
(c) Design the observer matrix **L** to estimate the states of the system: $\dot{\mathbf{x}} = \begin{bmatrix} -1 & 1 \\ 0 & -4 \end{bmatrix}\mathbf{x} + \begin{bmatrix} 0 \\ 4 \end{bmatrix}u$; $y = \begin{bmatrix} 1 & 0 \end{bmatrix}\mathbf{x}$, from the output y. Place the observer eigenvalues at $-10\pm10j$. [8+4+8]

[4] (a)



Consider the following tank filling problem:
Obtain a nonlinear state-space model of the system. Use suitable *linearization technique* and obtain an equivalent linear model. Name the technique employed.

(b) Consider:

$$\dot{x}_1 = -5x_1 + 6x_2 + \cos x_1$$
$$\dot{x}_2 = -x_2 \sin x_1 + u \sin(2x_1)$$

Obtain a nonlinear state-space model of the system. Use suitable *variable transformation* followed by *linearization technique* and obtain an equivalent linear model. Name the technique employed. [10+10]

[5] (a) Design an artificial neural network for a system with 2 inputs and 1 output. Choose 1 hidden layer with 3 neurons. Obtain the expression for training of the weights and biases if the activation functions for the hidden neurons are sigmoid and those for the output neurons are linear. Choose any symbols required with proper clarification.
(b) Draw schematic of an artificial neuron explaining all the terms. Name 4 possible activation functions. [15+5]

[6] (a) Consider a fuzzy logic controller for an electrohydraulic actuation system with position error and velocity error as the inputs and control voltage as the output. The ranges of position errors is ±0.1m, velocity error is ±1m/s and control voltage is ±10V. Define suitable membership functions for the inputs and output (3 for position error, 3 for velocity error and 3 for control voltage) and associated fuzzy rules. Show the fuzzy rules in terms of the membership functions in a graph paper. Also using the graph paper and the *Mamdani's Inference Method*, obtain the *fuzzified* the control voltage for position error of -0.06m and velocity error of +0.2m/s.
(b) What are the advantages of fuzzy control systems? [16+4]

[7] (a) Consider:

$$\dot{x}_1 = 2x_2$$
$$\dot{x}_2 = -4x_1 - 9x_2 + 5u$$

If the system lumped uncertainty can be expressed as $e(x, u, v, t) \leq 3$ 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. [14]
(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** and **V** are the external disturbances. With suitable assumptions, identify the *lumped uncertainty* **e(X,U,V,*t*)**. [14+6]