B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER EXAM 2025
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.*

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[1] Obtain the state space model for 2 degrees of freedom (heave and pitch) half-car suspension system. Assume any symbols necessary, clearly stating their meanings. [20]

[2] (a) For a system with plant transfer function $G(s) = 2/(s^2+4s+5)$, obtain a state space model in *companion form*. Hence design a state feedback control $u = -\mathbf{k}'\mathbf{x}$ to place the closed-loop eigenvalues at $-3\pm 2j$.
(b) What is meant by *observability* and *controllability*? [14+6=20]

[3] (a) Why are dynamic observers necessary? Why is it not possible to control a system by estimating the states from the state space model of the plant? Explain how a dynamic observer can be designed from the state space model.
(b) Derive a state model for the system with transfer function $\frac{C(s)}{R(s)} = \frac{s+3}{s(s+1)(s+2)}$ – for which the system matrix is *diagonal* [Hint: use partial fraction expansion of $\frac{C(s)}{R(s)}$]. [12+8=20]

[4] Design a Mamdani type Fuzzy Logic Controller (FLC) for a typical electro-hydraulic actuation system with actuator position error and velocity error feedbacks. The output of the FLC is the control signal to the proportional valve. The universe of discourse for the actuator position error is [-0.2 +0.2]m, for the actuator velocity error is [-0.5 +0.5]m/s and for the control signal is [-10 +10]V. Choose 3 membership functions for each of the inputs as well as for the output. Show the triangular membership functions, rule tables and the membership function combinations as per the rules. For a position error of 0.1m and velocity error of -0.25m/s, show the fuzzified control (you can use a graph paper). [20]

[5] (a) For an over-damped second order system, obtain the phase-plane equation and the isocline equation. Sketch the isoclines.
(b) State *Sylvester's Theorem* for a general quadratic form.
(c) Explain how a feedforward neural network is trained? [6+4+10=20]

[6] (i)What is the unique property of sliding mode control as compared to other nonlinear control strategies?
(ii) What is meant by sliding mode and reaching mode – explain with a sketch?
(iii) Consider a state model $\dot{\mathbf{X}} = \mathbf{AX} + \mathbf{BU} + \mathbf{\Delta AX} + \mathbf{\Delta BU} + \mathbf{GV}$ where $\mathbf{\Delta A}$ and $\mathbf{\Delta B}$ are the uncertainties associated with the state matrix **A** and the input matrix **B**; **V** are the external disturbances. What is meant by matching conditions and lumped uncertainty of the system.
(iv) What is meant by the boundedness of the lumped uncertainties?
(v) What is meant by the sliding condition? [3+6+6+2+3=20]

[7] (a) Give examples of 4 typical nonlinearities encountered in electrohydraulic actuation systems.
(b) For the system $\dot{\mathbf{x}} = \begin{bmatrix} 0 & 1 \\ -5 & -4 \end{bmatrix}\mathbf{x} + 2\mathbf{u}$; $y = [1 \quad 0]\mathbf{x}$, state feedback has been designed to place the closed loop eigenvalues at $-3\pm 3j$. Design the observer matrix **L** to estimate the states of the system from the output y – so that the observer eigenvalues are at three times distance of the closed loop eigenvalues from the origin. Is the observer designed a full order observer or a reduced order observer? [8+12=20]

[8] Write short notes on any FOUR (4) of the following:
(i) Lyapunov's Stability Theorem;
(ii) Effect of learning rate and momentum factor in Artificial Neural Network training;
(iii) Difference between crisp set and fuzzy set in defining a physical variable;
(iv) Formal Solution of the state space equations and Transition Matrix;
(v) State some typical features in response of a system that indicates existence of nonlinearity.
(vi) Linearization technique(s) [4×5=20]