# APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

(A State Government University)

**B. Tech, 2024**

**Minor Degree in**

**Control Engineering**

**Offered By : (Electrical Engineering)**

# CURRICULUM

| Minor (Control Engineering) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sl. No: | Semester | Course Code | Course Title (Course Name) | Credit Structure | | | SS | Total Marks | | Credits | Hrs./ Week |
| | | | | L | T | P | | CIA | ESE | | |
| 1 | 3 | MNEET329 | Introduction to Control Engineering/ MOOC# | 3 | 1 | 0 | 5 | 40 | 60 | 4 | 4 |
| 2 | 4 | MNEET429 | Modern Control Engineering*/ MOOC# | 3 | 1 | 0 | 5 | 40 | 60 | 4 | 4/5 |
| | | | | 3 | 0 | 2& | 5.5 | | | | |
| 3 | 5 | MNEET529 | Advanced Control System Design / MOOC | 3 | 1 | 0 | 5 | 40 | 60 | 4 | 4 |
| 4 | 6 | MNEET629 | Control of Robotic Systems/ MOOC | 3 | 0 | 0 | 4.5 | 40 | 60 | 3 | 3 |
| **Total** | | | | | | | **20/ 21** | | | **15** | **15/ 17** |

**Students must register for theory courses listed in the 3rd and 4th semesters of the Minor curriculum.*

#*Students who fail a theory course listed in the Minor curriculum are permitted to register for an alternate MOOC course specified in the Minor curriculum.*

&*The courses offered in the third and fourth semesters can be structured as either theory-based courses* ***or*** *a combination of theory and lab-based courses.*

# SYLLABUS

# SEMESTER 3

## SEMESTER 3

## INTRODUCTION TO CONTROL ENGINEERING

| Course Code | MNEET329 | CIE Marks | 40 |
|---|---|---|---|
| Teaching Hours/Week (L:T:P) | 3:1:0 | ESE Marks | 60 |
| Credits | 4 | Exam Hours | 2 Hrs. 30 Min. |
| Prerequisites (if any) | BEE/BME | Course Type | **Theory** |

**Course Objectives:**

1. To introduce various classical tools for analysis of linear control system in time domain
2. To introduce various classical tools for analysis of linear control system in frequency domain

## SYLLABUS

| Module No. | Syllabus Description | Contact Hours |
|---|---|---|
| 1 | **Introduction to Control Systems:**<br>Open loop and Closed loop control systems; Automatic control systems; Necessity and significance. *(2 hours)*<br>*Modelling of LTI systems:* Differential equations and transfer function representation of electrical, translational & rotational mechanical systems and DC servo-motor. Poles and zeros. (6 hours).<br>Block diagram representation - block diagram reduction. Signal flow graph -<br>Mason's gain formula. (4 hours) | 12 |
| 2 | **Performance Analysis of Control Systems:**<br>*Time domain analysis of control systems:* Impulse and Step responses of first and second order systems - Pole dominance for higher order systems. Time domain specifications. Steady state error analysis and static error constants. (6 hours)<br>*Stability analysis:* Characteristic equation. Routh stability criterion. (3 hours)<br>*Matlab Demo* - Impulse and Step response. Time domain specifications (2 hours) | 11 |
| 3 | *Root locus technique:* Construction of Root locus - stability analysis-effect of addition of poles and zeros. (5 hours)<br>**Frequency domain analysis:**<br>*Bode Plot:* Construction, Concept of gain margin and phase margin-stability analysis. (4 hours)<br>*Matlab Demo* - Root locus and Bode Plot (1 hour) | 10 |
| 4 | **Frequency domain analysis:**<br>Frequency domain specifications - correlation between time domain and frequency domain responses (Resonant peak and resonant frequency).<br>(3 hours)<br>Polar plot: Gain margin and phase margin, Stability analysis. (3 hours)<br>Nyquist stability criterion. (4 hours)<br>*Matlab Demo* - Polar plot, Nyquist plot. (1 hour) | 11 |

## Course Assessment Method
## (CIE: 40 marks, ESE: 60 marks)

**Continuous Internal Evaluation Marks (CIE):**

| Attendance | Assignment/ Microproject | Internal Examination-1 (Written) | Internal Examination- 2 (Written ) | Total |
|---|---|---|---|---|
| **5** | **15** | **10** | **10** | **40** |

**End Semester Examination Marks (ESE)**

*In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions*

| Part A | Part B | Total |
|---|---|---|
| • 2 Questions from each module.<br>• Total of 8 Questions, each carrying 3 marks<br><br>**(8x3 =24marks)** | • Each question carries 9 marks.<br>• Two questions will be given from each module, out of which 1 question should be answered.<br>• Each question can have a maximum of 3 sub divisions.<br>**(4x9 = 36 marks)** | **60** |

## Course Outcomes (COs)

At the end of the course students should be able to:

| | Course Outcome | Bloom's Knowledge Level (KL) |
|---|---|---|
| **CO1** | Understand fundamental concepts of control systems and model physical systems using differential equations and transfer functions. | **K2** |
| **CO2** | Analyse the time domain responses and steady state errors of linear systems for standard input functions. | **K3** |
| **CO3** | Analyse dynamical systems for their performance and stability using Root locus | **K3** |
| **CO4** | Apply frequency domain tools to analyse the performance of linear dynamical systems | **K3** |

Note*: K1- Remember, K2- Understand, K3- Apply, K4- Analyse, K5- Evaluate, K6- Create*

**CO-PO Mapping Table:**

| | PO1 | PO2 | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PO12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO1** | | | | | | | | | | | | |
| **CO2** | | | | | | | | | | | | |
| **CO3** | | | | | | | | | | | | |
| **CO4** | | | | | | | | | | | | |

| **Text Books** | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| **1** | Control Systems Engineering | Norman S. Nise | Wiley | 5th edition, 2009 |
| **2** | Control Systems Engineering | I. J. Nagrath, M. Gopal | New Age | 5th edition, 2009 |
| **3** | MATLAB for Control Engineers | Katsuhiko Ogata | Pearson Prentice Hall | 1st edition, 2007 |
| **4** | Modern Control Systems | Dorf R. C. and R. H. Bishop | Pearson Education | 14th edition, 2011 |

| **Reference Books** | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| **1** | Automatic Control Systems, | Kuo B. C. | Prentice Hall of India | 9th edition, 2014 |
| **2** | Control Systems Principles and Design | Gopal M. | Tata McGraw Hill. | 4th edition, 2012 |
| **3** | Modern Control Engineering | Katsuhiko Ogata | Pearson Prentice Hall | 5th edition, 2009 |

| **Video Links (NPTEL, SWAYAM…)** | |
|---|---|
| **Module No.** | **Link ID** |
| **1** | https://nptel.ac.in/courses/108106098 |
| **2** | https://nptel.ac.in/courses/108106098 |
| **3** | https://nptel.ac.in/courses/108106098 |
| **4** | https://nptel.ac.in/courses/108102043 |

# MODEL QUESTION PAPER

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**
**THIRD SEMESTER B. TECH MINOR DEGREE EXAMINATION, MONTH AND YEAR**

**Course Code:**
**Course Name:**

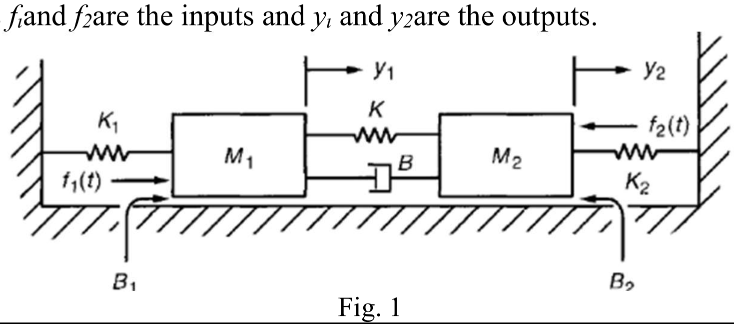
Max. Marks: 60 | Duration: 2 Hours 30 Minutes

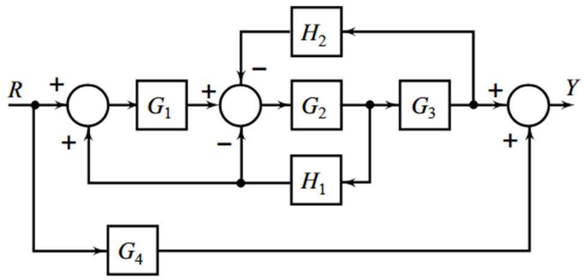
**PART A**

| | | *Answer all questions. Each question carries 3 marks* | CO | Marks |
|---|---|---|---|---|
| 1 | | Distinguish between open loop and closed loop system. | | (3) |
| 2 | | Derive the transfer function of an RLC series circuit with input voltage $V_i(s)$ and output voltage $V_o(s)$ being the voltage across the capacitor. | | (3) |
| 3 | | Determine the type and error constants of the for the step input if the open loop transfer function is $\frac{12(s+2)}{s^2(s^2+7s+12)}$. | | (3) |
| 4 | | A unity feedback control system is characterised by an open loop transfer function $G(s) = \frac{K}{s(s+10)}$. Determine the value of K so that the system will have a damping ratio of 0.5. | | (3) |
| 5 | | What is magnitude and angle criterion? | | (3) |
| 6 | | Explain how the stability of a system is analysed using Bode plot? | | (3) |
| 7 | | Sketch the polar plot of type 1 second order system? | | (3) |
| 8 | | Explain the Nyquist stability criterion. | | (3) |

**PART B**

***Answer any one full question from each module. Each question carries 9 marks***

| | | **Module 1** | CO | Marks |
|---|---|---|---|---|
| 9 | a) | Derive the transfer function of the mechanical system of Fig.1, where forces $f_1$ and $f_2$ are the inputs and $y_1$ and $y_2$ are the outputs.  Fig. 1 | | (4) |
| | b) | Reduce the block diagram shown in Fig. 2 using Mason's gain formula. | | (5) |

| | | | | |
|---|---|---|---|---|
| | |   Fig. 2 | | |
| 10 | a) | Derive the transfer function of an armature-controlled DC motor. | | (5) |
| | b) | Obtain the transfer function of the system described by, $$\dddot{y} + 6\ddot{y} + 11\dot{y} + 6y = \dddot{u} + 8\ddot{u} + 17\dot{u} + 8u$$ | | (4) |
| | | **Module 2** | | |
| 11 | a) | A unity feedback system is characterised by an open loop transfer function $G(s) = \frac{20}{s^2+5s+5}$. Determine the transient response when subjected to a unit step input and sketch the response. Evaluate the maximum overshoot and the corresponding peak time of the system. | | (4) |
| | b) | Define the time domain specifications with a neat sketch of step response of an underdamped second order system. | | (5) |
| 12 | a) | Using Routh-Hurwitz criterion, find the number of poles on the left half of s-plane and comment on the stability of the system with characteristic equation $F(s) = s^6 + 2s^5 + 7s^4 + 10s^3 + 14s^2 + 8s + 8$. | | (5) |
| | b) | Derive the expression for maximum peak overshoot and peak time of a second order system for a step input? | | (4) |
| | | **Module 3** | | |
| 13 | | Construct the bode plot for the system with open loop transfer function $G(s)H(s) = \frac{4}{s(1+0.5s)(1+0.08s)}$. Also, determine the gain margin and phase margin of the system. | | (9) |
| 14 | a) | Check whether the point $s = -1$ lies on the root locus of the open loop system $G(s)H(s) = \frac{K}{s(s+2)(s+3)}$ using angle condition. | | (5) |
| | b) | How do you determine the angle of departure of root locus branch from an open loop pole, using angle criterion. | | (4) |
| | | **Module 4** | | |
| 15 | a) | Plot the polar plot of the system with loop gain $G(j\omega)H(j\omega) = \frac{1}{j\omega+1}$. | | (3) |
| | b) | Test the stability using Nyquist criterion, for the system with open loop transfer function $G(s)H(s) = \frac{2}{s(s+2)(s+4)}$. | | (6) |
| 16 | a) | Derive and explain the dependence of damping factor on the resonant peak of a second order system? | | (4) |
| | b) | Draw the Nyquist plot of a unity negative feedback system with open loop transfer function $G(s) = \frac{5}{s(s-2)}$ and determine the closed loop stability of the system. | | (5) |
| | | ***** | | |

# SEMESTER 4

# SEMESTER 4

# MODERN CONTROL ENGINEERING

| | | | |
|---|---|---|---|
| **Course Code** | **MNEET429** | **CIE Marks** | 40 |
| **Teaching Hours/Week (L:T:P)** | 3:0:2 | ESE Marks | 60 |
| **Credits** | 4 | Exam Hours | 2 Hrs. 30 Min. |
| **Prerequisites (if any)** | **MNEET309** | Course Type | **Theory + Lab** |

**Course Objectives:**

1. To get a foundation on state space modelling of systems in continuous and discrete time.

## SYLLABUS

| Module No. | Syllabus Description | Contact Hours |
|---|---|---|
| 1 | **State space representation of systems:**<br>*Introduction to state-space modelling:* State variables, state equations. State-space modelling - advantages. State-space representation of electrical, mechanical systems and DC servo motor. (5 hours)<br>Controllable, Observable and Diagonal/Jordan canonical forms. Introduction to similarity transformations (concept only). (5 hours).<br>Derivation of transfer functions from state equations. (1 hour) | **11** |
| 2 | **Solution of state equations:**<br>State transition matrix - Properties of state transition matrix- Computation of state transition matrix using Laplace transform and Cayley Hamilton method. (4 hours)<br>Solution of state equations: Solution of time response of autonomous systems and forced systems. (4 hours) | **8** |
| 3 | **State Feedback Controller Design**<br>*Controllability & observability:* Kalman's and Gilbert's test. (2 hours). | **8** |

| | | |
|---|---|---|
| | *State feedback controller and Observer Design:* State feed-back design via pole placement technique. Duality principle. Design of full order observer. (6 hours) | |
| **4** | **State space modelling of Discrete Time control systems:**<br>*Introduction to Discrete time control systems:* Elements of discrete time control systems. Block diagram. Sampling process - sampling theorem - Aliasing effect. (4 hour)<br>*Signal reconstruction* - Zero-order and First-order hold circuits (3 hours).<br>Conversion from continuous to discrete time state space model. (2 hours) | **9** |

**Course Assessment Method**
**(CIE: 40 marks, ESE: 60 marks)**

**Continuous Internal Evaluation Marks (CIE):**

| Attendance | Continuous Assessment | Internal Examination-1 (Written) | Internal Examination-2 (Written) | Internal Examination- 3 (Lab Examination) | Total |
|---|---|---|---|---|---|
| 5 | 5 | 10 | 10 | 10 | 40 |

**End Semester Examination Marks (ESE)**

*In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions*

| Part A | Part B | Total |
|---|---|---|
| ● 2 Questions from each module.<br>● Total of 8 Questions, each carrying 3 marks<br>**(8x3 =24marks)** | ● Each question carries 9 marks.<br>● Two questions will be given from each module, out of which 1 question should be answered.<br>● Each question can have a maximum of 3 sub divisions.<br>**(4x9 = 36 marks)** | **60** |

**Course Outcomes (COs)**

At the end of the course students should be able to:

| | Course Outcome | Bloom's Knowledge Level (KL) |
|---|---|---|
| **CO1** | Model physical systems in state-space form and represent systems in canonical forms using similarity transformations. | **K2** |
| **CO2** | Solve state equations of dynamic systems using state transition matrices and analyze the time-domain response of both autonomous and non-autonomous systems. | **K3** |
| **CO3** | Design state feedback controllers and observers using pole placement technique. | **K3** |
| **CO4** | Understand discrete-time control systems and, convert continuous-time state-space models to discrete-time equivalents. | **K3** |

Note*: K1- Remember, K2- Understand, K3- Apply, K4- Analyse, K5- Evaluate, K6- Create*

**CO-PO Mapping Table:**

| | PO1 | PO2 | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PO12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO1** | | | | | | | | | | | | |
| **CO2** | | | | | | | | | | | | |
| **CO3** | | | | | | | | | | | | |
| **CO4** | | | | | | | | | | | | |

| Text Books | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| **1** | Modern Control Engineering | Katsuhiko Ogata | Pearson | 5th edition, 2009 |
| **2** | Control Systems Engineering | I. J. Nagrath, M. Gopal | New Age | 5th edition, 2009 |
| **3** | MATLAB for Control Engineers | Katsuhiko Ogata | Pearson Prentice Hall | 1st edition, 2007 |

| Reference Books | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| **1** | Modern Control Systems | Dorf R. C. and R. H. Bishop | Pearson Education | 14th edition, 2011 |
| **2** | Control Systems Engineering | Norman S. Nise | Wiley | 5th edition, 2009 |
| **3** | Digital Control System Analysis and Design | Charles L Phillips, James Brickley, Aranya Chakrabortty and H Trou Nagle | Pearson education | 4th Edition, 2014 |

| Video Links (NPTEL, SWAYAM…) | |
|---|---|
| **Module No.** | **Link ID** |
| **1** | NPTEL course on Advanced linear continuous control systems: applications with Matlab programming and Simulink - Yogesh Vijay Hote, Indian Institute of Technology, Roorkee https://archive.nptel.ac.in/courses/108/107/108107115/ |
| **2** | NPTEL course on Advanced linear continuous control systems: applications with Matlab programming and Simulink - Yogesh Vijay Hote, Indian Institute of Technology, Roorkee https://archive.nptel.ac.in/courses/108/107/108107115/ |
| **3** | NPTEL course on Advanced linear continuous control systems: applications with Matlab programming and Simulink - Yogesh Vijay Hote, Indian Institute of Technology, Roorkee https://archive.nptel.ac.in/courses/108/107/108107115/ |

## 1. Continuous Assessment (5 Marks)

**i. Preparation and Pre-Lab Work (2 Marks)**

- Pre-Lab Assignments: Assessment of pre-lab assignments or quizzes that test understanding of the upcoming experiment.
- Understanding of Theory: Evaluation based on students' preparation and understanding of the theoretical background related to the experiments.

**ii. Conduct of Experiments (3 Marks)**

- Procedure and Execution: Adherence to correct procedures, accurate execution of experiments, and following safety protocols.
- Skill Proficiency: Proficiency in handling equipment, accuracy in observations, and troubleshooting skills during the experiments.
- Teamwork: Collaboration and participation in group experiments.

***Final Marks Averaging:*** *The final marks for preparation and conduct of experiments are the average of all the specified experiments in the syllabus.*

## 2. Evaluation Pattern for Internal Lab Examination (10 Marks)

**1. Procedure/Preliminary Work/Conduct of Experiments (3 Marks)**

- Procedure Understanding and Description: Clarity in explaining the procedure and understanding each step involved.
- Preliminary Work and Planning: Thoroughness in planning and organizing materials/equipment.
- Setup and Execution: Proper setup and accurate execution of the experiment or programming task

**2. Result ( 5 Marks)**

- Accuracy of Results: Precision and correctness of the obtained results.

**3. Viva Voce (2 Marks)**

- Proficiency in answering questions related to theoretical and practical aspects of the subject.

# Experiment List

(Maximum 8 Experiments)

| Experiment No. | Experiment |
|---|---|
| 1 | **Step Response Analysis of an RLC Circuit in State-Space Form:** Analyze the step response of an RLC circuit modelled in state-space form for various damping ratios using MATLAB. Study the system's dynamic behaviour under underdamped, overdamped, and critically damped conditions. |
| 2 | **Stability, Controllability, and Observability of a DC Servo Motor:** Model an armature-controlled DC servo motor in state-space form and evaluate its open-loop stability, controllability, and observability using MATLAB tools. |
| 3 | **Diagonalization and Transfer Function Comparison via Similarity Transformation:** Apply similarity transformation to convert a state-space model into diagonal canonical form. Derive the transfer function from both the original and transformed models, and compare their characteristics. |
| 4 | **Position and Velocity Profile Simulation of a Mass-Spring-Damper System:** Simulate the motion of a mass-spring-damper system and obtain position and velocity profiles using:<br>a) Numerical methods in MATLAB, and<br>b) Simulation in Simulink.<br>Compare the results from both approaches. |
| 5 | **State Feedback Controller Design Using Pole Placement:** Design a state feedback controller for a linear system using the pole-placement technique in MATLAB. Analyze system performance and verify the placement of closed-loop poles. |
| 6 | **Speed Control of a DC Servo Motor Using State Feedback:** Develop a state feedback controller for an armature-controlled DC servo motor using pole-placement. Evaluate the controller’s effectiveness in achieving desired speed control. |
| 7 | **Speed Control of a DC Servo Motor Using State Feedback:** Develop a state feedback controller for an armature-controlled DC servo motor using pole-placement. Evaluate the controller’s effectiveness in achieving desired speed control. |
| 8 | **Speed Control of a DC Servo Motor Using State Feedback:** Develop a state feedback controller for an armature-controlled DC servo motor using pole-placement. Evaluate the controller’s effectiveness in achieving desired speed control. |

# MODEL QUESTION PAPER

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**
**FOURTH SEMESTER B. TECH MINOR DEGREE EXAMINATION, MONTH AND YEAR**

**Course Code:**

**Course Name:**

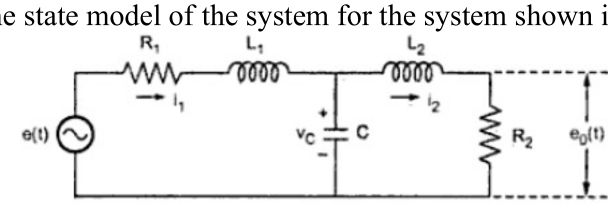
| Max. Marks: 60 | | Duration: 2 hours 30 minutes |
|---|---|---|

## PART A

| | | ***Answer all questions. Each question carries 3 marks*** | CO | Marks |
|---|---|---|---|---|
| 1 | | A series RLC circuit with R= 1Ω, L=1H and C=1F is excited by v =10V. Write state equations in matrix form. | | (3) |
| 2 | | Explain the terms (i) state (ii) state variables (iii) state vector | | (3) |
| 3 | | Determine state transition matrix for the system described by, $\dot{\boldsymbol{x}}(\boldsymbol{t}) = \begin{bmatrix} 0 & 1 \\ -4 & -4 \end{bmatrix} x(t)$ | | (3) |
| 4 | | State the properties of state transition matrix. | | (3) |
| 5 | | Define observability. Explain with a suitable example, how can we check the observability of a system? | | (3) |
| 6 | | Find the complete controllability for the system described by, $\dot{x(t)} = \begin{bmatrix} -0.2 & 0.4 \\ 0.1 & -0.1 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u(t)$ <br> $C = [1 \quad 0]x(t)$ | | (3) |
| 7 | | Find the state variable representation of SISO LTI discrete system given by, $y(k+2) - 1.7y(k+1) + 0.72y(k) = u(k)$ | | (3) |
| 8 | | State Sampling theorem. | | (3) |

## PART B

***Answer any one full question from each module. Each question carries 9 marks***

| | | **Module 1** | | |
|---|---|---|---|---|
| 9 | a) | Obtain the state model of the system described by, $\dddot{y} + 6\ddot{y} + 11\dot{y} + 6y = \dddot{u} + 8\ddot{u} + 17\dot{u} + 8u$ using phase variables. | | (5) |
| | b) | Obtain the state model of the system for the system shown in Fig. 1 <br>   <br> Fig. 1 | | (4) |
| 10 | a) | Convert the given state space model of the system described below to transfer function <br> $\dot{x(t)} = \begin{bmatrix} 0 & 1 \\ -3 & -4 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 2 \end{bmatrix} u(t)$ <br> $C = [1 \quad 2]x(t)$ | | (3) |

| | | | | |
|---|---|---|---|---|
| | b) | Obtain the state space model of the system in Jordan canonical form for the system transfer function given by, $$F(s) = \frac{1}{s^3 + 4s^2 + 5s + 2}$$ | | (6) |
| | | **Module 2** | | |
| 11 | a) | Compute the solution of the system described by, $$\dot{x(t)} = \begin{bmatrix} -8 & 6 \\ -6 & 4 \end{bmatrix} x(t) + \begin{bmatrix} 4 \\ -6 \end{bmatrix} u(t)$$ $$C = [1 \quad -1]x(t)$$ For a unit step input. | | (9) |
| 12 | a) | Find$f(A) = A^{10}$for $A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$. | | (6) |
| | b) | Derive the state transition matrix using Laplace transforms for a non-homogeneous system. | | (3) |
| | | **Module 3** | | |
| 13 | a) | Given $\dot{X} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -2 & -3 \end{bmatrix} X + \begin{bmatrix} 0 \\ 0 \\ 10 \end{bmatrix} U$. Check controllability and design a state feedback controller for the system with closed loop poles at $(-1 \pm j1)$ and $-2$. | | (6) |
| | b) | How the state controllability differs from the output controllability? | | (3) |
| 14 | a) | How will you assess the controllability, when the system is in Jordan canonical form? Explain with an example. | | (3) |
| | b) | Consider the system described by the state model: $$\dot{X} = AX; Y = CX$$ where, $A = \begin{bmatrix} -1 & 1 \\ 1 & -2 \end{bmatrix}; C = [1 \quad 0]$ Design a full order state observer for the desired Eigen values at $\mu_1 = -5$ and at $\mu_2 = -5$ | | (6) |
| | | **Module 4** | | |
| 15 | a) | Derive the transfer function for Zero-order and First-order hold circuit. | | (6) |
| | b) | Explainaliasing effect. | | (3) |
| 16 | a) | Explain the process of sampling and reconstruction. | | (5) |
| | b) | Obtain the discrete time state space model of the system described by, $$F(s) = \frac{2s + 2}{s^3 + 3s^2 + 3s + 2}$$ | | (4) |
| | | ***** | | |

# SYLLABUS

# SEMESTER 5

## SEMESTER 5

## ADVANCED CONTROL SYSTEM DESIGN

| Course Code | MNEET529 | CIE Marks | 40 |
|---|---|---|---|
| Teaching Hours/Week (L:T:P) | 3:1:0 | ESE Marks | 60 |
| Credits | 4 | Exam Hours | 2 Hrs. 30 Min. |
| Prerequisites (if any) | MNEET309/409 | Course Type | Theory |

**Course Objectives:**

1. To introduce various classical controller and compensator design using root- locus and frequency domain techniques
2. To introduce non-linear system behavior and assessment of stability using Lyapunov method

## SYLLABUS

| Module No. | Syllabus Description | Contact Hours |
|---|---|---|
| 1 | PID controllers: Effect of P/I/D terms in a P/PI/PD controller design. (2 hours)<br>PID controllers: PID tuning using Ziegler-Nichols methods. (2 hours)<br>PID controller tuning using time-domain and frequency domain specifications. (5 hours) | 9 |
| 2 | Compensators basics: Lag compensator-lead compensator and lag lead compensator transfer function and characteristics. (2 hours)<br>Compensators design: Design of lag, lead and lag-lead compensators using Root locus technique. (7 hours) | 9 |
| 3 | Compensator Realisation: Compensator realisation using passive and active networks. (2 hours)<br>Compensators design: Design of lag, lead and lag-lead compensators using frequency domain specifications. (7 hours) | 9 |
| 4 | Nonlinear systems: Linear and nonlinear systems-characteristics (2 hours)<br>Singular points and phase portrait (only approximate construction) (3 hours)<br>Lyapunov stability - Lyapunov functions - Lyapunov direct and indirect methods. (4 hours) | 9 |

## Course Assessment Method
## (CIE: 40 marks, ESE: 60 marks)

**Continuous Internal Evaluation Marks (CIE):**

| Attendance | Assignment/ Microproject | Internal Examination-1 (Written) | Internal Examination- 2 (Written ) | Total |
|---|---|---|---|---|
| 5 | 15 | 10 | 10 | 40 |

**End Semester Examination Marks (ESE)**

*In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions.*

| Part A | Part B | Total |
|---|---|---|
| • 2 Questions from each module.<br>• Total of 8 Questions, each carrying 3 marks<br><br>**(8x3 =24marks)** | • Each question carries 9 marks.<br>• Two questions will be given from each module, out of which 1 question should be answered.<br>• Each question can have a maximum of 3 subdivisions.<br>**(4x9 = 36 marks)** | **60** |

## Course Outcomes (COs)

At the end of the course students should be able to:

| | Course Outcome | Bloom's Knowledge Level (KL) |
|---|---|---|
| **CO1** | To design P/PI/PID controllers using time domain and frequency domain specifications. | K3 |
| **CO2** | To design compensators using root-locus techniques. | K3 |
| **CO3** | To design compensators using frequency domain specifications. | K3 |
| **CO4** | To understand the characteristics of non-linear systems | K2 |
| **CO5** | To determine the stability of the system using Lyapunov method | K2 |

Note*: K1- Remember, K2- Understand, K3- Apply, K4- Analyse, K5- Evaluate, K6- Create*

**CO-PO Mapping Table:**

| | PO1 | PO2 | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PO12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO1** | | | | | | | | | | | | |
| **CO2** | | | | | | | | | | | | |
| **CO3** | | | | | | | | | | | | |
| **CO4** | | | | | | | | | | | | |

| Text Books | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| 1 | Modern Control Engineering | K. Ogata | Pearson College Div. | Fifth Edition, 2009 |
| 2 | Control Systems: Principles and Design | M. Gopal | McGraw Hill Education | Fourth Edition, 2012 |
| 3 | Nonlinear Systems | H.K. Khalil | Pearson India Education Pvt. Ltd. | Third Edition, 2014 |

| Reference Books | | | | |
|---|---|---|---|---|
| **Sl. No** | **Title of the Book** | **Name of the Author/s** | **Name of the Publisher** | **Edition and Year** |
| **1** | Automatic Control Systems | Kuo B. C. | Prentice Hall of India | 9th edition, 2014 |
| **2** | Control Systems Engineering | Norman S. Nise | Wiley | 5th edition, 2009 |
| **3** | Modern Control Systems | Dorf R. C., Bishop R. H | Pearson Education India | 12th edition, 2013 |

| Video Links (NPTEL, SWAYAM…) | |
|---|---|
| **Module No.** | **Link ID** |
| **1** | https://nptel.ac.in/courses/108106098 |
| **2** | https://nptel.ac.in/courses/108106098 |
| **3** | https://nptel.ac.in/courses/108106098 |
| **4** | https://nptel.ac.in/courses/108101002 |

| | | | | |
|---|---|---|---|---|
| **MODEL QUESTION PAPER** | | | | |
| **APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**<br>**FIFTH SEMESTER B. TECH MINOR DEGREE EXAMINATION, MONTH AND YEAR** | | | | |
| **Course Code: MNEET509** | | | | |
| **Course Name: Advanced Control System Design** | | | | |
| Max. Marks: 60 | | Duration: 2 Hours 30 Minutes | | |
| | | **PART A** | | |
| | | ***Answer all questions. Each question carries 3 marks*** | CO | Marks |
| 1 | | Briefly explain the individual effect of proportional (P), integral (I), and derivative (D) terms on the transient and steady-state behavior of a control system. | | (3) |
| 2 | | Write the transfer function for a PI controller ? What is the effect of adding I term in the PI controller design? | | (3) |
| 3 | | Why are lag-lead compensators called so? Also draw the pole-zero plot of the lag-lead compensator after writing its transfer function. | | (3) |
| 4 | | Draw the ideal frequency response characteristics of a lead compensator. | | (3) |
| 5 | | Explain how to realise a lag compensator using passive components. | | (3) |
| 6 | | Explain how to realise a lead compensator using active components. | | (3) |
| 7 | | Explain with the help of an example the characteristics to be satisfied by a Lyapunov function to qualify itself as a suitable candidate to ascertain asymptotic stability of a system. | | (3) |
| 8 | | List any three unique characteristics exhibited by a nonlinear system with examples. | | (3) |
| **PART B** | | | | |
| ***Answer any one full question from each module. Each question carries 9 marks*** | | | | |
| | | **Module 1** | | |
| 9 | | Explain the steps involved in the design of the PID controller using any one of the Ziegler-Nichols tuning methods. | | (9) |
| 10 | | Consider a unity feedback system with open loop transfer function, $\frac{100}{(s+1)(s+2)(s+5)}$. Design a PI controller so that the phase margin of the system is 60° at a frequency of 0.5 rad/sec. | | (9) |
| | | **Module 2** | | |
| 11 | | Explain the steps involved in the design of a lead compensator using root-locus techniques | | (9) |
| 12 | | Consider a unity feedback system with open loop transfer function, $\frac{K}{s(s+1)(s+10)}$. It is required that the velocity error constant $K_v \geq 50$, while the damping ratio is 0.707. Design a suitable compensator to meet the given specifications. | | (9) |
| | | **Module 3** | | |
| 13 | | Explain the steps involved in the design of a lag compensator using frequency domain specifications. | | (9) |
| 14 | | Design a lead compensator for a unity feedback system with open loop | | (9) |

| | | | | |
|---|---|---|---|---|
| | | transfer function, $\frac{K}{s(s+1)(s+5)}$, to satisfy the following specifications of velocity error constant, $K_v \geq 50$, and phase margin $\geq 20^0$. | | |
| | | **Module 4** | | |
| 15 | | Identify the singular points and draw the approximate phase portrait around the equilibrium points for $$\ddot{y} - \left(0.1 - \frac{10}{3}\dot{y}^2\right)\dot{y} + y + y^2 = 0$$ | | (9) |
| 16 | | Apply Lyapunov's indirect method and determine the stability about the origin for the following system for constants b,a >0 $$\dot{x}_1 = x_2, \qquad \dot{x}_2 = -a\sin x_1 - bx_2$$ | | (9) |
| | | ***** | | |

# SEMESTER 6

## SEMESTER 6

## CONTROL OF ROBOTIC SYSTEMS

| Course Code | MNEET629 | CIE Marks | 40 |
|---|---|---|---|
| Teaching Hours/Week (L:T:P) | 3:0:0 | ESE Marks | 60 |
| Credits | 3 | Exam Hours | 2 Hrs. 30 Min. |
| Prerequisites (if any) | MNEET309/409/509 | Course Type | Theory |

**Course Objectives:**

- To introduce the fundamentals of robotic systems and their electric actuator control mechanisms
- Obtain the kinematic model of mobile robots and robotic manipulators
- Design kinematic controllers for mobile robots and robotic manipulators
- Obtain the dynamic model of robotic manipulators and design a controller for the same

## SYLLABUS

| Module No. | Syllabus Description | Contact Hours |
|---|---|---|
| 1 | **Introduction to Robotic Systems and Control of actuators for robots**<br><br>Overview of robotic systems and applications, Necessity of a control system in a robot.<br><br>Bird's eye view of typical actuators in robot control systems-hydraulic, pneumatic and electric actuators- Position Control of DC and AC servo motors, Speed control of DC motor, speed control of Brushless DC motors,control of linear actuation mechanisms.<br><br>Basic idea of feedbacks in robotic systems-sensors-eg. Linear and rotary encoders. | 11 |
| 2 | **Kinematic Modelling and control of Mobile Robots**<br>Kinematic model of Differential drive robot, Control based on this kinematic model- Controller for moving to a point, following a line and following a path.<br>Kinematic model of steered robot, Control based on this kinematic model- Controller for moving to a point, following a line and following a path. | 11 |
| 3 | **Kinematic modelling and Control of robotic manipulators**<br>Forward and inverse Kinematics: Coordinate frames, rotations and translations, Transformation matrix, Composite Transformation, Jacobian Matrix.<br><br>Kinematic modelling of 1 and 2 DoF planar manipulator.Kinematic position | 11 |

| | | |
|---|---|---|
| | Control and Kinematic Velocity Control using Jacobian (Resolved Motion Rate Control) | |
| **4** | **Dynamic Modelling and Control of robotic manipulator**<br><br>Dynamic model of 1 DoF manipulator using Lagrange's equation, dynamic modelling of 1DOF robot including motor and gearbox<br><br>PID control of a single link manipulator, selection of PID controller gains; PD gravity control, computed torque control, Resolved Motion acceleration control | **11** |

**Course Assessment Method**
**(CIE: 40 marks, ESE: 60 marks)**

**Continuous Internal Evaluation Marks (CIE):**

| Attendance | Assignment/ Microproject | Internal Examination-1 (Written) | Internal Examination- 2 (Written ) | Total |
|---|---|---|---|---|
| **5** | **15** | **10** | **10** | **40** |

**End Semester Examination Marks (ESE)**

*In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions*

| Part A | Part B | Total |
|---|---|---|
| • 2 Questions from each module.<br>• Total of 8 Questions, each carrying 3 marks<br><br>**(8x3 =24marks)** | • Each question carries 9 marks.<br>• Two questions will be given from each module, out of which 1 question should be answered.<br>• Each question can have a maximum of 3 sub divisions.<br>**(4x9 = 36 marks)** | **60** |