VEERMATA JIJABAI TECHNOLOGICAL INSTITUTE
(VJTI)
MATUNGA, MUMBAI 400 019

(Autonomous Institute affiliated to University of Mumbai)

Curriculum
(Scheme of Instruction & Evaluation and Course contents)

For

Two Year Postgraduate Programme Leading to
Master of Technology (M.Tech.) Degree in
Electrical Engineering with specialization in Control Systems

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In

207 Electrical Engineering (with specialization in Control Systems)

SEMESTER I

Scheme of Instruction				Scheme of Evaluation				
S. No	**Course code**	**Course Title**	**L-T-P (Hours / week)**	**Credits**	**TA**	**IST**	**ESE**	**ESE hours**
1.	EE5001S	Computational Methods	3-1-0=4	4	20	20	60	3
2.	EE5002S	Optimal Control	3-1-0=4	4	20	20	60	3
3.	EE5003T	Dynamical Systems	3-0-0=3	3	20	20	60	3
	EE5003P	Dynamical Systems Lab	0-0-2=2	1	100 % CIE			
4.	EE5004T	Linear Control Design	3-0-0=3	3	20	20	60	3
	EE5004P	Linear Control Design Lab	0-0-2=2	1	100 % CIE			
5.		Program Elective course 1	3-1-0=4	4	20	20	60	3
6.		Program Elective course 2	3-0-0=3	3	20	20	60	3
		Program Elective course 2 Lab	0-0-2=2	1	100 % CIE			
		Total	**27**	**24**				

SEMESTER II

Scheme of Instruction				Scheme of Evaluation				
S. No	**Course code**	**Course Title**	**L-T-P (Hours / week)**	**Credits**	**TA**	**IST**	**ESE**	**ESE hours**
1.	EE5005S	Research Methodology	3-1-0=4	4	20	20	60	3
2.	EE5006S	Non Linear System Analysis	3-1-0=4	4	20	20	60	3
3.	EE5007T	Non-linear Control Design	3-0-0=3	3	20	20	60	3
	EE5007P	Non-linear Control Design Lab	0-0-2=2	1	100 % CIE			
4.	EE5008T	System identification, estimation and filtering	3-0-0=3	3	20	20	60	3
	EE5008P	System identification, estimation and filtering Lab	0-0-2=2	1	100 % CIE			
5.		Program Elective course 2	3-0-0=3	3	20	20	60	3
6.		Program Elective course 3	3-0-0=3	3	20	20	60	3
		Program Elective course 3 Lab	0-0-2=2	1	100 % CIE			
	EE5801D	Technical Seminar	0-0-4=4	2	100 % CIE			
		Total	**30**	**25**				

Abbreviations: **L**: Lecture, **T**: Tutorial, **P**: Practical, **TA**: Teacher Assessment / Term work Assessment, **IST**: In Semester Tests (comprise of average of two in semester tests), **ESE**: End Semester Written Examination, **CIE**: Continuous In-semester Evaluation

List of Electives:

Sr. No	Course code	Course Title
Program Elective Course 1	**EE5101S**	Robotics: Dynamics and Control
	EE5102S	Stochastic Control
Program Elective Course 2	**EE5103T**	Decentralized Control
	EE5103P	Decentralized Control Lab
	EE5104T	Mathematical System Theory
	EE5104P	Mathematical System Theory Lab
Program Elective Course 3	**EE5111S**	Multivariable Control
	EE5112S	High Performance Electric Drives
Program Elective Course 4	**EE5113T**	Intelligent Control Theory
	EE5113P	Intelligent Control Theory Lab
	EE5114T	Embedded Systems
	EE5114P	Embedded Systems Lab

SEMESTER III and SEMESTER IV – Project work

S. No	Course Category	Course Code	Course Title	Credits	Evaluation pattern	Semester
1.	Project	EE6901D	Stage –I Presentation	4	Graded evaluation by a committee of at least two examiners including supervisor (guide)	III
2.	Project	EE6902D	Stage –II Presentation	4	Graded evaluation by a committee of at least two examiners including supervisor (guide)	III
3	Project	EE6903D	Stage –III Presentation	4	Graded evaluation by a committee of at least two examiners including guide (guide)	IV
4.	Project	EE6904D	Final Presentation and Viva Voce	12	Graded evaluation by a committee of at least two examiners including supervisor (guide) and an external examiner	IV

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

- ***To strengthen the ability of students to select and apply the knowledge of mathematics, science, engineering, and technology to engineering technology problems.***
- ***To produce post graduates who will pursue life-long learning and professional development.***
- ***Develop leadership and team building skills.***

PROGRAM OUTCOMES (POs)

At the end of Post Graduate Program, students will have

- ***An ability to apply knowledge of mathematics, allied sciences, and engineering to problems related to System Engineering and Control***
- ***An ability to conduct independent research both of an academic and applied nature in the area of mathematical and applied control theory.***
- ***An ability to use the techniques, skills, and modern control engineering tools necessary for engineering practice.***
- ***An ability to be conversant with practical control system design, operation, control, and testing issues.***
- ***An ability to communicate effectively to convey the ideas acquired through research.***
- ***Enhanced knowledge and skill set required in control engineering program for problem solving so as to arrive at appropriate technological solutions.***
- ***An understanding of professional and ethical responsibility.***

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I
Course Code	**EE5001S**
Course Title	**COMPUTATIONAL METHODS**

COURS OBJECTIVES

The course is designed to provide M. Tech. Students across all engineering disciplinea view of using various computational techniques and tools for analysis, decision making and solution of engineering problems. Following are the course objectives:

- Students will be able to develop mathematical models of lower level engineering problems.
- Students will learn how to solve nonlinear equations numerically.
- Students will be introduced to fundamental matrix algebra concepts and shown how to solve simultaneous linear equations numerically.
- Students will learn how to curve fit (interpolation and regression) discrete date.
- Students will learn how to numerically integrate continuous and discrete functions.
- Students will learn how to numerically solve ordinary differential equations that are initial value or boundary value problems.

COURSE OUTCOMES

In the course Computational Methods, the program objectives are met as follows;

- Understand the concept and steps of problem solving - mathematical modeling, solution and implementation.
- Knowledge and understanding of, and the ability to use, mathematical techniques.
- Ability to understand and apply mathematical reasoning in several different areas of mathematics.

Overview

Module 1: Algebraic Equations		**10 Hrs**
	Formulation and solution of linear system of equations, Gauss elimination, LU, QR decomposition, iteration methods (Gauss-Seidal), convergence of iteration methods, Singular value decomposition and the sensitivity of rank to small perturbation	
Module 2: Interpolation & Regression Methods		**08 Hrs**
	Newton's divided difference, interpolation polynomials, Lagrange interpolation polynomials, Linear and non-linear regression, multiple linear regression, general linear least squares	
Module 3: Transform Techniques		**07 Hrs**
	Vector spaces, Basis vectors, Orthogonal/Unitary transform, Fourier transform, Laplace transform	
Module 4: Optimization Techniques for Engineers		**10 Hrs**
	Local and global minima, Line searches, Steepest descent method, Conjugate gradient method, Quasi Newton method, Penalty function	
Module 5: Graph Theory		**07 Hrs**

	Graphs and Matrices, simple graph, cyclic graph, complete graph, properties of the Laplacian matrix and relation with graph connectivity. Non-negative matrices. Applications of graph theory to engineering problems.	

Tutorials: At least 3 tutorials on each Module covering relevant engineering applications

Recommended Reading

01 “Numerical Methods for Engineers’, Steven C. Chapra and Raymond P. Canale, McGraw Hill

02 “Probability and Statistics in Engineering and Management Studies”, Hines and Montrogmery, John

03 “Numerical Methods for Engineers”, Santosh Gupta, New age international publishers

04 “Graphs and Matrices”, R. B. Bapat, TRIM Series, Hindustan Book Agency, 2011

05 “Algebraic Graph Theory “, C. Godsil and G. Royle, Springer, New York, 2001 (Available in Indian edition)

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5002S**
Course Title	**OPTIMAL CONTROL**

COURSE OBJECTIVES

- To impart knowledge about formulation of optimal control problems from specifications on dynamics, constraints and control objective.
- To explain how various control objectives affect the optimal performance
- To describe how the Dynamic programming principle works (DynP) and apply it to discrete optimal control problems over finite and infinite time horizons.

COURSE OUTCOMES

- Students shall be able to combine the mathematical methods used in optimal control to derive the solution to variations of the problems studied in the course.
- Students shall be able to use the standard algorithms for numerical solution of optimal control problems and use Matlab to solve fairly simple but realistic problems.
- Students shall be able to integrate the tools learnt during the course and apply them to more complex problems.

Overview

Module 1: Introduction		**04 Hrs**
	Problem formulation, State variable representation of system	
Module 2: The Performance Measure		**12 Hrs**
	Performance measure for optimal control problem, Selecting a performance Measure, Selection of performance Measure: the carrier landing of Jet Aircraft	
Module 3: Dynamic Programming		**12 Hrs**
	Optimal control law, Principle of optimality, Application of the optimality to decision making, Dynamic programming applied to a routing problem, An optimal control system, Interpolation, A recurrence relation of dynamic programming, Computational procedure for solving control problems, Characteristics of dynamic programming solutions, Analytical results- discrete linear regulator problem, The Hamilton-Jacobi-Bellman equation, Continuous linear regulator problems.	
Module 4: The calculus of variations		**12 Hrs**
	Fundamental concepts, functions of a single function, fundamental theorem of calculus of variations, functions involving several independent functions, the simplest varational problem, piecewise smooth extremals, constrained extrema	
Module 5: Pontryagin Maximum principle		**08 Hrs**
	Heuristic Proof of Pontryagin Maximum principle, Langrange-Mayer, Principle of Optimality, Temporal Variations of u, spatial variations of u, the variational equation, Terminal cone, separating hyper plane, Adjoint equation, Final proof.	

Module 6:		08 Hrs
	Time Optimal control problems, the bang-bang principle, Existence of optimal controls, Finite Horizon LQR problem, Riccati Differential equation.	

Recommended Reading

01 M. Athans and P. L. Flab Optimal control: An introduction to the theory and its applications (1966) McGraw-Hill, New York

02 Optimal control theory: An Introduction by Donald E .Kirk, Dover Publications 2004

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I
Course Code	**EE5003T**
Course Title	**DYNAMICAL SYSTEMS**

COURSE OBJECTIVES

- To lay emphasis on the qualitative and geometric properties of ordinary differential equations and their solutions, helping the student to get a feel for the subject.
- To emphasize through examples and connections with mechanics the physical reasoning used as a substitute for much longer formal mathematical reasoning.
- To introduce the students to the modern language and theories of vector fields flows, one parameter transformation groups, symmetries etc.

COURSE OUTCOMES

- The students shall be able to go beyond the routine presentation of algorithms for solving special classes of equations.
- The students shall be able to integrate the geometric viewpoint in their scientific thought process.
- The students shall be able to build a clear connection between differential equations, their qualitative properties and the modeling and behavior of physical systems.

Overview

Module 1: Basic Concepts	**Hrs**
Phase spaces and Phase flows-Examples of evolutionary processes, phase flows, Diffeomorphisms, Vector fields, The basic problem of the theory of ordinary differential equations, examples of vector fields.	
Module 2: Vector Fields and Phase Flows	**Hrs**
Solutions of differential equations, integral curves. Phase flows on the line- one parameters group of linear transformation, the differential equations of one parameter group, the general form of a one parameter group, conditions for existence of phase flow	
Module 3: The Tangent Space	
Definition of the tangent vector, definition of the tangent space, the inverse function theorem, action of the diffeomorphism on a vector field.	
Module 4: Basic Theorems	
Rectification theorem- rectification of direction field, implicit function theorem. Existence and uniqueness theorem. Theorems on continuous and differentiable dependence of the solutions on the initial conditions. Transformation over the time interval. Theorems on continuous and differentiable dependence on a parameter.3	

Recommended Reading

01 Ordinary Differential Equations by Dr. Vladimir Arnold

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5003P**
Course Title	**DYNAMICAL SYSTEMS LAB**

COURSE OBJECTIVES

- To lay emphasis on the qualitative and geometric properties of ordinary differential equations and their solutions, helping the student to get a feel for the subject.
- To emphasize through examples and connections with mechanics the physical reasoning used as a substitute for much longer formal mathematical reasoning.
- To introduce the students to the modern language and theories of vector fields flows, one parameter transformation groups, symmetries etc.

COURSE OUTCOMES

- The students shall be able to solve differential equations and plot integral curve, phase curves and vector field diagram using MATLAB.
- The students shall be able use MATHEMATICA to plot phase portrait
- The students shall be able to perform stability analysis and qualitative analysis of wein bridge system using MATLAB.

Overview

1. To solve ODE and plot integral curve using MATLAB
2. To solve ODE and plot phase curves using MATLAB
3. To Solve ODE and plot Vector field diagram using MATLAB
4. To plot phase portraits using MATHEMATICA.
5. To perform stability analysis using Eigen values
6. To study qualitative behavior for Wein bridge system

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I
Course Code	**EE5004T**
Course Title	**LINEAR CONTROL DESIGN**

COURSE OBJECTIVES

Study the principles of system modeling, system analysis and feedback control, and use them to design and evaluate feedback control systems with desired performance; specifically, to acquire the related knowledge and techniques to meet the following course objectives:

- Control system analysis: analysis of properties of control systems, such as sensitivity, stability, controllability, tracking, in time and frequency domains;
- Control system design: design of feedback controllers to meet desired system performance specifications.
- Introduction to modern robust control theory techniques for large- scale uncertain systems: stability and performance; computer-aided tools for both system analysis and controller design.

COURSE OUTCOMES

- The student shall be able to appreciate and apply the acquired knowledge of mathematics and science to real world problems across different disciplines of engineering.
- The students shall be able to ability to identify, formulate, and solve control related engineering problems
- The students shall be able to specify, design, analyze and test a wide range of systems to meet a set of desired goals, within the context of a broader system application.

Overview

Module 1: Introduction	**08 Hrs**
Introduction to basic control theory, Issues in control system design, Design via root locus, Design via Frequency response, Design via state-space	
Module 2 : Basic Review of Stability Theory	**08 Hrs**
Basic review of Stability theory, Root locus methods, Bode methods, Nyquist theory	
Module 3 : Compensator Design	**08 Hrs**
Dynamic Compensator design using Root Locus, Nyquist Plot and Bode Plot.	
Module 4 : State Space Modelling	**08 Hrs**
State space modelling, Controllability and Observality concepts, Observer's and Controller design	
Module 5 : Introduction to concepts of model uncertainty	**08 Hrs**
Introduction to concepts of model uncertainty, including both parametric and dynamic un-certainty. Fundamental concept of robustness and the relationship	

between physical systems and mathematical models. Mathematical background including norms for vectors, matrices, signals, and systems. The singular value decomposition (SVD) and its application to perturbation analysis.	
Module 6 : Loop Shaping	**08 Hrs**
Loop shaping, the basic technique of loop shaping, The phase formula, optimal controllers, Plants with RHP poles and zeros.	

Recommended Reading

01 John Doyle, Bruce Francis, Allen Tannenbaum, “Feedback Control Systems”, Macmillan Publishing Co.1990.

02 Kemin Zhou, “Robust And Optimal Control”, Prentice Hall, Englewood Cliffs, New Jersey. Norman S. Nise, “Control Systems Engineering”, John Wiley & Sons.

03 Joao P. Hespanha, “Linear Systems Theory”, Princeton University Press.

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5004P**
Course Title	**LINEAR CONTROL DESIGN LAB**

COURSE OBJECTIVES

- Control system analysis: analysis of properties of control systems, such as sensitivity, stability, controllability, tracking, in time and frequency domains.
- Control system design: design of feedback controllers to meet desired system performance specifications.
- Introduction to modern robust control theory techniques for large- scale uncertain systems: stability and performance; computer-aided tools for both system analysis and controller design.

COURSE OUTCOMES

- The student shall be able to apply the acquired knowledge of mathematics in-order to apply control for any given application.
- The students shall design perform simulation of various compensator circuits.

Overview

1) To study step response of a zero order system using transfer function.
2) To plot bode plot, Nyquist plot and root locus of the given system
3) To study controllability and observability of the given systems
4) To design lead compensator using SISO tools
5) To study compensation using pole placement method.
6) To design a simple pendulum using Simulink.

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5101S**
Course Title	***PROGRAM ELECTIVE COURSE 1*** **ROBOTICS: DYNAMICS & CONTROL**

COURSE OBJECTIVES

- To explore and investigate issues in kinematics and dynamics modeling of various types of robots
- To apply different control techniques and methodologies for stabilization and trajectory tracking problems in Robotics
- To study role of Robotics in industrial automation.

COURSE OUTCOMES

- Student shall be able to obtain forward, reverse kinematics and dynamics model of the industrial robot arm.
- Student shall be able to propose and synthesize control law for a given application
- Student shall be able to classify robots and decide specifications depending on the application

Overview

Module 1: Introduction	**04 Hrs**
Robot terminology, Robot classification	
Module 2: Rigid Body Motion	**12 Hrs**
Rigid body transformation, Rotational motion in $\Re 3$, Homogeneous representation, Velocity of a rigid body, Wrenches.	
Module 3: Manipulator Kinematics	**12 Hrs**
Forward kinematics, Kinematic parameters, D-H algorithm, Inverse kinematics, Manipulator workspace, manipulator Jacobian (Analysis of - 2 Axis and 3 Axis Planar, Four axis SCARA Robot, Five axis Articulated robot).	
Module 4: Robot Dynamics and Control	**12 Hrs**
Lagrange's equations, Inertial properties of rigid bodies, Newton-Euler equations for a rigid body, Dynamics of a two-link planar robot, Lagrangian for an open-chain manipulator, Lyapunov stability theory, Linear feedback systems, Single-axis PID control, PD-Gravity control, Computed torque control, Variable-structure control, Impedance control.	
Module 5: Advanced Topics	**08 Hrs**
Quaternion, Control of constrained manipulators, Nonholonomic behaviour in robotic systems, Examples of nonholonomic systems, Lie brackets and Frobenius theorem, nonlinear controllability.	

Recommended Reading

1) "A mathematical Introduction to Robotic Manipulation", Richard Murray, Zexiang Li, S. Shankar Sastry, CRC Press, 1994

2) "Robot Dynamics and Control", Mark Spong and M. Vidyasagar, John Wiley & Sons, 1989
3) "Introduction to Robotics", J. J. Craig, Pearson Education.
4) "Robotics", Fu, Gonzales and Lee, McGraw Hill, 1987
5) "Fundamentals of Robotics- Analysis and Control", Robert Schilling, Pearson Education, 1990

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I
Course Code	**EE5102S**
Course Title	***PROGRAM ELECTIVE COURSE 1*** **STOCHASTIC CONTROL**

COURSE OBJECTIVES

- To develop skills in building stochastic models using Markov chains.
- To better understand inventory/production control in light of stochastic models.
- To develop an understanding of queuing systems under different configurations.
- To develop skills in analysing and interpreting the results.

COURSE OUTCOMES

- To develop skills in analyzing and interpreting the results.
- Master essential stochastic modeling tools including Markov chains and queuing theory.
- Be able to formulate and solve problems which involve setting up stochastic models

Overview

Module 1: Random Variables and Stochastic Processes	Hrs
Random Variables, Probabilistic Concepts Applied to Random Variables, Special Stochastic Process, Covariance Function, Concept of Spectral Density and analysis of Stochastic Process, Gauss–Markov Processes, Gauss–Markov Processes.	
Module 2: Stochastic State Models	**Hrs**
Discrete Time Systems, solutions to differential Equations, Continues time systems, Stochastic Integrals, Linear and nonlinear Stochastic Differential Equations, Stochastic Calculus.	
Module 3: Dynamical Systems with Stochastic Process Input	**Hrs**
Discrete Time Systems, Spectral Factorization of Discrete Time Processes, Analysis of Continuous Time Systems whose Input Signals Are Stochastic Processes, Spectral Factorization of Continuous Time Processes.	
Module 4: Parametric Optimization	**Hrs**
Evaluation of Loss Functions for Discrete Time Systems, Evaluation of Loss Functions for Continuous Time Systems, Reconstruction of State Variables for Discrete Time Systems, Reconstruction of State Variables for Continuous Time Systems	
Module 5: Stochastic Control and the Linear Quadratic Gaussian Control Problem	**Hrs**
Filtering and Estimation, Stochastic Control Problem with Perfect Observation, Stochastic LQ Problems with Perfect Information, Continuous and discrete time LQG Problems	

Recommended Reading

01 Stochastic Processes, Estimation, and Control, - George N. Saridis Wiley, 03-Apr-1995.

02 Introduction to Stochastic Control Theory, Karl J. Åström, Dover Publications

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5103T**
Course Title	***PROGRAM ELECTIVE COURSE 2*** **DECENTRALIZED CONTROL**

COURSE OBJECTIVES

- To introduce the students to the idea of and issues related to Complex systems
- To build an appreciation of the need for decentralized information and control structures to enable fast control action in response to local input, and perturbations in large systems
- To interweave theories from optimization, output feedback, graph theory, overlapping decompositions and reliability for analyzing and controlling complex systems.

COURSE OUTCOMES

- The students shall be able to appreciate the need for effective utilization of graph theoretic tools for analysis, estimation and control of modern Large – scale /complex systems.
- The students shall be able to develop and apply efficient graph algorithms for handling complex systems
- The students shall also to be able to decompose Large systems appropriately and analyze their stability

Overview

Module 1: Structured systems	**Hrs**
Graphs and Dynamic Systems, Input and Output Reachability, Partitions and Condensations, Structural Controllability and Observability, Plant and Feedback Structures, Structurally Fixed Modes.	
Module 2 : Robust --Stabilization	
Connective Stability, Vector Liapunov Functions, Stabilization, Connective Stabilizability,Graph- Theoretic Algorithm	
Module 3: Optimization	
Sub optimality. Complex Systems, Robustness of Suboptimal Control, Optimality and Robustness, Decentrally Optimal Systems.	
Module 4: Estimation and Control	
An Interconnected Observer, Decentralized Feedback, Separation Property, Decentralized Observer, Stochastic Control, Estimation, Incomplete State Information, Structural Perturbations, Degenerate Control.	
Module 5 : Output Control	
Dynamic Output Feedback, Structured Almost Invariant Subspaces, Graph-Theoretic Characterization, Decentralized Stabilizability, Adaptive Control, Known Subsystems, Adaptive Output Feedback	

Module 6: Decomposition Techniques	
Input Decompositions, Stabilization, Input-Output Decompositions, Sequential Optimization, Epsilon Decomposability, Decomposition Algorithm, Control Applications, Nested Connective Stability, Block Diagonal Dominance.	
Module 7: Overlapping Decompositions & Reliable Control	
Preliminaries, The Inclusion Principle, Optimization, Nonlinear Systems, Multiple Control Systems, Reliability of Control Structures, Design of Reliable Control, Maintained Control Systems.	

Recommended Reading

01 "Decentralized Control of Complex Systems"- DragoslavSiljak, Mathem,atics in Science, Vol.184, Academic Press Ltd.

02 "Control of Complex Systems: Structural Constraints and Uncertainty" – Aleksandar Zecevic, Springer Publications, New York, Dordrecht, Hieldeberg, London

03 "Efficient Modeling and Control of Large-Scale Systems" - JavadMohammadpour, Karolos M. Grigoriadis, Springer Publications, New York, Dordrecht, Hieldeberg, London

04 "Decentralized control of large-scale systems",-Edward J Davison; Amir G Aghdam, New York; London: Springer, 2010.

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5103P**
Course Title	**DECENTRALIZED CONTROL LAB**

COURSE OBJECTIVES

- To introduce the students to the idea of and issues related to Complex systems
- To build an appreciation of the need for decentralized information and control structures to enable fast control action in response to local input, and perturbations in large systems
- To interweave theories from optimization, output feedback, graph theory, overlapping decompositions and reliability for analyzing and controlling complex systems.

COURSE OUTCOMES

- Students shall be able study Lypanov stability of any given system.
- Students shall design observer, and analyze non-linear control system using MATLAB
- Students will be able to design and analyze compensators and optimization based controllers.

Overview

1. To Study Lypanov stability of given system.
2. To design an observer.
3. To design decentralized observer.
4. To analyze of nonlinear control system with MATLAB Simulink.
5. To Design lead Lag Compensator.
6. To design optimization based controller.

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I**
Course Code	**EE5104T**
Course Title	***PROGRAM ELECTIVE COURSE 2*** **MATHEMATICAL SYSTEM THEORY**

COURSE OBJECTIVES

- To serve as a prerequisite to the advanced control courses in the syllabus
- An introduction to the fundamental concepts of Linear Algebra and the various mathematical structures used in modern system and control theory.
- To develop the general skill for mathematics, especially for the purpose of the understanding how mathematical theories can be developed from axioms, definitions, theorems and proof.

COURSE OUTCOME

- Understand the concept of linear vector space and concepts like subspace, linear span, linearly independent, set of base vectors, dimension and coordinates.
- Know how to find eigenvalues, eigenvectors and eigenspaces of matrices, and be able to perform such calculations for small matrices and know how to diagonalize a matrix.
- Develop a basic understanding of a broad range of mathematical structures such as groups, rings, modules, finite fields etc. and hence a proper appreciation of their role in the various controls courses in the present syllabus.

Overview

Module 1: Introduction	**Hrs**
Introduction to set theory, mappings and integers	
Module 2: Group Theory	**Hrs**
Group theory, definition of a group ,examples of group, lemmas on groups, subgroups, a counting principal, normal subgroups and Quotient groups, homomorphisms, automorphisms, Cayley's theorem, permutation groups, another counting principal, Sylow's theorem, direct products, finite abelian groups	
Module 3: Ring Theory	**Hrs**
Ring theory, definition and examples of rings ,special classes of rings, homomorphisms, ideal and quotient Rings, The field of quotients of an integral domain, Euclidean rings, a particular Euclidean ring, polynomial rings, polynomial over the rational field, polynomial rings over commutative rings	
Module 4: Vector Spaces and modules	**Hrs**
Vector spaces and modules, elementary basic concepts, linear independence and bases, dual spaces, inner product spaces, modules	
Module 5 : Fields	**Hrs**
Fields, Extension fields, The transcendence of 'e', roots of polynomial s, construction with straightedge and compass, More about roots, The elements of Galois theory, solvability by radicals, Galois groups over the rational	

Recommended Reading

01 I. N. Herstein - Topics in Algebra, 2nd edition, John Wiley & Sons
02 Gilbert Strang - Introduction to Linear Algebra, 4th Edition

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER I
Course Code	**EE5104P**
Course Title	**MATHEMATICAL SYSTEM THEORY LAB**

COURSE OBJECTIVES

- To develop the general skill for mathematics, especially for the purpose of the understanding how mathematical theories can be developed from axioms, definitions, theorems and proof.
- Use Mathematica and Maple as a tool for solving different problems.

COURSE OUTCOMES

- Understand the concept of linear vector space and concepts like subspace, linear span, linearly independent, set of base vectors, dimension and coordinates.

- Know how to find eigen values, eigenvectors and eigen spaces of a matrices, and be able to perform such calculations for small matrices and know how to diagonalize a matrix.

Overview

1. Tutorial related to groups, cyclic groups and permutation groups.
2. Tutorial on Quotient groups, homomorphisms, automorphisms and Cayley's theorem.
3. Tutorial on homomorphisms, ideal and quotient Rings.
4. Tutorial on Fields.
5. Tutorial on basis vector and vector spaces.
6. Tutorials on dual vector space.
7. Tutorial on quotient space.

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	**EE5005S**
Course Title	**RESEARCH METHODOLOGY**

COURSE OBJECTIVES

- To develop understanding of the basic framework of research process, various research designs and techniques.
- To identify various sources of information for literature review and data collection.
- To develop an understanding of the ethical dimensions of conducting applied research.

COURSE OUTCOMES

- Understand research terminology.
- Be aware of the ethical principles of research, ethical challenges and approval processes.
- Describe quantitative, qualitative and mixed methods approaches to research.
- Identify the components of a literature review process.
- Critically analyze published research.

Overview

Module 1: Motivation and importance of research methodology	Hrs
Why research needs to be done, What is research, Research problem formulation, Literature survey, Analysis of the problem, Experimental evaluation of the problem, Survey techniques, Statistical analysis	
Module 2: Presentation of the reports	**Hrs**
Writing of short and long abstracts, Writing and format of international and national journal papers, Report writing	
Module 3: Presentation skill	**Hrs**
English writing and communication skills, Power point and other presentation skills.	
Module 4: Statistics	**Hrs**
Concept of mean mode median arithmetic mean, geometric mean, harmonic mean etc, Probability and problem solving, Distributions: Gaussian, chi-square, student-t distribution, Design of experiment, Hypothesis, testing and identification, Problems on hypothesis testing.	

Recommended Reading

01 Research Methodology: Methods and Techniques : C.R. Kothari

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	**EE5006S**
Course Title	**NON LINEAR SYSTEM ANALYSIS**

COURSE OBJECTIVES

- To introduce students to nonlinear dynamical systems and phenomena with examples drawn from various engineering and scientific domains.
- To provide methods of characterizing and understanding the behavior of systems that can be described by nonlinear ordinary differential equations.
- To develop student understanding of the notion of stability, and familiarity with techniques for testing the stability of nonlinear systems.

COURSE OUTCOME

- The student will gain insight into the complexity of nonlinear systems.
- The student will be able to apply methods of characterizing and understanding the behavior of systems that are described by nonlinear ordinary deferential equations.
- The student will be able to use tools for analysis of nonlinear control systems, including computer-aided analysis (Matlab/Scilab)

Overview

Module 1: Introduction	**04 Hrs**
Introduction to Nonlinear models and nonlinear phenomena, Examples: Pendulum equation, Tunnel diode circuit, Mass-Spring System, Negative Resistance Oscillator, Artificial Neural Network, Adaptive Control.	
Module 2:	**12Hrs**
Second-Order Systems, Qualitative Behavior of Linear Systems, Multiple Equilibria, Qualitative Behavior Near Equilibrium Points, Limit Cycles, Numerical Construction of Phase Portraits, Existence of Periodic Orbits, Bifurcation.	
Module 3: Mathematical Preliminaries	**12 Hrs**
Euclidean Space, Mean Value and Implicit Function Theorems, Gronwall-Bellman Inequality, Contraction Mapping.	
Module 4 :	**12 Hrs**
Lyapunov Stability, Autonomous Systems, The Invariance Principle, Linear Systems and Linearization, Non-autonomous Systems, Linear Time-Varying Systems and Linearization.	
Module 5 :	**08 Hrs**
Input-Output Stability, L Stability, Input-to-Output Stability, L2 Gain, Absolute Stability, Circle Criterion, Popov Criterion, Simultaneous Lyapunov Functions, Srnall-Gain Theorem, Passivity Approach.	

Recommended Reading

1. Hassan K Khalil, “Nonlinear Systems”, 2nd Edition, Prentice Hall.
2. M. Vidyasagar, Nonlinear Systems Analysis, Prentice Hall, Englewood Cliffs, New Jersey, second edition, 1993

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II**
Course Code	**EE5007T**
Course Title	**NON-LINEAR CONTROL DESIGN**

COURSE OBJECTIVE

- Introduce the students to nonlinear feedback control and the modern language of control design for complex systems.
- To expose the students to fundamentals of differential geometry and its application to the synthesis of nonlinear control systems.
- The development of systematic methods addressing outstanding design problems like feedback linearization, no interacting control, disturbance decoupling, and model matching.

COURSE OUTCOME

- For students specializing in nonlinear control theory this course would provide a firm starting point for doing research in this area.
- The student will be able to apply deeper ideas from mathematics and specifically from geometry to engineering problems.
- The student shall be able to analyze and design nonlinear controllers with the aid of software tools such as Maple/Mathematica.

Overview

Module 1 : Introduction	**04 Hrs**
Introduction to Advanced Calculus, Elementary notions of Topology, Smooth Manifolds, Sub-manifolds, Tangent Vectors, Vector Fields	
Module 2:	**12 Hrs**
Distributions, Frobenius Theorem, The Differential Geometric Point of View, Invariant Distributions, Local Decompositions of Control systems, Local Reachability, Local Observability.	
Module 3:	**12 Hrs**
Sussmann’s Theorem and global Decompositions. The Control Lie Algebra, The observation space.	
Module 4:	**12 Hrs**
Local Co-ordinates Transformations, Exact Linearization Via Feedback, The Zero dynamics, Local Asymptotic Stabilization, Asymptotic Output Tracking, Disturbance Decoupling, High Gain Feedback, Additional Results on Exact Linearization, Observers with Linear Error Dynamics.	

Recommended Reading

1. AlbetroIsidori, “Nonlinear Control Systems”,Springer-Verlag,.1995.
2. H. Nijmeijer, Van Der Schaft, “Nonlinear Dynamical Control System”, New York, Springer-Verlag.1995

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	**EE5007P**
Course Title	**NON-LINEAR CONTROL DESIGN LAB**

COURSE OBJECTIVE

- Introduce the students to nonlinear feedback control and the modern language of control design for complex systems.
- To expose the students to fundamentals of differential geometry and its application to the synthesis of nonlinear control systems.
- The development of systematic methods addressing outstanding design problems like feedback linearization, no interacting control, disturbance decoupling, and model matching.

COURSE OUTCOME

The student shall be able to analyze and design nonlinear controllers with the aid of software tools such as Maple/Mathematica.

Overview

Experiment based on design and simulation of the following:

1. To study PID tuning for the given system.
2. To design LQR for the given system.
3. Getting started with MAPPLE.
4. To solve and plot ODE using MAPPLE.
5. To find Lie bracket and lie derivative using MAPPLE.
6. To design a controller for the given system using MAPPLE.

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	**EE5008T**
Course Title	**SYSTEM IDENTIFICATION, ESTIMATION AND FILTERING**

COURSE OBJECTIVE

- The objective of this course is to provide a broad theoretical basis for system identification, estimation, and learning.

COURSE OUTCOME

- Students shall have thorough knowledge of least squares estimation, Kalman filters,
- Students should able to understand and apply function approximation theory, neural nets, radial basis functions, frequency domain analysis, maximum likelihood estimate to the problems
- Student should aware applicability of Cramer- Rao lower bound, Kullback-Leibler information distance, Akaike's information criterion for engineering problems

Overview

Module 1: Estimation	04 Hrs
Recursive Least Square (RLS) Algorithms, Properties of RLS, Random Processes, Active Noise Cancellation, Discrete Kalman Filter-1, Discrete Kalman Filter-2, Continuous Kalman Filter, Extended Kalman Filter.	
Module 2: Representation and Learning	**04 Hrs**
Prediction Modeling of Linear Systems, Model Structure of Linear Time-invariant Systems, Time Series Data Compression, Laguerre Series Expansion, Non-linear Models, Function Approximation Theory, Radial Basis Functions, Neural Networks, Error Back Propagation Algorithm.	
Module 3: System Identification	**12 Hrs**
Perspective of System Identification, Frequency Domain Analysis, Informative Data Sets and Consistency, Informative Experiments: Persistent Excitation, Asymptotic Distribution of Parameter Estimates, Experiment Design, Pseudo Random Binary Signals (PRBS), Maximum Likelihood Estimate, Cramer-Rao Lower Bound and Best Unbiased Estimate, Information Theory of System Identification: Kullback-Leibler Information Distance, Akaike's Information Criterion.	

Recommended Reading

1. Ljung, Lennart. *System Identification: Theory for the User*. 2nd ed. Upper Saddle River, NJ: Prentice-Hall, 1999.
2. Goodwin, Graham, and Kwai Sang Sin. *Adaptive Filtering, Prediction, and Control*. Englewood Cliffs, NJ: Prentice-Hall, 1984.
3. Burnham, Kenneth, and David Anderson. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. 2nd ed. New York, NY: Springer, 2003.
4. Brown, Robert, and Patrick Hwang. *Introduction to Random Signals and Applied Kalman Filtering*. 3rd ed. New York, NY: Wiley, 1996.

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II**
Course Code	**EE5008P**
Course Title	**SYSTEM IDENTIFICATION, ESTIMATION AND FILTERING LAB**

COURSE OBJECTIVE

- The objective of this course is to provide a broad theoretical basis for system identification, estimation, and learning.

COURSE OUTCOME

- The student shall be able to design and implement various filters and controllers for engineering applications.

Overview

1. To find autocorrelation for a given function
2. To implement KALMAN filter using Scilab
3. To implement EKF using Scilab
4. To implement UKF using Scilab
5. To design learning controller.
6. To design adaptive controller.

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	EE5111S
Course Title	*ELECTIVE 3*: MULTIVARIABLE CONTROL

COURSE OBJECTIVE

- The objective of this course is to introduce the students to the analysis and design techniques of feedback Control for multivariable systems from an external description approach (input-output).
- A special emphasis on the use of feedback to reduce system sensitivity to perturbations and uncertainties.
- To introduce the methods for model reduction and the problems those appear in controller's implementation.

COURSE OUTCOME

- The student shall be able to use the basics of linear classical control and linear Multivariable control in continuous time systems
- the students shall be able to analyse the benefits and limitations of control systems and their applications

Overview

Module 1: Introduction	Hrs
The process of control system, The Control Problem, Transfer functions, Scaling, Driving linear Models	
Module 2: Classical feedback Control	
Frequency response, feedback control, Close loop stability, evaluating Close loop performance, controller design, loop shaping, shaping close loop transfer function.	
Module 3: Multivariable control	
Introduction, Transfer function of MIMO system, Multivariable frequency response analysis, Control of multivariable plants, Introduction to multivariable RHPzeros, Condition number and RGA, Introduction to robustness, General control problem formulation.	
Module 4: Elements of linear system theory	
Static and dynamic background modeling - frame subtraction- optical flow techniques- Handling occlusion- scale and appearance changes - Shadow removal.	

Recommended Reading

1. W. Murray Wonham, "Linear Multivariable Control: A Geometric Approach", Springer-VerlagBerlin.Heidelberg. Newyork 1974.
2. F.R. Gantmakher, "The Theory of Matrices." Vol 1, Chelsea, New York, 1959.
3. E.G..Gilbert, "Controllability and observability in multivariable control systems." SIAM J. Control 1(2), 1963,pp. 128-151

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II**
Course Code	**EE5112S**
Course Title	***ELECTIVE 3*: HIGH PERFORMANCE ELECTRICAL DRIVES**

COURSE OBJECTIVE

- To explain the basic building blocks of high performance electrical drives.
- To develop mathematical models of AC & DC machines & use these models for designing high performance drives.
- To impart a thorough understanding of power electronic converters for drives & Controller design also.

COURSE OUTCOME

- Students should be able to identify the various building blocks of electrical drives & suggest improvements /additions to make it a high performance drive.
- Students should be able to model AC & DC machines & use these models to evaluate the performance of drives.
- Students should be able to design controllers for better parameter control in drives.

Overview

Module 1: Introduction	**05 Hrs**
Module 2: Modeling of DC machines	**10 Hrs**
Module 3: Phase-controlled DC Motor Drives	**10 Hrs**
Module 4: Chopper-controlled DC Motor Drives	**05 Hrs**
Module 5: Permanent-Magnet Synchronous & Brushless DC Motor Drives	**05 Hrs**
Module 6: Polyphase Induction Machines	**05 Hrs**
Module 7: Phase-controlled Induction Motor Drives	**05 Hrs**
Module 8: Frequency-controlled Induction Motor Drives	**05 Hrs**
Module 9: Vector-controlled Induction Motor Drives	**05 Hrs**

Recommended Reading

1) R Krishnan, Electric Motor Drives Modelling Analysis and Control
2) B K Bose, Power Electronics for AC drives
3) G K Dubey, Electrical Drives

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II**
Course Code	**EE5113T**
Course Title	***ELECTIVE 4*: INTELLIGENT CONTROL THEORY**

COURSE OBJECTIVES

- To explore soft computing tools for intelligent control.
- To study fuzzy logic and its role in developing control strategy.
- To apply artificial neural network and neuro-fuzzy tools for system identification and control

COURSE OUTCOME

- Student shall be able to design fuzzy logic based controller.
- Student shall be able to apply supervised and unsupervised neural network learning strategies.
- Student shall be able to apply neuro-fuzzy tools for other control specific applications like interpolation, fault detection etc .

Overview

Module 1: Biological foundations to intelligent systems I	**04 Hrs**
Artificial neural networks, Back-propagation networks, Radial basis function networks, and recurrent networks.	
Module 2: Biological foundations to intelligent systems II	**12 Hrs**
Biological foundations to intelligent systems II: Fuzzy logic, knowledge representation and inference mechanism, genetic algorithm, and fuzzy neural networks.	
Module 3: Fuzzy control	**12 Hrs**
Fuzzy and expert control (standard, Takagi-Sugeno, mathematical characterizations, design example), Parametric optimization of fuzzy logic controller using genetic algorithm.	
Module 4: System identification	**12 Hrs**
System identification using neural and fuzzy neural networks.	
Module 5: Stability analysis	**12 Hrs**
Lyapunov stability theory and Passivity Theory.	
Model 6: Adaptive Control	
Adaptive control using neural and fuzzy neural networks, Direct and Indirect adaptive control, and Self-tuning Pill Controllers.	

Recommended Reading

1) Stanislaw H. Zak, Systems and Control, Oxford University Press, 2003.
2) A.S. Poznyak, E. N. Sanchez and Wen Yu, Differential Neural Networks for Robust Nonlinear Control, World Scientific, 2001.
3) Kevin M. Passino and Stephen Yurkovich, Fuzzy Control, Addison Wesley Longman, Menlo Park, CA, 1998.

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	**EE5113P**
Course Title	**INTELLIGENT CONTROL THEORY LAB**

COURSE OBJECTIVES

- To explore soft computing tools for intelligent control.
- To study fuzzy logic and its role in developing control strategy.
- To apply artificial neural network and neuro-fuzzy tools for system identification and control.

COURSE OUTCOME

- Student shall be able to design fuzzy logic based controller
- Student shall be able to apply supervised and unsupervised neural network learning strategies using MATLAB.

Overview

1. To plot output for a given Neural Network for a given range of inputs
2. Classification of linear separable data using perceptron
3. To design Basic Logic Gates using Neural Networks.
4. To Design XOR gate using multi-layer perceptron
5. To study back propagation neural network for data forecasting
6. To design fuzzy logic controller for the given system

Programme Name	**M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II**
Course Code	**EE5114T**
Course Title	***ELECTIVE 4*: EMBEDDED CONTROL SYSTEM DESIGN**

COURSE OBJECTIVE

- To present a unified theory for control system design that captures the essential issues and can be applied for a wide range of practical problems.
- Learn the roles and responsibilities of innovation project engineers in companies that design and develop such embedded control systems.
- Systems-level thinking: every part of the system is selected and tuned for the goals of the whole system.
- Roadmap-driven development process.

COURSE OUTCOME

- Students should be able to understand Interaction between the control design and control implementation
- Students should able to do modelling of systems.
- Understanding of what an embedded system R&D project is, and the activities it involves.

COURSE SYLLABUS

Module 1: Embedded Systems – Basic Concept	**05 Hrs**
The Main Architecture of Embedded Control Systems, Communication Networks in Embedded Systems, Planning Embedded System Development	
Module 2: Introduction into Embedded Control System Design	**10 Hrs**
Requirements for Control System Design, Mathematical Models for Control, Control System's Characteristics, Performance Specifications for Linear Systems.	
Module 3: System Identification and Model-Order Reduction	**10 Hrs**
Model Building and Model Structures, Input Signal Design for System Identification, Model Validation in Time and Frequency Domain, Model-Order Reduction Methods,	
Module 4: Classical Controller Design	**05 Hrs**
Controller Design Based on Pole-Zero Cancellation, Root Locus Technique, PID, Controller Design for Systems with Time Delays, Disturbance Rejection, and Validation of the Control Systems	
Module 5: Embedded Safety Loop Development	**05 Hrs**
Classification of Faults, Calculation of Probability of Failure on Demand, Software Testing and Validation	

Recommended Reading

1. Alexandru Forrai, "Embedded Control System Design A Model Based Approach", Mitsubishi Elevator Europe Veenendaal The Netherlands—Springer.
2. Adamski, Marian Andrzej, Karatkevich, Andrei, Wegrzyn, Marek , "Design of Embedded Control Systems", Springer

Programme Name	M. Tech. (Electrical Engineering with specialization in Control Systems), SEMESTER II
Course Code	EE5114P
Course Title	EMBEDDED CONTROL SYSTEM DESIGN LAB

COURSE OBJECTIVE

- Study of different Software
  - MATLAB® and SciLab for model simulation.
  - Arduino, Keil compiler and flash magic for embedded systems.
- To perform experiments on the Embedded open source Arduino Board.
- To perform experiments in MATLAB®, SciLab for Model verification and simulation

COURSE OUTCOME

- Students should be able to do Embedded programming.
- Students should be able to design and develop basic embedded control strategies.
- Students should get introduced with practical implementation of basic control system in different form.

1. Study of Software
   - System modeling and validation: MATLAB®, SciLab.
   - Embedded system: Arduino, Keil, Flash Magic.
     - How to model, debug, and troubleshoot.
     - Embedded C-code compile and Test.
     - Testing of interface

2. Embedded Open-source Development Kit: To study Arduino Open-source Boards, Arduino, MATLAB® Interface, Testing and troubleshooting

3. Embedded Programming: Programming of Arduino, MATLAB®/SciLab Algorithm design and C code generation.

4. Embedded Communication System design: - Verification of Communication Protocol like, CAN, Zigbee etc.

5. Embedded Testing:-Logic Analyzer for Embedded Testing.

6. Embedded Controller: PID Algorithm design testing and implementation in Arduino Development Board.

7. Embedded control application: motor speed control PWM.

8. Embedded control application: Quadrotor PID Control.