CURRICULUM & SYLLABI

M.Tech. CONTROL & AUTOMATION

Effective from AY: 2024-25



NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

WARANGAL, TELANGANA

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Vision and Mission of the Institute
National Institute of Technology Warangal

VISION

Towards a Global Knowledge Hub, striving continuously in pursuit of excellence in Education, Research, Entrepreneurship and Technological services to the society

MISSION

- Imparting total quality education to develop innovative, entrepreneurial and ethical future professionals fit for globally competitive environment.
- Allowing stake holders to share our reservoir of experience in education and knowledge for mutual enrichment in the field of technical education.
- Fostering product-oriented research for establishing a self-sustaining and wealth creating centre to serve the societal needs.

Vision and Mission of the Department
Electrical Engineering

VISION

To excel in education, research and technological services in electrical engineering in tune with societal aspirations.

MISSION

- Impart quality education to produce globally competent electrical engineers capable of extending technological services.
- Engage in research & development in cutting edge and sustainable technologies.
- Nurture scientific temperament, professional ethics and industrial collaboration.

Program: M.Tech. Control & Automation

Program Educational Objectives

PEO-1	Pursue successful industrial, academic and research careers in specialized fields of control, automation and inter-disciplinary areas
PEO-2	Apply the knowledge of advanced topics in automation and control engineering to meet contemporary needs of industry and research.
PEO-3	Communicate effectively to propagate ideas and promote teamwork
PEO-4	Attain professional competency to address the technological needs of society and industry.

Program Articulation Matrix

PEO / Mission Statements	PEO-1	PEO-2	PEO-3	PEO-4	PEO-5
Impart quality education to produce globally competent electrical engineers capable of extending technological services	3	3	3	2	3
Engage in research & development in cutting edge and sustainable technologies	3	3	2	3	3
Nurture scientific temperament, professional ethics and industrial collaboration	3	3	2	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Program Outcomes

PO-1	**Develop** scientific temperament and rational thinking abilities to pursue research and tackle complex problems related to control & automation.
PO-2	**Communicate** with technical communities on engineering issues while creating awareness for all sections of society.
PO-3	**Employ** the knowledge of control & automation to contribute towards the development of products / technologies which require a team with multidisciplinary expertise.
PO-4	**Develop** eco-friendly and sustainable technologies using the knowledge of control & automation.
PO-5	**Cultivate** an attitude of self-learning to cope with ever changing tools and technologies and be productive throughout his / her career.
PO-6	**Foster** a temperament to manage projects, organizations and entrepreneurial ventures maintaining financial integrity and professional ethics.

CURRICULUM
M.Tech. Control & Automation

1st Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE46001	Linear Control System	3-0-0	3
2	CH16061	System Identification & Adaptive Control	3-0-0	3
3	EEXXXX	Professional Elective –I	3-0-0	3
4	EEXXXX	Professional Elective –II	3-0-0	3
5	CHXXXX	Professional Elective -III	3-0-0	3
6	EE46003	Linear Control Systems Lab	0-1-2	2
7	CH16063	System Identification & Adaptive Control Lab	0-1-2	2
			Total Credits	**19**

2nd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE46002	Non-linear dynamical systems	3-0-0	3
2	CH16060	Advanced Process Control	3-0-0	3
3	EEXXXX	Professional Elective –IV	3-0-0	3
4	EEXXXX	Professional Elective –V	3-0-0	3
5	CHXXXX	Professional Elective – VI	3-0-0	3
6	EE46004	Advanced Control System Lab	0-1-2	2
7	CH16062	Process Control & Automation Laboratory	0-1-2	2
8	EE46096	Minor Project	0-0-0	2
			Total Credits	**21**

3rd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE46089	Seminar and Technical Writing	0-0-0	2
2	EE46091	Summer Internship/Research Experience	0-0-0	2
3	EE46093	Comprehensive Viva-Voce	0-0-0	2
4	EE46097	Dissertation: Part-A	0-0-0	8
			Total Credits	**14**

4th Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE46098	Dissertation: Part-B	0-0-0	12
			Total Credits	**12**

Professional Elective Courses

Professional Electives- I, II & III		
S.No.	**Code**	**Course Title**
1	EE46021	Industrial Automation
2	EE46023	Embedded Control Systems
3	EE46025	Autonomous Vehicles & Drones
4	EE46027	Multivariable Control Systems
5	EE46029	Guidance & Control of Aerodynamic System
6	EE46031	Robust Control System
7	CH16035	Industrial Instrumentation
8	CH16065	Performance assessment and Plant wide control
9	CH16067	Data-driven Control
10	CH16069	Fractional order systems and control
11	CH16071	Quantitative Feedback theory
12	CH16073	Statistical Process Control
Professional Electives- IV, V & VI		
S.No.	**Code**	**Course Title**
1	EE46022	Optimal and Robust Control Systems
2	EE46024	Digital Control Systems
3	EE46026	Networked Control Systems
4	EE46028	Cyber-Physical Systems
5	EE36028	Industrial Internet of Things
6	EE26032	Machine Learning applications in Power Engineering
7	CH16024	Engineering Optimization
8	CH16064	Automotive Control systems
9	CH16066	Estimation & Filtering Techniques
10	CH16068	Multi Sensor Data Fusion
11	CH16070	Learning based Control systems
12	CH16072	Intelligent Control

The Overall Credit Structure

Credits in Each Semester					
	I Sem	**II Sem**	**III Sem**	**IV Sem**	**Total**
Core courses(PCC)	10	10	0	0	20
Elective courses (PEC)	9	9	0	0	18
Seminar and Technical Writing	0	0	2	0	2
Minor Project	0	2	0	0	2
Summer internship/ research experience	0	0	2	0	2
Comprehensive Viva-Voce	0	0	2	0	2
Dissertation: Part-A	0	0	8	0	8
Dissertation: Part-B	0	0	0	12	12
Total credits (Sem. wise)	**19**	**21**	**14**	**12**	**66**

SYLLABI

M.Tech: Control and Automation

1st Semester

EE46001 **3-0-0 (3)**

Linear Control System

Pre-Requisites: None

Course Outcomes:

CO-1	Model the dynamical systems using the state-space concept.
CO-2	Solve the state space equation and perform the stability analysis
CO-3	Design the state feedback controller for linear state space systems.
CO-4	Implement the observer based controller concept and optimal control problem

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	2	1	1
CO-2	2	-	3	2	1	1
CO-3	2	-	3	2	1	1
CO-4	2	-	3	2	1	1

1 - Slightly; - Moderately; 3 – Substantially

Syllabus:

Mathematical modelling of LTI control systems: impulse response model, differential equation model, transfer function model, frequency response model, state space model-Introduction to state and state variables – State space - physical systems - Representation using state space approach- Modelling of electrical systems

Control system Analysis in state space: State space representations of transfer functions, Solution of state space equation- State transition matrix -Matrix exponential-Controllability and observability

Control system Design in State space: Pole placement approach to Regulator design-Full order observer- Observer based regulator design-

Stability concept: Stability in the sense of Lyapunov - stability of linear systems – Lyapunov equation-Generation of Lyapunov functions-Krasovskii's method Quadratic optimal control-Lyapunov's approach to quadratic optimal regulator design.

Learning Resources:

Text Books:

1. Katsuhiko Ogata , Modern control Engineering, Pearson Education India, 2020, 5th Edition.
2. M. Gopal, Modern Control Systems Theory, New Age International Publisher, 2023, 5th Edition.

Reference Books:

1. P.J. Antsaklis, A.N. Michel, A Linear Systems Primer, Birkhauser Boston Inc, 2007, 1st Edition.
2. Roy Choudhary, Modern Control Engineering, Prentice Hall India, 2005, 1st Edition.
3. Brogan W. L, Modern Control Theory, Prentice Hall, 2011, 3rd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108106150
2. https://nptel.ac.in/courses/101108057

CH16061 **3-0-0 (3)**

System Identification & Adaptive Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Develop mathematical models of various engineering and physical systems using classical and energy approach.
CO-2	Apply system identification concepts for different engineering system
CO-3	Estimate system parameters using regression analysis
CO-4	Synthesis the adaptive controller for different engineering systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	2	2	1
CO-2	2	-	2	2	2	2
CO-3	3	-	3	2	2	1
CO-4	3	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

System Modelling approaches: Modeling by first principle approach of simple mechanical, electrical, thermal, chemical systems. Energy approach based modelling using Euler-Lagrangian and Hamiltonian methods.

Representation of dynamical systems: Linearization of nonlinear models- state space approach for analyzing the dynamic models: Continuous time and discrete time system- Z-transform-Models of Discrete-Time Linear Time invariant (LTI) Systems – Difference equations- Stability of Discrete time LTI system-Discretization, Sampling and Hold operations, Sampling theorem.

Discrete time series models: Finite Impulse Response (FIR) and Auto regressive exogeneous (ARX) models- Parametric model structures – ARX by least square estimation, Auto Regressive Moving Average exogeneous (ARMAX), Output Error (OE), Box Jenkins (BJ) models.Regression methods: Non-parametric models based on impulse response, step response and frequency response models.Estimating parameters in Dynamical Systems, Experimental conditions, Prior information, maximum likelihood estimation (MLE), Recursive least square (RLS),Instrument variable method.

Deterministic Self tuning regulators (STR): Pole placement design, Indirect self tuning regulators, Continuous time self tuners, Direct self tuning regulators, disturbances with known characteristics.

Model reference adaptive control (MRAS): The MIT Rule, Determination of adaptation gain, Lyapunov theory, Design of MRAS using Lyapunov theory, BIBO stability, Output feedback, Relations between MRAS and STR.

Learning Resources:

Text Books:

1. L. D. Landau, R. Lozano, M. M'Saad, A. Karimi, Adaptive Control: Algorithms, Analysis and Application, Springer, 2013, 2nd Edition.
2. Sankar Sastry, Marc Bodson, Adaptive Control: Stability, Convergence and Robustness, Springer, 2011, 1st Edition.
3. A.K. Tangirala, Principles of System Identification: Theory and Practice, CRC Press, 2017,1st Edition.

Reference Books:

1. P.A. Ioannou, J. Sun, Robust Adaptive Control, Dover Publications, 2013, 1st Edition.
2. K. J. Astrom, B. Wittenmark, Adaptive Control, Pearson Education, 2008, 2nd Edition.
3. P.A. Ioannou, B. Fidan, Adaptive Control Tutorial, SIAM, 2007, 11th Edition.
4. K. Ogata, System Dynamics, Pearson Education India, 2014, 4th Edition.
5. Karel J. Keesman, System Identification – An Introduction, Springer, 2011, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108102113
2. https://nptel.ac.in/courses/112101312
3. https://nptel.ac.in/courses/112104158
4. https://nptel.ac.in/courses/108105056
5. https://nptel.ac.in/courses/103106149

EE46003 **0-1-2 (2)**

Linear Control System Lab

Pre-Requisites: **None**

Course Outcomes:

CO-1	Formulate and Design the optimal controllers for complex robotic and aircraft system
CO-2	Design the state feedback controller for Power converter and Servo system
CO-3	Perform stability analysis and multivariable controller design for Helicopter
CO-4	Design the state observer for different engineering systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	2	1	3	2
CO-2	2	-	2	1	3	2
CO-3	3	-	2	1	2	2
CO-4	3	-	3	1	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. State feedback controller design for Power converters system
2. Synthesis of State observer based feedback gain controller for Position control system
3. Design of State feedback gain based Integral controller for Power converter system
4. Design of Infinite horizon Linear quadratic regulator (LQR) for robotic manipulator
5. Position Controller design for DC Servo system using Pole placement approach
6. Cascade Control scheme for DC Servo system: Speed and Position control
7. State feedback based controller for angular position of Inverted Pendulum
8. LQR based position controller design for Unstable Magnetic levitation System
9. LQR based disturbance rejection controller design for Rotary flexible link system
10. Design of Multivariable controller for 2-DOF (pitch and yaw axis) Helicopter setup
11. Two degree of freedom controller for Industrial plant emulator position control system

Learning Resources:

Reference Books:

1. A.E. Bryson, Yu-Chi Ho, Applied Optimal Control: Optimization, Estimation and Control, CRC Press, 2018, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105019

CH16063 **0-1-2 (2)**

System Identification & Adaptive Control Lab

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify models for Single Input Single Output (SISO) systems
CO-2	Evaluate Identification methods for Multi Input Multi Output (MIMO) systems
CO-3	Design of adaptive controllers for identified models
CO-4	Apply identification and control methods on nonlinear processes

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	3	1	2
CO-2	3	-	3	3	1	2
CO-3	3	-	3	3	1	2
CO-4	3	-	3	3	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. Simulate and compare different identification methods for SISO systems
2. Simulate and compare different identification methods for MIMO systems
3. Identification of minimum and non-minimum phase systems using relay feedback
4. Identify and design controller for SISO processes with noisy data
5. Identify and design controller for MIMO processes with noisy data
6. Data based model development and control for conical tank process
7. Data based model development and control for spherical tank process
8. Data based model development for MIMO conical tank process
9. Simulate different identification methods and adaptive control strategies on different processes

Learning Resources:

Reference Books:

1. Karel J. Keesman, System Identification – An Introduction, Springer, 2015, 2nd Edition.
2. Lennart Ljung, System Identification: Theory for the User, Pearson education, 1997, 2nd Edition.
3. Rolf Isermann and Marco Munchhof, Identification of Dynamic Systems: An Introduction with Applications, Springer, 2011, 1st Edition.

2nd Semester

EE46002 **3-0-0 (3)**

Nonlinear Dynamical Systems

Pre-Requisites: **EE46001**

Course Outcomes:

CO-1	Characterize the features of nonlinear dynamical systems
CO-2	Analyze the stability of linear and nonlinear system using Lyapunov method
CO-3	Apply the describing function concept to approximate the hard nonlinearities
CO-4	Design the nonlinear controllers using different methods for nonlinear system

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	2	2	1
CO-2	2	-	3	2	2	1
CO-3	2	-	3	3	2	1
CO-4	2	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Characteristics of nonlinear systems, classification of equilibrium points, Phase plane analysis, limit cycles, analysis of systems with piecewise constant inputs, perturbation techniques, periodic orbits, stability of periodic solutions, singular perturbation model, slow and fast manifolds.

Lyapunov Stability: Stability of Nonlinear Systems - Lyapunov stability, local stability, local linearization and stability in the small, Direct method of Lyapunov, generation of Lyapunov function for linear and nonlinear systems, variable gradient method, Centre manifold theorem, region of attraction, Invariance theorems - Input output stability, L_2 stability, Lyapunov based design, Lyapunov redesign, Robust stabilization, Lyapunov stability analysis for Discrete time linear system.

Harmonic Linearization and Describing Function Method: Harmonic linearization, describing function (DF) of standard nonlinearities, study of limit cycles (amplitude and frequency) using Single Input DF, Dual Input Describing function, study of sub- harmonic oscillations, correction on describing functions.

Feedback Stabilization: Analysis of feedback systems, Circle Criterion, Popov Criterion, Multiplier method, simultaneous Lyapunov functions, Feedback linearization, stabilization, regulation via integral control, gain scheduling, input state linearization, input output linearization, Input to state stability (ISS), Backstepping method.

Learning Resources:

Text Books:

1. Hassan K. Khalil, Nonlinear Control, Pearson Education, 2019, 1st Edition.
2. A Isidori, Nonlinear Control systems, Springer verlag, 2014, 4th Edition.

Reference Books:

1. H. Nijmeijer, A.J. Vander Schaft, Nonlinear Dynamic control Systems, Springer, 2016,1st Edition.
2. H. Marquez ,Nonlinear Control Systems: Analysis and Design, Wiley-Interscience, 2008, 1st Edition.
3. W.M. Haddad, V. Chellabonia, Nonlinear Dynamical Systems and Control: A Lyapunov-Based Approach, Princeton University Press, 2008, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108101002
2. https://nptel.ac.in/courses/108106024
3. https://nptel.ac.in/courses/112101429

CH16060 **3-0-0 (3)**

Advanced Process Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify controlled and manipulated variables of the process
CO-2	Design regulatory control scheme for a given process
CO-3	Analyse the controlled and manipulated variables in multivariable processes.
CO-4	Design the linear and nonlinear model predictive control for a given system

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	1	2	2
CO-2	2	-	3	1	2	1
CO-3	2	-	3	1	2	1
CO-4	3	-	3	1	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Hierarchy of control layers, Selection of controlled and manipulated variables. System linearization; state space and transfer function models, Controllability, Observability..

Regulatory control schemes: Cascade control, feed-forward control, ratio control, split-range control, time delay compensator, and inverse response compensator.

Multivariable control: Challenges; Control pairing; Interactions in closed-loop systems; Relative Gain Array (RGA) and variants. Centralized, decentralized, decoupled control schemes. Directionality, Design examples.

Model Predictive Control (MPC): Concepts; Theory and implementation; Relation with Linear Quadratic regulator(LQR) control. Implementation of MPC, State update and model prediction. Receding Horizon implementation; Issues and Challenges, Design examples.

Extensions of MPC: Economic MPC, Nonlinear Model Predictive Control (NMPC) – Theory and implementation. Controller performance assessment and diagnosis – minimum variance benchmark.

Learning Resources:

Text Books:

1. D. E.Seborg, T. F. Edgar, D. AMillechamp,.F.J. Doyle III, Process Dynamics and Control, Wiley, 2016, 4th Edition.
2. R. Rengaswamy, B.Srinivasan, N. P. Bhatt, Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, CRC Press, 2020,1st Edition.

Reference Books:

1. F. Borrelli, A. Bemporad, M.Morari, Predictive Control for Linear and Hybrid Systems, Cambridge University Press, 2017, 1st Edition.
2. J-P Corriou , Process Control: Theory and Applications, Springer, 2018, 2nd Edition.
3. L. Wang, Model Predictive Control System Design and Implementation using MATLAB, Springer, 2009, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/103101003
2. https://nptel.ac.in/courses/103101142

EE46004 **0-1-2 (2)**

Advanced Control System Lab

Pre-Requisites: None

Course Outcomes:

CO-1	Apply feedback linearization strategies to control the engineering system
CO-2	Design and implement the robust controller for mechatronic system
CO-3	Apply the optimal control scheme for complex engineering system
CO-4	Synthesis a robust sliding mode controller for power converter

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	2	3	1
CO-2	2	-	3	1	2	1
CO-3	2	-	3	2	2	1
CO-4	3	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments:

1. Study on phase portrait for different linear system
2. Design of feedback linearization based control for Mechatronic system
3. Synthesis the Backstepping approach based controller for robotic system
4. Lyapunov redesign method based controller for mechatronic system
5. Motion control of an Industrial Plant Emulator System using loopshaping approach
6. Dynamic Programming based Stabilization of an Aircraft
7. Pontryagin's Maximum Principle based optimal control of robot path planning
8. H-infinity based robust controller design for mechatronic system
9. QFT based robust controller design for Power converters
10. Vehicle suspension control system design using the QFT approach.
11. Design of sliding mode controller (SMC) for Power converter

Learning Resources:

Reference Books:

1. A.E. Bryson, Yu-Chi Ho, Applied Optimal Control: Optimization, Estimation and Control, CRC Press, 2018, 1st Edition.
2. Mario Garcia-Sanz, Robust Control Engineering: Practical QFT Solutions, CRC Press, 2017, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108106150

CH16062 **0-1-2 (2)**

Process Control and Automation Lab

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply the identification concepts for linear systems.
CO-2	Design the controllers for linear systems.
CO-3	Identify and control the interacting processes.
CO-4	Apply feed-forward and ratio control schemes on the given process.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	1	2	2
CO-2	3	-	3	1	3	2
CO-3	3	-	3	1	3	1
CO-4	3	-	3	1	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments:

1. Feed forward control for temperature process.
2. Ratio control for linear system
3. Interaction analysis in a coupled tank system.
4. Identification and PID control of level in a coupled tank system.
5. Design of cascade control system for level/flow process.
6. Data driven model development for a spherical tank process
7. Control of level in a spherical tank process.
8. Data driven model development for a SISO conical tank process
9. Control of level in an SISO conical tank process.

Learning Resources:

Reference Books:

1. J-P Corriou , Process Control: Theory and Applications, Springer, 2018, 2nd Edition.
2. Liuping Wang, Model Predictive Control System Design and Implementation using MATLAB, Springer, 2009, 1st Edition.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc21_ge01/preview

EE46096 **0-0-0 (2)**

Minor Project

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world projects
CO-2	Plan and monitor project tasks individually or as a team
CO-3	Demonstrate practical experience in project execution
CO-4	Communicate project findings clearly through reports and presentations

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	1	3	1
CO-2	2	1	2	1	3	1
CO-3	2	3	2	1	3	1
CO-4	2	3	2	1	3	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real world or relevant problems and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel can decide the suitability and worthiness of the project.

Learning Resources:

1. Journal and conference papers from reputed publishers such as IEEE, Elsevier, and Wiley.
2. Research Articles / Reports available on Internet.

3rd Semester

E46089 **0-0-0 (2)**

Seminar and Technical Writing

Pre-Requisites: **None**

Course Outcomes:

CO-1	Consolidate ideas based on expert talks attended
CO-2	Prepare a well-organized report employing elements of critical thinking and technical writing
CO-3	Demonstrate the ability to describe, interpret and analyze the subject matter and develop competence in presenting

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	1	2	2
CO-2	2	1	1	1	2	2
CO-3	2	1	3	1	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Seminar and Technical Writing, every student is expected to prepare a well-organized report based on one / all of the following:

- by attending at least 5 expert lectures/ invited talks/ Seminar/ Popular lectures etc. organized by the institute/any of the departments, ideally in a specific domain or with the same theme.
- prepare a business or marketing plan based on patent search

The student is expected to consolidate the ideas from these lectures/patent searches and may even include material from other sources to strengthen the content of the report. The student should prepare a well-organized report based on the above and present it to the panel constituted by the department, for evaluation.

Learning Resources:

1. Journal and conference papers from reputed publishers such as IEEE, IET, Elsevier, and Wiley.
2. Research Articles / Reports available on Internet.

EE46091 **0-0-0 (2)**

Summer Internship/Research Experience

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world problems, gaining practical experience
CO-2	Plan, manage and execute the work with ethical consideration
CO-3	Review the social and environmental impact of the work
CO-4	Communicate the learnings through report and presentation

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	2	2	3	2
CO-2	1	1	2	2	3	3
CO-3	1	2	2	2	3	2
CO-4	1	3	2	2	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Every student has to undergo either a Summer Internship / Research project. The summer internship may be undergone in an Industry/Research organization or any premier academic Institution, including NIT Warangal for 6-8 weeks. The research project shall be registered under the guidance of any faculty member in the institute. The student is required to submit a report and present the work before an evaluation committee, nominated by the Head of the Department.

Learning Resources:

1. Journal and conference papers from reputed publishers such as IEEE, IET, Elsevier, and Wiley.
2. Research Articles / Reports available on Internet.

EE46093 **0-0-0 (2)**

Comprehensive Viva-Voce

Pre-Requisites: **None**

Course Outcomes:

CO-1	Comprehend the knowledge gained in the course work
CO-2	Demonstrate the ability in problem solving
CO-3	Communicate effectively using engineering terminology

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	1	1	2	-
CO-2	1	2	1	1	2	-
CO-3	1	3	1	1	2	-

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Comprehensive viva-voce each student will be evaluated for their overall comprehension of the course work and laboratory training that they have undergone. The students will be expected to answer questions orally, write down simple equations, draw plots, schematics, write simple code etc. as questioned by the panel. Assessment will be done by the panel based on the student response.

Learning Resources:

1. Reading Material of all the courses.
2. Case Studies/Industrial training reports
3. Minor projects taken up.

EE46097 **0-0-0 (8)**

Dissertation: Part-A

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify a topic in advanced areas of Electrical Engineering
CO-2	Review literature to identify gaps and define objectives and scope of the work
CO-3	Employ the ideas from literature and develop research methodology
CO-4	Develop a model, experimental set-up and / or computational techniques necessary to meet the objectives

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	1	1	3
CO-2	3	2	3	1	1	3
CO-3	3	3	3	3	3	3
CO-4	3	3	3	3	3	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – A will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria

The student will be evaluated by the panel based on the below criteria. Weightage for each criterion will be determined by the panel and will be informed to the students.

Criteria	Description	Weightages
I	Selection of Topic	10
II	Literature Survey	25
III	Defining the Objectives and Solution Methodology	35
IV	Performance of the Task	30

Evaluation Criteria - CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4
I	**X**			
II		**X**		
III			**X**	
IV				**X**

Refer to the M.Tech. – Regulations for any further information regarding mid-term review and end semester evaluation, etc.

4th Semester

EE46098 **0-0-0 (12)**

Dissertation: Part-B

Pre-Requisites: None

Course Outcomes:

CO-1	Identify the materials and methods for carrying out experiments/develop a code.
CO-2	Execute the research methodology with a concern for society, environment and ethics
CO-3	Analyse, discuss and justify the results/trends and draw valid conclusions.
CO-4	Prepare the report as per recommended format and present the work orally adhering to stipulated time.
CO-5	Explore the possibility to publish/present a paper in peer reviewed journals/conference proceedings without plagiarism.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	3	2	3
CO-2	2	-	3	3	2	3
CO-3	3	-	3	3	2	3
CO-4	3	3	3	3	3	3
CO-5	3	3	3	-	-	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – B will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria as a continuation of Dissertation Part A. Weightage for each criterion will be determined by the panel and will be informed to the students.

Task	Description	Weightages
I	Performance of the Task	30
II	Dissertation Preparation	20
III	Review (Presentation & Understanding)	30
IV	Viva-Voce	10
V	Publications /Possibility of publication	10

Evaluation Criteria-CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4	CO5
I	**X**	**X**			
II				**X**	
III			**X**		
IV				**X**	
V					**X**

Refer to the M.Tech. – Regulations for any further information regarding mid-term review, end semester evaluation, template for report preparation and plagiarism guidelines etc.

Professional Electives

EE46021 **3-0-0 (3)**

Industrial Automation

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the impact and architecture of industrial automation systems
CO-2	Develop the PLC programming for processes.
CO-3	Analyse and understand the different industrial bus protocols
CO-4	Apply SCADA and DCS for processes.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	2	3	1	1
CO-2	2	-	2	3	1	1
CO-3	2	-	2	3	1	2
CO-4	2	-	2	3	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Impact of automation on process industries, architecture of industrial automation systems, Data loggers, Data Acquisition Systems (DAS), Direct Digital Control (DDC). Supervisory Control and Data Acquisition Systems (SCADA), sampling considerations. Computer control systems. Alarms, interrupts. Characteristics of digital data, Piping & Instrumentation diagram (P&ID) for process.

Programmable logic controller (PLC): Definition, overview of PLC systems, input/output modules, power supplies, isolators. General PLC programming procedures, Ladder logic diagram, Auxiliary commands and functions. PLC intermediate and advanced functions. Interface and backplane bus standards for instrumentation systems.

Field bus: Introduction to smart sensor, industrial field bus, concept. Highway Addressable Remote Transducer (HART) protocol: Method of operation, structure, operating conditions and applications, Overview of protocols such as Control Area Network (CAN), MODBUS and PROFIBUS.

SCADA Systems: Definition, SCADA Architecture, Communication requirements, Desirable properties of SCADA system, Features, Generations of SCADA- Monolithic, Distributed, Networked Architecture, SCADA systems in operation and case studies.

Distributed control systems (DCS): Definition, Local Control (LCU) architecture, LCU languages, LCU - Process interfacing issues, communication facilities, configuration of DCS, displays, redundancy concept - case studies in DCS.

Learning Resources:

Text Books:

1. Jamkar, R. G.,Industrial Automation using PLC, SCADA and DCS, Global press, 2018, 1st Edition.
2. John. W. Webb, Ronald A Reis, Programmable Logic Controllers - Principles and applications, Pearson Education India, 2015, 5th Edition.

Reference Books:

1. Ronald L Krutz ,Securing SCADA System, Wiley Publication, 2005, 1st Edition.
2. F. Petruzella, Programmable Logic Controllers, McGraw Hill,2023, 6th Edition.

Online Resources:

1. https://nptel.ac.in/courses/108105088
2. https://nptel.ac.in/courses/108105063

EE46023 **3-0-0 (3)**

Embedded Control systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Configure and use analog to digital and digital to analog signal conversions
CO-2	Develop the models based on state machine, graph-based methods
CO-3	Program the embedded systems with High level language
CO-4	Design the real time embedded control system using different processors

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	3	2	1	1
CO-2	2	-	3	1	2	1
CO-3	2	-	3	2	2	1
CO-4	2	-	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

System Design: Definitions, Classifications and brief overview of micro-controllers, microprocessors and Digital Signal Processors. Embedded processor architectural definitions. Typical application scenario of embedded systems.

Data acquisition basics: Introduction to data acquisition on PC, Sampling fundamentals, Input/Output techniques and buses. ADC, DAC, Digital I/O, counters and timers, DMA, Software and hardware installation, Calibration, Resolution, Data acquisition interface requirements, Interface Issues Related to Embedded Systems: A/D, D/A converters, timers, actuators, power, FPGA, ASIC, diagnostic port.

Techniques for Embedded Systems: State Machine and state tables in embedded design, Simulation and Emulation of embedded systems. High-level language descriptions for embedded system, Java embedded system design.

Real time Models, Language and Operating Systems: Event based, process based and graph based models, Petrinet models – Real time languages – The real time kernel, OS tasks, task states, task scheduling, interrupt processing, clocking communication and synchronization, control blocks, memory requirements and control, kernel services.

Software programming: Optimization, concurrent programming. Real time scheduling, I/O Management, Embedded Operating Systems. Developing Embedded Systems, Building Dependable Embedded Systems, Controller Implementation. Case Studies: Discussion of specific examples of complete embedded systems using mc8051, DSP TMS320F28069, PIC series of microcontroller.

Learning Resources:

Text Books:

1. S. Chattopadhyay, Embedded System Design, PHI Learning Pvt. Ltd, 2023, 3rd Edition.
2. Herma K, W. Steiner, Real Time Systems – Design for Distributed Embedded Applications, Springer International Publishing AG, 2022, 3rd Edition.

Reference Books:

1. C.M. Krishna, Kang G. Shin, Real Time Systems, McGraw Hill, 2017, 1st Edition.
2. Tim Wiscott, Applied control for embedded systems, Elsevier Publications, 2011,1st Edition.
3. Jim Ledin, Embedded control systems in C/C++, CRC Press, 2003, 1st Edition.

Online Resources:

1. https://nptel.ac.in/courses/108102045
2. https://nptel.ac.in/courses/108102169

EE46025 **3-0-0 (3)**

Autonomous Vehicles and Drones

Pre-Requisites: None

Course Outcomes:

CO-1	Modelling the various autonomous vehicles
CO-2	Develop the Cooperative control strategies for multiple autonomous vehicles
CO-3	Design the control system for unmanned aerial vehicles
CO-4	Develop the path planning algorithm for autonomous vehicles

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	3	1	2	1
CO-2	1	-	3	1	2	1
CO-3	2	-	3	1	2	1
CO-4	2	-	3	1	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Preliminaries: Introduction to graph theory and associated concepts, Body and inertial reference frames, rigid body motion, degrees of freedom, motion constraints, kinematic model, dynamic model, Review on Lagrange and Newton-Euler formulations.

Autonomous Ground Vehicles: Modelling and control of differential-drive and steering wheel drive vehicles, longitudinal and lateral dynamics of ground vehicles, control of longitudinal and lateral dynamics, cooperative control of ground vehicles- Guidance strategies to cooperative control - multi-vehicle path planning, collision avoidance, rendezvous/docking problems.

Autonomous Aerial Vehicles: Introduction to the unmanned aircraft systems (UAS). UAS design parameters, UAS components: mechanical & electrical, Overview of UAS Guidance and Navigation, Mechanics of flight (performance requirements, forces/moments, dynamics), UAS feedback control system characteristics, UAS control system stability and performance, Frequency response methods for UAS Flight Control Design.

Dynamics of Drones (quadcopter and hexacopter): Helicopter and fixed-wing aerial vehicles. Hovering control of aerial vehicles, attitude control, trajectory tracking in all three dimensions, cooperative control of aerial vehicles.

Path Planning: Perception in autonomous vehicles, layers of planning, motion-planning primitives, planning scenarios , Basics of optimal control, optimization-based planning, sampling- based planning, graph theoretic heuristics in path planning, model predictive control based path planning, fuzzy-logic and machine learning-based path planning

Learning Resources:

Text Books:

1. H. Fazlollahtabar, M. Saidi-Mehrabad, Autonomous Guided vehicles: Methods and Models for Optimal path planning, Springer, 2015, 1st Edition.

2. H.Nijmeijer, K.Y. Pettersen, T.I. Fossen, Sensing and Control for Autonomous vehicles,Springer International Publishing, 2018, 1st Edition.

Reference Books:

1. R. Rajamani, Vehicle Dynamics and Control, Springer, 2014, 2nd Edition.
2. Hugh H.T. Liu, Bo Zhu, Formation Control of Multiple Autonomous Vehicle Systems, Wiley, 2018, 1st Edition.
3. K. Nonami, M. Kartidjo, K-J Yoon, A. Budiyono, Autonomous Control Systems and Vehicles: Intelligent Unmanned Systems, Springer, 2016, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/112106298

EE46027 **3-0-0 (3)**

Multivariable Control Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Model the Multi Input Multi Output (MIMO) system and understand their mathematical properties
CO-2	Demonstrate the interaction analysis and stability strategies for MIMO system.
CO-3	Analyze and design the different decoupling methods for decentralized control
CO-4	Design the control algorithms for MIMO systems using different methods.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	1	3	–
CO-2	3	1	2	3	2	–
CO-3	3	–	2	3	3	1
CO-4	3	2	3	2	3	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Multi Input Multi Output (MIMO) Systems: Issues with Single Loop design- Limitations on Performance- Right Half Plane Zeros and Poles-Bode's Integral Theorem, Waterbed effect-Representation of MIMO linear system

Different Forms and its stability: Transfer function matrix (TFM) and State space Matrix- Poles and Zeros of a TFM – Smith-McMillan form of a TFM- Matrix fraction description of a TFM- Internal Stability- Generalized Nyquist stability criterion- Nyquist array and Gershgorin bands– Case Study.

Decentralized and Decoupled Control: System Decomposition, Grouping of Variables-Multi Loop control: Pairing Selection- Condition number, Relative gain array analysis, Stability analysis using Diagonal Dominance- Feedforward Decoupling, Feedback Decoupling, Singular Value Decomposition (SVD).

Performance and Robustness: Principal gains (Singular values) and its usage- Principal gains and characteristic loci - Multivariable Design techniques – Sequential loop closing, Characteristic locus method- Direct Nyquist array (DNA) method -Inverse Nyquist array (INA) method- Perron Frobenius theory for Diagonal dominance- Pseudo diagonalization-– Case Study.

Control Methods: Linear quadratic Gaussian (LQG) Method – Performance and robustness of optimal feedback- Loop transfer recovery (LTR) - Design procedure for square Systems- Shaping the principal gain- H-infinity control problem- The Youla parametrization –Case Study.

Learning Resources:

Text Books:

1. S.P.Bhattacharyya, L.H.Keel, Linear Multivariable Control Systems, Cambridge University Press, 2022, 1st Edition.

2. S Skogestad, I. Postlethwaite, Multivariable Feedback Control, Analysis and design, Wiley, 2014, 2nd Edition.

Reference Books:

1. F. Assadian, K.R. Mallon, Robust Control: Youla Parametrization Approach, Wiley-ASME Press series, 2022, 1st Edition.
2. P. Albertos, S. Antonio, Multivariable Control Systems: An Engineering Approach, Springer London Ltd, 2004, 1st Edition.
3. O. Gasparyan, Linear and Nonlinear Multivariable Feedback Control: A Classical Approach, Wiley, 2008, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108103007
2. https://ocw.mit.edu/courses/6-245-multivariable-control-systems-spring-2004/download/

EE46029 **3-0-0 (3)**

Guidance & Control of Aerodynamic System

Pre-Requisites: **None**

Course Outcomes:

CO-1	Develop navigation and guidance schemes for missiles
CO-2	Analyze and design the different control configuration for a missile
CO-3	Apply the basic hardware for the missile control systems
CO-4	Analyze and understand the aerodynamic and motion dynamics of a missile

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	2	1	1
CO-2	1	-	3	1	1	1
CO-3	2	-	3	1	1	1
CO-4	1	-	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Missile guidance: Missiles, missile guidance laws (pursuit, line-of-sight, proportional navigation), capturability analysis from manoeuvring and non-manoeuvring targets.

Flight Control Systems: Guidance, Navigation and Control- Flight Control Channels- Methods of Flight Control- Aerodynamic consideration- Static and Dynamic stability- Missile Dynamics- Maneuverability and Stability- Static Margin- Variations of Center Pressure- Hinge Moment- Aeroelastic Effect.

Different Control System: Performance and its types-Canarad Control- Wing Control- Tail Control- Fin Configuration effects- Side Jet Control- Thrust Vector Control- Variation of Mass and CG.

Actuators and Sensors: Servomechanism- Hydraulic actuator- Pneumatic actuators- Electric actuators- Accelerometers- Gyroscopes- LVDT, RVDT, Encoders, Potentiometer.

Aerodynamic control system for Missiles: Coordinate systems- Motion dynamics- Transfer functions of Roll, Pitch and Yaw- STT Vs BTT- Roll control- Lateral Control- Attitude control systems.

Learning Resources:

Text Books:

1. Q. Zaikang, L. Defu, Design of Guidance and Control systems for tactical missiles, CRC Press, 2019, 1st Edition.
2. P. Zarchan, Tactical and Strategic Missile Guidance, American Institute of Aeronautics and Astronautics (AIAA) Press, 2019, 7th Edition.

Reference Books:

1. S.N. Balakrishnan, A. Tsourdos, B.A. White, Advances in Missile Guidance, Control and Estimation, CRC Press, 2017, 1st Edition.
2. E.L. Freeman, Missile Design Guide, AIAA Press, 2022, 1st Edition.
3. G.M. Siouris, Missile Guidance and Control Systems, Springer-Verlag New York Inc, 2010, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/101108054

EE46031 **3-0-0 (3)**

Robust Control System

Pre-Requisites: **None**

Course Outcomes:

CO-1	Formulate and design the sliding mode controller for a given application
CO-2	Analyse and design the special sliding mode controllers for different engineering systems
CO-3	Analyse and model the hybrid dynamical system
CO-4	Reachability and stability study using multiple Lyapunov functions

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	2	3	2	1
CO-2	1	-	2	3	2	1
CO-3	1	-	3	3	2	1
CO-4	2	-	3	3	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Nonlinear control preliminaries-Types of Uncertainty- Matched and Unmatched uncertainties- Sliding modes in nature- Variable Structure Systems- Development of Sliding Mode Control (SMC)-Concept of Sliding Surface- State feedback sliding surface design- Reachability Conditions- Switching Control Action- Chattering Phenomena- Fillipov Trajectories- Concept of Equivalent Control.

Special Sliding Mode Controllers: Integral Sliding mode control (ISMC)- Stability of ISMC- Terminal SMC- Stability of Terminal SMC- Composite nonlinear feedback (CNF) control- ISM with CNF control- Control law derivation- Stability of ISM-CNF control- Examples

Discrete Time SMC: Chattering in Continuous Time- Discrete time development-quasi-sliding mode-discrete reaching laws and sliding surface design- multirate output feedback- discrete time integral and terminal sliding modes- Case Study examples

Hybrid Systems: Modelling frameworks of hybrid systems, Basic nonsmooth analysis, differential inclusion, Hybrid state trajectory, Filippov solution, zeno phenomena, Lyapunov theory, Linear Matrix Inequality (LMI), Stability under arbitrary switching, stability under constrained switching, Multiple-Lyapunov function, LMI based synthesis using multiple-Lyapunov function

Reachability Analysis and Computation: Differential games and Hamilton-Jacobi-Isaacs (HJI) equations, HJI based reachability analysis, Discrete-time reachability through polyhedral operations.

Learning Resources:

Text Books:

1. Y. Shtessel, C. Edwards, L. Fridman, A. Levant, Sliding Mode Control and Observation, Springer Birkhauser, 2014, 1st Edition.

2. Francesco Borrelli, Alberto Bemporad, Manfred Morari ,Predictive Control for Linear and Hybrid Systems, Cambridge University Press, 2017, 1st Edition.

Reference Books:

1. Utkin V, Guldner J, Shi J., Sliding Mode Control in Electromechanical Systems, 2nd Edition., Taylor and Francis, 2009, 1st Edition.
2. J. Lygeros, S. Sastry and C. Tomlin,Hybrid Systems: Foundations, advanced topics and applications, Springer, 2012, 1st Edition

Other Suggested Readings:

1. K.D.Young, V.I. Utkin U. Ozguner, " A Control Engineers Guide to Sliding Mode control " , Vol. 7, no. 3, pp. 328-342, 1999.

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=761053

CH16035 **3-0-0 (3)**

Industrial Instrumentation

Pre-Requisites: None

Course Outcomes:

CO-1	Apply the techniques for level and pressure measurement
CO-2	Measure temperature using contact and non-contact techniques
CO-3	Analyse the measurement methods for torque and velocity.
CO-4	Select appropriate methods for acceleration, vibration and density measurement

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	–	2	3	1	1
CO-2	2	–	3	2	1	1
CO-3	2	–	3	3	1	2
CO-4	2	–	3	3	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Level measurement: Gauge glass technique coupled with photo electric readout system, float type level indication, different schemes, measurement using displacer and torque tube – bubbler system. Differential pressure method. Electrical types of level gauges using resistance, capacitance, nuclear radiation and ultrasonic sensors.

Pressure measurement: Manometers, pressure gauges – Bourde type bellows, diaphragms. Electrical methods – elastic elements with LVDT and strain gauges. Capacitive type pressure gauges. Measurement of vacuum – McLeod gauge – thermal conductivity gauges – Ionization gauge cold cathode and hot cathode types – testing and calibration.

Temperature measurement: Thermometers, different types of filled in system thermometer, bimetallic thermometers. Electrical methods signal conditioning of industrial RTDs and their characteristics –3 lead and 4 lead RTDs. Thermocouples and pyrometers.

Measurement of force torque, velocity: Electric balance – different types of load cells – magnets – elastics load cell-strain gauge load cell. Different methods of torque measurement, strain gauge, relative regular twist-speed measurement-revaluation counter- capacitive tacho-drag up type tacho D.C and A.C tacho generators – stroboscope.

Measurement of acceleration, vibration and density: Accelerometers – LVDT, piezo-electric, strain gauge and variable reluctance type accelerometers, calibration of vibration pickups, Baume scale API scale – pressure head type densitometer – float type densitometer.

Flow measurement: Volumetric flow measurement through electromagnetic, ultrasonic and vortex techniques. Mass flow measurement through Coriolis principle. Basics of analyzers -single and multiple components through chromatography. Control valves – different types, characteristics and smart valves

Learning Resources:

Text Books:

1. William C. Dunn, Fundamentals of Industrial Instrumentation and Process Control, McGraw-Hill, 2018, 2nd Edition.
2. C.E. Faruk Poyen, Principles of Industrial Instrumentation: An Introduction, LAP LAMBERT Academic Publishing, 2017, 1st Edition.

Reference Books:

1. B.G. Liptak, Instruments Engineers Handbook: Volume Two, CRC Press, 2018, 4th Edition.
2. A. Baura, Fundamentals of Industrial Instrumentation, Wiley India, 2011, 1st Edition.
3. E.O. Doebelin, Dhanesh N. Manik, Doebelin's Measurement Systems, McGraw Hill, 2019, 7th Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105064

CH16065 **3-0-0 (3)**

Performance Assessment & Plant Wide Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Analyse the minimum variance bench mark
CO-2	Estimate and use interactor matrices
CO-3	Apply unified approach for performance assessment
CO-4	Development of degrees of freedom for plant wide control

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	3	3	1	1
CO-2	2	–	3	3	1	1
CO-3	2	–	3	3	1	2
CO-4	2	–	3	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Unitary Interactor Matrices and Minimum Variance Control - Weighted unitary interactor matrices and singular LQ control. Estimation of the Unitary Interactor Matrices, Determination of the order of interactor matrices, Factorization of unitary interactor matrices. Estimation of the interactor matrix under closed-loop conditions, Numerical rank.

Feedback Controller Performance Assessment: Simple Interactor. Multivariable performance index. Feedback Controller Performance Assessment - Diagonal Interactor, effect of non minimum phase zeros. Performance assessment with both stochastic and deterministic disturbances. Performance assessment with pure deterministic disturbances.

Plant wide Control Fundamentals: Introduction, Integrated Processes - Material Recycle, Energy Integration. Effects of Recycle. Time Constants in Recycle Systems, Steady-State Design. Dynamic Controllability.

Steady state operation: Degrees of freedom, Design, steady operation and control DOF, DOFs for Economic optimum design, Steady economic process operation, Economic CVs for self-optimizing control Economic trade-offs in plant design and steady operation Process Dynamics, PI(D) Control, Controller Tuning and Pairings.

Optimum design and operation of complete plants: Steady state economic optimum design, Steady state optimum operating policy. The bottom-up pairing approach, Systematic top-down plant wide control design procedure, Simple control structure design examples.

Learning Resources:

Text Books:

1. Andrzej Ordys, Damien Uduehi, Michael A Johnson, Process Control Performance Assessment: From Theory to Implementation, Springer, 2007, 1st Edition.
2. Mohieddine Jelali, Control Performance Management in Industrial Automation, Springer, 2013, 1st Edition.

Reference Books:

1. Biao Huang, Ramesh Kadali, Dynamic Modeling, Predictive Control and Performance Monitoring, Springer, 2008, 1st Edition.
2. Vinay Kariwala and G.P. Rangaiah, Plantwide Control: Recent Developments and Applications, Wiley, 2012, 1st Edition.
3. Biao Huang and Sirish L. Shah, Performance Assessment of Control Loops: Theory and Applications, Springer-Verlag, 1999,1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/103104050

CH16067 **3-0-0 (3)**

Data-Driven Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Analyze the input-output data for controller design
CO-2	Develop iterative learning controller for the given system
CO-3	Design the virtual reference feedback controller for stable and Unstable system
CO-4	Synthesis the controller for parameter varying systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	2	2	1
CO-2	2	-	3	2	2	1
CO-3	2	-	3	3	2	1
CO-4	2	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Model-Based Control Limitations of model-based control-Benefits of Model free approaches-Combined design of identification and control.

Iterative Feedback Tuning (IFT): Virtual Reference Feedback Tuning (VRFT), non-iterative Correlation-based Tuning. VRFT design for stable, integrating and unstable processes. Selection of reference models and their impact. Advantages and limitations direct data-driven control over traditional model-based design.

Non-iterative Methods: Direct data-driven tuning of multivariable controllers. PID controller design directly based on data. Advantages and limitations.

Advanced Methods: Nonparametric control design and regularization. The receding horizon approach. Data-driven selection of control specifications.

Direct data-driven control: Linear parameter-varying and piece-wise affine systems. Model-free predictive control for hierarchical schemes. Willems' Fundamental Lemma. Learning-based Adaptive Control: An Extremum Seeking Approach. Model free adaptive control for SISO and MIMO systems.

Learning Resources:

Text Books:

1. Ali Khaki-Sedigh, An Introduction to Data-Driven Control Systems, Wiley-IEEE Press, 2023, 1st Edition.
2. Z.Hou, S. Jin, Model Free Adaptive Control: Theory and Applications, CRC Press, 2013, 1st Edition.

Reference Books:

1. Steven L. Brunton, J. Nathan Kutz , Data –Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control, Cambridge University Press, 2019, 1st Edition.
2. M. Benosman, Learning-based Adaptive Control: An Extremum Seeking Approach,Butterworth-Heinemann, 2016, 1st Edition.
3. A.S. Bazanella, L. Campestrini, D. Eckhard, Data-driven controller design: The H_2 approach , Springer, 2012, 1st Edition.

Other Suggested Readings:

1. Zhong-Sheng Hou, Zhuo Wang, " From model-based control to data-driven control: Survey, classification and perspective ",Information Sciences, Volume 235, Pages 3-35, 2013.
https://www.sciencedirect.com/science/article/pii/S0020025512004781
2. D.Soudbakhsh,A.M. Annaswamy,Y.Wang, S.L. Brunton, J.Gaudio, H.Hussain,D.Vrabie,J Drgona, D.Filev, "Data-Driven Control: Theory and Applications", pp. 1922-1939, American Control Conference, San Diego, CA, USA. May 31 - June 2, 2023 .
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10156081
3. A. Karimi, B. Bahrani, D. Zheng and S. S. Madani, "Data-Driven Control and Its Applications to Microgrids," *IEEE Conference on Control Technology and Applications (CCTA)*, Trieste, Italy,pp. 1-18, 2022.
https://ieeexplore.ieee.org/document/9966006

CH16069 **3-0-0 (3)**

Fractional Order Systems and Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Illustrate the concept of fractional calculus
CO-2	Develop the fractional order models for dynamical system
CO-3	Analyze the fractional dynamics in time domain and in frequency domain
CO-4	Design and analyzes different fractional control strategies

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	3	2	-	1
CO-2	2	–	3	2	1	1
CO-3	2	–	3	2	1	1
CO-4	2	–	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Review of basic definitions of integer-order (IO) derivatives and integrals and their geometric and physical interpretations, Definition of Riemann-Liouville (RL) integration, Definitions of RL, Caputo and Grunwald-Letnikov (GL) fractional derivatives (FDs), Various geometrical and physical interpretations of these FDs, Computation of these FDs for some basic functions, Laplace and Fourier transforms of FDs.

Important Mathematical functions: Gamma function, Mittag-Leffler function, Dawson's function, Hypergeometric function, etc, Analysis of linear fractional-order differential equations (FDEs): formulation, Solution with different FDs, Initial conditions, Problem of initialization and the remedies.

Fractional order modelling: Concepts of 'memory' and 'non-locality' in real-world and engineering systems, non-exponential relaxation, 'Mittag-Leffler' type decay and rise, Fractional-order (FO) modeling of electrical circuit elements like inductor, capacitor, electrical machines like transformer, induction motor and transmission lines, FO modeling of viscoelastic materials, concept of fractional damping, Models of mechanical systems using FO elements

Fractional order representation: Concepts of multivalued functions, branch points, branch cuts, Riemann surface and sheets, Fractional-order transfer function (FOTF) representation, Concepts like commensurate and noncommensurate transfer functions, stability.

Comparative study: Comparison of FO control over the conventional IO control-FO lead lag compensators, FO PID control, design of FO state-feedback, Realization and implementation issues for FO controllers.

Learning Resources:

Text Books:

1. O. Naifar, A. Ben Makhlouf, Fractional-order Systems: Control Theory and Applications Springer, 2021, 1st Edition.
2. A. Monje, Y. Q. Chen, B. M. Vinagre, D. Xue, V. Feliu, Fractional-order Systems and Control: Fundamentals and Applications, Springer-Verlag London Limited, UK, 2010, 1st Edition.

Reference Books:

1. I. Petras Fractional-Order Nonlinear Systems: Modeling, Analysis and Simulation, Springer-Verlag Berlin, 2011, 1st Edition.
2. R. Caponetto, G. Dongola, L. Fortuna, I. Petras Fractional Order Systems: Modeling and Control Applications, , World Scientific, Singapore, 2010, 1st Edition.
3. B. Gibson, Theory and Applications of Fractional Differential Equations, NY Research Press, 2023, 1st Edition.

Other Suggested Readings:

1. I. Podlubny, "Fractional-order systems and $PI^{\lambda}D^{\mu}$ controllers," IEEE Transactions on Automatic Control, vol. 44, no. 1, pp. 208-214, Jan. 1999.

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=739144

CH16071 **3-0-0 (3)**

Quantitative Feedback Theory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the importance of Quantitative feedback theory (QFT) based robust control
CO-2	Model and design the robust QFT controller and prefilter for the Single input single output uncertain system
CO-3	Design the QFT controller/prefilter for unstable and non-minimum phase system using the loop-shaping methods
CO-4	Perform the QFT synthesis for cascade control systems and for discrete time system

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	2	3	2
CO-2	3	-	3	2	2	2
CO-3	3	-	3	2	2	2
CO-4	3	-	3	2	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Principle and purpose of feedback- Stability of linear time invariant (LTI) Feedback systems: Asymptotic stability and internal stability- Single input single output (SISO) Degrees of freedom (DOF) feedback structures: one and two DOF – Review of classical control concepts: Nyquist stability criterion- Nichols Chart- Uncertain systems- Description of Uncertainties: Parametric and Non-parametric uncertainty- Need for Robust control- Overview of robust control design methods.

Quantitative feedback theory procedure: System (Plant) modelling- Types of robust control problem- Robust performance : disturbance rejection and tracking problem– Robust Stability- Guidelines to select the specifications- Zero, Exclusion principle- Loop transmission function and its importance- Concept of loop shaping-Sensitivity function and Complementary sensitivity function- Water Bed effect- Benefits and Cost of feedback.

QFT Synthesis of SISO LTI Uncertain feedback Systems: QFT Design Procedure for SISO LTI system: QFT Templates/ Value set generation- QFT Bound generation methods: Template manipulation and Quadratic Inequality (QI) approach- Derivation of QIs for different design specifications- QFT Controller design using Loop shaping approach- Optimal shaping of nominal loop transfer function- Shaping of QFT Prefilter- Design Examples.

QFT Synthesis of SISO Unstable and Non-Minimum Phase system: Fundamental limitations on Loop transmission function: Unstable pole and right half plane (RHP) zero- Nyquist Stability criterion in the Nichols Chart- Guidelines to Design Controllers- QFT Synthesis of Unstable Systems – Synthesis of NMP System: QFT Bound adjustment step- All pass system- Robust Design of Smith Predictor- Design Examples.

QFT Synthesis for special control structures: Cascade Control of SISO Uncertain System: Inner- Outer loop design, Outer-Inner loop design – QFT based Feedforward Controller design - Digital QFT Control design- QFT design for Model matching problem- Introduction to Multi-input Multi output (MIMO) QFT design: Sequential and Non Sequential approaches – Design Examples.

Learning Resources:

Text Books:

1. C. H. Houpis, S.J. Rasmussen, Mario Garcia-Sanz, Quantitative Feedback Theory: Fundamentals and Applications, CRC Press, 2018, 2nd Edition
2. Mario Garcia-Sanz, Robust Control Engineering: Practical QFT Solution, CRC Press, 2017, 1st Edition

Reference Books:

1. Oded Yaniv, Quantitative feedback design of Linear and Nonlinear Control Systems, Springer, 1999, 1st Edition.
2. Marcel J. Sidi, Design of Robust Control Systems: From Classical to Modern Practical Approaches, Krieger Publishing Company, 2001, 1st Edition
3. Horowitz, Quantitative Feedback Design Theory (QFT), QFT Publishers Denver, CO, 1993, 1st Edition

Other Suggested Readings:

1. https://nptel.ac.in/courses/115108104

CH16073 **3-0-0 (3)**

Statistical Process Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply statistical methods for process control
CO-2	Use univariate charts and cumulative sum charts
CO-3	Design Control strategies for the processes with attribute based charts
CO-4	Develop multivariate statistical process control methods

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	3	1	1
CO-2	2	-	2	2	2	1
CO-3	2	-	3	3	2	1
CO-4	2	-	2	2	1	1

1 - Slightly; 2 - Moderately; 3- Substantially

Syllabus:

Introduction: Statistical process control: Basic statistical concepts and methods – population and population distribution, continuous and discrete distributions, parametric and non parametric statistical inferences.

Univariate Shewhart charts for numerical and categorical variables: Process capability analysis. Univariate CUSUM charts – monitoring the mean and variance of a normal process, self-starting and adaptive CUSUM charts.

Univariate EWMA charts: Monitoring the mean and variance of a normal process, self-starting and adaptive EWMA charts.

Process control by attributes: Underlying concepts, np-charts for number of defectives or non conforming units, p-charts for proportion defective or non-conforming units, c-charts for number of defects/non-conformities, u-charts for number of defects/non-conformities per unit, Attribute data in non-manufacturing.

Cumulative sum (CUSUM) charts: Introduction, Interpretation of simple cusum charts, Product screening and pre-selection, Cusum decision procedures.

Multivariate statistical process control (MSPC):overview of conventional methods, Independent component analysis, Principal Component Analysis, Partial Least Squares, Factor Analysis, Independent Component Analysis, Kernal Principal Component Analysis. Process monitoring charts, Fault detection, Scatter diagrams, Non-negative quadratic monitoring statistics, Fault isolation and identification, Contribution charts, Residual-based tests, Variable reconstruction, Geometry of variable projections, Linear dependency of projection residuals, Geometric analysis of variable reconstruction. Examples.

Learning Resources:

Text Books:

1. Peihua Qiu, Introduction to Statistical Process Control, CRC Press, 2013, 1st Edition.
2. John Oakland, Statistical Process Control, Elsevier, B-H Publications, 2008, 6th Edition.

Reference Books:

1. Zhiqiang Ge, Zhihuan Song, Multivariate Statistical Process Control, Springer, 2013, 1st Edition.
2. Uwe Kruger, LessiXie, Statistical Monitoring of Complex Multivariate Processes, Wiley, 2012, 1st Edition.

Other Suggested Readings:

1. https://www.sciencedirect.com/topics/engineering/statistical-process-control

EE46022 **3-0-0 (3)**

Optimal and Robust Control System

Pre-Requisites: **None**

Course Outcomes:

CO-1	Formulate an optimal control problem and determine the optimal trajectories.
CO-2	Design the optimal controller using the DP and Minimum principle.
CO-3	Design the H_∞ and QFT based robust control strategies for the uncertain system.
CO-4	Design and analysis the robust controller for the liner system using SMC concept

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	2	2	1
CO-2	2	-	3	2	2	1
CO-3	2	-	3	2	2	1
CO-4	2	-	3	1	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Performance measures of Optimal Control - Linear Quadratic Regulator (LQR)-Problem formulation–Finite and infinite horizon case- Dynamic Programming (DP) –Bellman's Principle of optimality, multistage decision process– computational procedure, Characteristics of DP solution-Conditions for optimality.

Variational approaches: Euler-Lagrange approach, Hamiltonians formulation, transversality conditions–Necessary conditions for optimal control -Lagrange Multiplers - Pontryagin's Maximum Principle-Conditions for optimality- Application to minimum time, energy and control efforts problems and terminal control problems

Modelling of Uncertain Systems: Unstructured Uncertainties, Parametric Uncertainties, Linear Fractional Transformations, Structured Uncertainties. Robust Design Specifications: Small-Gain Theorem – nominal stability, nominal performance, robust stability, robust performance. Structured Singular Values-Kharitonov Theorem and its applications to power converter control.

Robust controller design: Function Space, Computation of H_2 and H_∞ Norms. Robust Control Problem as H_2 and H_∞ Control- Concept of Loop shaping-Quantitative feedback theory(QFT)-QFT Design Procedure for Single Input Single output Linear system: QFT Templates/ Value set generation- QFT Bound generation methods- QFT Controller design using Loop shaping approach- Shaping of QFT Prefilter- Case study on Power system stabilizer design.

Sliding mode control: Variable Structure Systems- Development of Sliding Mode Control (SMC)-Concept of Sliding Surface- State feedback sliding surface design- Reachability Conditions- Switching Control Action- Chattering Phenomena- Fillipov Trajectories- Concept of Equivalent Control- Case study on stabilization of Inverted pendulum system

Learning Resources:

Text Books:

1. A.E. Bryson, Yu-Chi Ho, Applied Optimal Control: Optimization, Estimation and Control, CRC Press, 2018, 1st Edition.
2. K-Z. Liu, Y. Yao, Robust control: Theory and Applications, Wiley Publisher, 2016, 1st Edition.

Reference Books:

1. Mario Garcia-Sanz, Robust Control Engineering: Practical QFT Solutions,CRC Press, 2017, 1st Edition.
2. Y. Shtessel, C. Edwards, L. Fridman, A. Levant, Sliding Mode Control and Observation, Springer Birkhauser, 2014, 1st Edition.
3. S.Skogestad, . Postlethwaite, Multivariable Feedback Control: Analysis and Design, John Wiley & Sons, 2007, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105019
2. https://nptel.ac.in/courses/101108057
3. https://nptel.ac.in/courses/115108104

EE46024 **3-0-0 (3)**

Digital Control Systems

Pre-Requisites: **EE46001**

Course Outcomes:

CO-1	Model the discrete time (DT) system in state space form
CO-2	Perform the stability analysis of DT dynamical system
CO-3	Design the state feedback control for DT system
CO-4	Formulate and solve the DT optimal control problem

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	3	2	2	1
CO-2	2	-	3	2	2	1
CO-3	2	-	3	2	2	1
CO-4	2	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Continuous and Discrete time system-Digital control systems - Quantizing and quantization error, Sampling theorem.

Z-Transform: Z-transforms of elementary functions, important properties and theorems, Inverse Z-transform, Z-transform method of solving difference equations.

Z-Plane Analysis of Discrete-Time Control Systems: Impulse sampling and data hold, Pulse transfer function, Realization of digital controllers and digital filters, Mapping between s-plane and z-plane, Stability analysis of closed loop systems in z-plane, Transient and steady state analyses.

State Space Analysis of digital control systems: Solution of discrete time state space equations, Discretization of continuous time state space equations, Lyapunov stability analysis for Discrete linear system, Pole Placement and Observer Design, Controllability, Observability concepts.

Discrete Optimal Control Systems: Linear Quadratic Regulator (LQR) Design via pole placement, Discrete State observers, Quadratic optimal control, Steady state quadratic optimal control, Quadratic optimal control of a servo system.

Learning Resources:

Text Books:

1. K. Ogata, Discrete time control systems, Pearson Education India, 2015, 2nd Edition.
2. M. Gopal, Digital Control and State Variable Methods, McGraw Hill Education, 2017, 4th Edition.

Reference Books:

1. C.L. Phillips, H.T. Nagle, A. Chakrabortty,Digital Control System Analysis and Design, Pearson, 2014, 4th Edition.

2. B.C. Kuo, Digital Control Systems, Oxford University Press, 2012, 2nd Edition.

3. C.A. Rabbath, N. Lechevin, Discrete-Time Control System Design with Applications, Springer-Verlag New York Inc, 2014, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105186

2. https://nptel.ac.in/courses/108103008

EE46026 **3-0-0 (3)**

Networked Control System

Pre-Requisites: **None**

Course Outcomes:

CO-1	Model the networked control problems using graph theory
CO-2	Analyze the stability and performance of networked control systems
CO-3	Develop distributed control strategies for multi-agent robotics
CO-4	Develop strategies for implementing mobile sensor and communication networks

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	2	2	1
CO-2	1	-	3	1	2	1
CO-3	2	-	3	1	2	1
CO-4	1	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Basic Concepts in Networked Control: Review of Graph Theory - Connected Graph - Incidence Matrix - Tree - cutse t- loop/cycles - Minimum Spanning Tree - Network Models - graphs, random graphs, random geometric graphs, state-dependent graphs – Networked control systems - Proximity graphs - Algebraic and spectral graph theory - Connectivity: Cheeger's inequality - switching networks - From biological swarms to graph-based models - Rendezvous: A canonical problem

Decentralized Control: The agreement protocol: static case - Reaching decentralized agreements - Consensus equation: Static case – Leader networks and distributed estimation - Discrete time consensus- The agreement protocol: dynamic case: Switched networks - Lyapunov-based stability - Consensus equation: Dynamic Case-Biological models: Flocking and swarming - Alignment and Kuramoto's coupled oscillators – Cucker- Smale model Distributed estimation - Computational, communications, and controls resources in networked control systems - Distributed control - Convex Optimization - Optimization-based control design.

Multi Agent systems: Formations - Graph rigidity - Persistence - Formation control, sensor and actuation models-distance based formations, rigidity, position based formations, formation infeasibility - Consensus problem - static, dynamic, distributed estimation, leader-follower architectures for consensus-Reaching decentralized agreements through cooperative control - leader-follower networks-Network controllability - Network feedback - Averaging Systems – Positive Systems - nonholonomic, double integrator, rigid body dynamics - Collision avoidance: potential fields, navigation functions. Introduction to artificial intelligence and deep learning for multi-agent robotics.

Mobile Sensor and Communication Networks: Sensor networks: Coverage control - Coverage and detection problems-Gabriel and Voronoi graphs- Voronoi-based cooperation strategies - Random graphs - LANdroids: Communication networks Communication models – mobile communications networks - connectivity, connectivity maintenance, sampling, delays, packet losses, quantization, security - Swarming - sensor networks: sensing constraints, aggregation, dispersion, coverage control, deployment, flocking - Internet of things (IOT).

Learning Resources:

Text Books:

1. Francesco Bullo , Lectures on network systems, Kindle Direct Publishing, 2020,1st Edition.
2. Wei Ren, Randal W. Beard, 'Distributed Consensus in Multi-vehicle Cooperative Control', Springer-Verlag,London, 2010, 1st Edition.

Reference Books:

1. P. J. Antsaklis and P. Tabuada, Networked Embedded Sensing and Control, Springer, 2006, 1st Edition.
2. Mehran Mesbahi and Magnus Egerstedt, 'Graph Theoretic Methods in Multiagent Networks,' Princeton University Press, 2010, 1st Edition.
3. F. Bullo, J. Cortes, and S. Martinez, 'Distributed Control of Robotic Networks', Princeton, 2009, 1st Edition.

Other Suggested Readings:

1. X. -M. Zhang *et al.*, "Networked control systems: a survey of trends and techniques," in *IEEE/CAA Journal of Automatica Sinica*, vol. 7, no. 1, pp. 1-17, January 2020, doi: 10.1109/JAS.2019.1911651

EE46028 **3-0-0 (3)**

Cyber-Physical Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Analyse and model the cyber-physical systems (CPS) using different Automata
CO-2	Identify safety specifications and critical properties
CO-3	Implement the state flow for CPS
CO-4	Identify and solve different cyber security threats

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	2	2	3	1
CO-2	1	-	3	1	2	1
CO-3	2	-	3	3	3	1
CO-4	2	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Cyber-Physical Systems (CPS) in the real world, Basic principles of design and validation of CPS, Industry 4.0, AutoSAR, Industrial Internet of Things (IIOT) implications, Building Automation, Medical CPS, CPS Hardware platforms- Processors, Sensors, Actuators.

CPS Network: Wireless Hart, CAN, Automotive Ethernet, CPS Software stack – Real Time Operating System, Scheduling Real Time control tasks Principles of Automated Control Design: Dynamical Systems and Stability Controller Design Techniques, Stability Analysis, stability under slow switching, Performance under Packet drop and Noise.

State flow CPS implementation: State flow; From features to software components, Mapping software components to ECUs, CPS Performance Analysis - effect of scheduling, bus latency, sense and actuation faults on control performance, network congestion Formal Methods for Safety Assurance of Cyber-Physical Systems.

Automata: Modelling of CPS using Automata, Timed and Hybrid Automata, Definition of trajectories, Formal Analysis: Flow pipe construction, reachability analysis, Analysis of CPS Software: Weakest Pre-conditions, Bounded Model checking, CPS Software Verification: Frama-C.

Information System Security Technology: Types and classes of attack, Policies, Standards, Guidelines and procedures, Malicious code and attacks, Firewalls, Cryptography, Attacks against cryptosystems. CBMC Secure Deployment of CPS: Attack models, Secure Task mapping and Partitioning, State estimation for attack detection Automotive Case study: Vehicle ABS hacking, Power Distribution Case study: Attacks on Smart Grids.

Learning Resources:

Text Books:

1. Rajeev Alur, Principles of Cyber-Physical Systems, The MIT Press, 2023, 1st Edition.
2. S. Roy, S.K. Das, Principles of Cyber-Physical Systems : An Interdisciplinary approach, Cambridge University Press, 2020, 1st Edition

Reference Books:

1. R. Rajkumar, Dionisio De Niz, M. Klein, Cyber-Physical Systems, Pearson Education, 2017, 1st Edition.
2. André Platzer, Logical Analysis of Hybrid Systems: Proving Theorems for Complex Dynamics, Springer, 2014, 1st Edition.
3. David J. Teumim, Industrial Network Security, ISA Press, 2016, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/106105241

EE36028 **3-0-0 (3)**

Industrial Internet of Things

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand and evaluate the characteristics of Domestic & Industrial appliances.
CO-2	Understand the behaviour of Industrial IoT and their applications
CO-3	Manage smart communication systems with multiple sensors and protocols
CO-4	Design and simulate smart homes and smart cities with IoTs and cloud computing

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	2	–
CO-2	3	1	2	–	1	–
CO-3	3	–	3	3	2	2
CO-4	3	2	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

IoT Communication Technologies: Introduction to IoT, Sensing, Actuation, Basics of Networking, Communication Protocols, Sensor Networks, Machine-to-Machine Communications. Interoperability in IoT.

IoT Control Technologies and Programming: Introduction to Arduino Programming, Integration of Sensors and Actuators with Arduino, Internet of Things Open-Source Systems. Introduction to Python programming, Introduction to Raspberry. Implementation of IoT with Raspberry Pi, Smart Grid Hardware Security.

Domestic & Industrial Appliances: Solid State Lamps: Introduction - Review of Light sources - white light generation techniques-Characterization of LEDs for illumination application. Power LEDs- High brightness LEDs-Electrical and optical properties. LED driver considerations-Power management topologies -color issues of white LEDs- Dimming of LED sources, BLDC motors for pumping and domestic fan appliances, inverter technology-based home appliances, Smart devices and equipment. Industrial IoT applications- Factories and Assembly Line- Power Plants, Plant Safety and Security (Including AR and VR safety applications)- Oil and chemical Industry- Applications of UAVs in Industries.

IoT Cloud Computation and Applications: Introduction to SDN. SDN for IoT, Data Handling and Analytics, Cloud Computing, Sensor- Cloud. Fog Computing, Smart Cities and Smart Homes, Electric Vehicles, Industrial IoT, Case Study: Agriculture, Healthcare, Activity Monitoring, Role of ML and AI in IoT.

Learning Resources:

Text Books:

1. Sudip Misra, Chandana Roy, Anandarup Mukherjee, Introduction to Industrial Internet of Things and Industry 4.0, CRC press, 2021.
2. Kostas Siozios, Dimitrios Anagnostos, Dimitrios Soudris, Elias Kosmatopoulos, IoT for Smart Grids: Design Challenges and Paradigms, Springer publishers, 2019.

3. Vinod Kumar Khanna, Fundamentals of Solid-State Lighting: LEDs, OLEDs, and Their Applications in Illumination and Displays, CRC press, 2014, 1st Edition.

Reference Books:

1. Alasdair Gilchrist, Industry 4.0: The Industrial Internet of Things, Apress Publishers, 2016.
2. Craig Di Louie, Advanced Lighting Controls: Energy Savings, Productivity, Technology and Applications, River publishers, 2006, e-book, 2021,1st Edition.
3. Chang-liang Xia, Permanent Magnet Brushless DC Motor Drives and Controls, John Wiley & Sons Singapore Pte. Ltd., 2012, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/106105166

EE26032 **3-0-0 (3)**

Machine Learning Applications in Power Engineering

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand basic concepts of Machine Learning Techniques
CO-2	Distinguish between supervised learning, unsupervised learning and reinforced learning
CO-3	Develop the skills in using machine learning software for solving practical problems
CO-4	Apply Machine Learning Algorithms for Electrical Engineering problems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	3	1	3	2
CO-2	2	1	3	1	3	2
CO-3	2	1	3	1	3	2
CO-4	2	1	3	1	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Neural networks- Introduction to Neural Networks, Models of Neuron Network, Architectures – Knowledge representation, Artificial Intelligence and Neural Networks – Learning Process, Error Correction Learning, Multi-layer perceptron using Back Propagation Algorithm (BPA)

Learning Theory- Introduction to Machine Learning: What is Learning – Learning Objectives – Data needed – Bayesian inference and Learning – Bayes theorem – inference – naïve Bayes – Regularization – Bias-Variance Decomposition and Trade-off – Concentration Inequalities – Generalization and Uniform Convergence – VC –dimension- Types of Learning- Supervised Learning – Unsupervised Learning and Reinforcement Learning

Supervised learning- Simple linear Regression – Multiple Linear Regression- Logistic Regression – Exponential Family and Generalized Linear Models- Generative Models: Gaussian Discriminate Analysis, Naïve Bayes – Kernal Method: Support Vector Machine (SVM) – Kernal function – Kernal SVM - Gaussian Process – Tree Ensembles: Decision Trees- Random Forests – Boosting and Gradient Boosting

Unsupervised learning (clustering)- K –means Clustering Algorithm – Gaussian Mixture Model (GMM) – Expectation Maximization (EM) – Variational Auto Encoder (VAE) – Factor Analysis – Principle Components Analysis (PCA) – Independent Component Analysis (ICA)

Reinforcement learning- Markov Decision Processes (MDP) – Bellman's Equations- Value Iteration and Policy Iteration - Value Function Approximation – Q – Learning

Applications of ML- Load Forecasting – Energy Market forecasting – Renewable energy forecasting, Fault identification and localization – Renewable Uncertainty estimation. ML for solar power MPPT, False data injection attack detection-Control of Power Converters.

Learning Resources:

Text Books:

1. Christopher Bishop, Pattern Recognition and Machine Learning, Springer, 2011.
2. E. Alpaydin, Machine Learning, MIT Press, 2010.
3. A. Srinivasaraghavan, Vincy Joseph, Machine Learning, Wiley, 2019.

Reference Books

1. Giuseppe Bonaccorso, Machine Learning Algorithms, Packt Publishing, 2018, 2nd Edition.

2. Tom M. Mitchell, Machine Learning, McGraw Hill International Edition, 2013

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc22_cs24

2. https://nptel.ac.in/courses/106106198

CH16024 **3-0-0 (3)**

Engineering Optimization

Pre-Requisites: **None**

Course Outcomes:

CO-1	Formulate objective function for a given problem.
CO-2	Solve unconstrained single and multi-variable optimization problems.
CO-3	Apply linear programming and nonlinear programming techniques.
CO-4	Use dynamic programming for optimization.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	2	1	3	1
CO-2	3	-	2	1	3	1
CO-3	2	-	2	1	3	1
CO-4	2	-	2	1	3	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

The Nature and Organization of Optimization Problems: What Optimization is all about, Why Optimize? Scope and Hierarchy of Optimization, Examples of applications of Optimization,The Essential Features of Optimization Problems, General Procedure for Solving OptimizationProblems, Obstacles to Optimization.

Basic Concepts of Optimization: Continuity of Functions, Unimodal vs multimodal functions,Convex and concave functions, convex region, Necessary and Sufficient Conditions for an Extremum of an Unconstrained Function, Interpretation of the Objective Function in terms of itsQuadratic Approximation.

Optimization of Unconstrained Functions: One Dimensional search Numerical Methods forOptimizing a Function of One Variable, Scanning and Bracketing Procedures, Newton and Quasi-Newton Methods of Unidimensional Search, Polynomial approximation methods, How One-Dimensional Search is applied in a Multidimensional Problem, Evaluation of Unidimensional Search Methods.

Unconstrained Multivariable Optimization: Direct methods, Indirect methods – first order, Indirect methods – second order.

Linear Programming and Applications: Basic concepts in linear programming, Degenerate LP's – Graphical Solution, Natural occurrence of Linear constraints, The Simplex methods of solving linear programming problems, standard LP form, Obtaining a first feasible solution, Sensitivity analysis, Duality in linear programming.

Nonlinear programming with constraints: The Lagrange multiplier method, Necessary and sufficient conditions for a local minimum, introduction to quadratic programming.

Optimization of Staged and Discrete Processes: Dynamic programming, Introduction tointeger and mixed integer programming, Assignment problem (Hungarian method)

Learning Resources:

Text Books:

1. Singiresu S Rao, Engineering Optimization: Theory and Practice, John Wiley & Sons Ltd., 2019, 5th Edition.
2. Stoecker W. F., Design of Thermal Systems, McGraw-Hill, 2011, 3rd Edition.

Reference Books:

1. Edgar T.F. and D. M. Himmelblau, Optimization of Chemical Processes, McGraw Hill, 2001, 2nd Edition.
2. Stephen Boyd, Lieven Vandenberghe, Convex optimization, Cambridge University Press, 2004.
3. Applied Optimization with MATLAB Programming, P. Venkataraman, Wiley, 2009, 2nd Edition

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/103/105/103105139/

CH16064 **3-0-0 (3)**

Automotive Control Systems

Pre-Requisites: None

Course Outcomes:

CO-1	Understand the engine control loop in a vehicle
CO-2	Model the dynamics of different motions on the vehicle
CO-3	Analyze and apply the different vehicle control systems
CO-4	Development of the autonomous driving control of vehicle

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	1	1	1
CO-2	3	-	3	1	1	1
CO-3	3	-	3	3	2	1
CO-4	3	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Engine operations- Engine control loops- Control oriented Engine modelling- Coordinates and notation of vehicle dynamics- Vehicle control structures.

Modeling of Drive Dynamics: Vehicle dynamic modeling- Tire traction and force transfer-Vehicle motions: Longitudinal, lateral and Vertical behavior- Roll and Pitch Dynamics- Parameter and State estimation methods for vehicle dynamics

Dynamic Control of Chassis Components: Different types of control -Braking control – Steering control systems– Suspension control systems.

Driver Assistance System: On Driver-assistance system (DAS)- Advanced DAS for longitudinal and lateral guidance – Automatic driving: Classification- Longitudinal vehicle control –lateral vehicle control – Anti-collision control system – Autonomous driving.

Learning Resources:

Text Books:

1. R. Isermann, Automotive Control: Modelling and Control of Vehicles, Springer, 2021, 1st Edition.
2. A. Gailp Ulsoy, H. Peng and M. Cakmakci, Automotive Control systems, Cambridge University Press, 2012, 1st Edition.

Reference Books:

1.P.Lunger and J. Edelmann, Vehicle Dynamics of Modern Passenger Cars, Springer, 2018, 1st Edition.

2. U. Kiencke and L. Nielsen, Automotive Control systems: For Engine Driveline and Vehicle, Springer, 2005, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/107106088

CH16066 **3-0-0 (3)**

Estimation & Filtering Techniques

Pre-Requisites: **None**

Course Outcomes:

CO-1	Estimate the states using statistical and fundamental theories
CO-2	Develop Kalman filter algorithms for linear and nonlinear state estimation
CO-3	Apply the particle filters for state estimation
CO-4	Apply optimization techniques for state estimation

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	2	1	1
CO-2	3	-	3	2	1	1
CO-3	3	-	3	2	1	1
CO-4	3	-	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Preliminaries of statistical theory- State and parameter estimation - Steady-state perspective, State-space model formulation from fundamental theories. Observers. Continuous and discrete state space model and its relationships.

Kalman Filter: Development of Kalman Filter - Predictor-Corrector form, Analysis of Kalman Filter from various view-points, Kalman Filter algorithms - Orthogonality Principle, Divergence Problems, Suboptimal Error Analysis, Reduced-Order Sub-optimality.

Variants of Kalman Filter: Extended Kalman Filter (EKF) – Extensions to handle Non-Linearity and Non-Gaussian in processes. Development of EKF Predictor-Corrector form. Unscented Kalman Filter (UKF) - Concept of unscented sampling, UKF Predictor-Corrector form, estimation of the states with examples. Smoothing – Fixed point smoother, Fixed lag smoother, Fixed interval smoother. Performance of estimators – bias and covariance.

Particle Filters: Sequential Monte Carlo method- Enhancements to handle Delayed or infrequent measurements. Differential Algebraic Equation systems- Limitations of particle filters.

Optimization based State Estimation: Extensions to handle Non-Linearity and Constraints. Moving Horizon Estimator - Problem formulation, Connections to Kalman Filter. Receding Horizon Kalman Filter - Problem formulation, Connections to Kalman Filter

Learning Resources:

Text Books:

1. C.K.Chui, G.Chen, Kalman Filtering with Real-Time Applications, Springer, 2017, 5th Edition.

2. B.P. Gibbs, Advanced Kalman Filtering, Least-Squares and Modeling, Wiley, 2011,1st Edition.

Reference Books:

1. F. Vander Heijden, R.P.W. Duin, D. de Ridder, D.M.J. Tax, Classification, Parameter Estimation and State Estimation: An Engineering Approach Using MATLAB, Wiley, 2017, 2nd Edition.

2. Robert G. Brown and P.Y.C. Hwang, Introduction to Random Signals and Applied Kalman Filtering, John Wiley & Sons, 2012, 4th Edition.

3. Mohinder S. Grewal and Angus P. Andrews, Kalman Filtering: Theory and Practice Using MATLAB, Wiley, 2015, 3rd Edition.

4. Dan Simon, Optimal State Estimation: Kalman, H_∞ and Nonlinear Approaches, Wiley- Interscience, 2006, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105059

CH16068 **3-0-0 (3)**

Multi Sensor Data Fusion

Pre-Requisites: **None**

Course Outcomes:

CO-1	Infer the data collected from multiple sensors
CO-2	Develop mathematical models and algorithms for multi sensor data fusion
CO-3	Understand the variety of methods available for data fusion and sensor fusion
CO-4	Use data structures for implementing data fusion systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	2	1	1
CO-2	3	-	3	2	1	1
CO-3	3	-	3	2	1	1
CO-4	3	-	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Sensors and sensor data, Use of multiple sensors, Fusion applications. The inference hierarchy: output data-Models of the Data Fusion Process and Architectures: Data Fusion Models - Joint Directors of Laboratories Model, Modified Waterfall Fusion Model, Intelligence Cycle–Based Model, Boyd Model, Omnibus Model. Fusion Architectures - Centralized Fusion, Distributed Fusion, Hybrid Fusion

Data Fusion Mathematical tools: Algorithms, co-ordinate transformations, rigid body motion. Dependability and Markov chains, Meta – heuristics. Taxonomy of algorithms for multi sensor data fusion. Data association. Identity declaration.

Unified Estimation Fusion Models: Definition of the Estimation Fusion Process Unified Fusion Models Methodology, Unified Optimal Fusion Rules, Kalman Filter Technique as a Data Fuser. Bayesian and Dempster–Shafer Fusion Methods - Bayesian Method, Bayesian Method for Fusion of Data from Two Sensors, Dempster–Shafer Method, Comparison of the Bayesian Inference Method and the Dempster–Shafer Method.

Data information filter: Extended information filter. Decentralized and scalable decentralized estimation. Sensor fusion and approximate agreement. Optimal sensor fusion using range trees recursively. Distributed dynamic sensor fusion.

High performance data structures: Tessellated, trees, graphs and function. Representing ranges and uncertainty in data structures. Designing optimal sensor systems within dependability bounds. Implementing data fusion system.

Learning Resources:

Text Books:

1. H. Fourati, Multisensor Data Fusion, CRC Press, 2015, 1st Edition.
2. Jitendra R. Raol, Data Fusion Mathematics: Theory and Practice, CRC Press, 2015, 1st Edition.

Reference Books:

1. Lawrence A. Klein, Sensor and Data Fusion, SPIE Press, 2012, 2nd Edition.
2. Martin Liggins, David Hall, James Llinas, Handbook of Multi Sensor Data Fusion: Theory and Practice, CRC Press, 2008, 2nd Edition.
3. Multi Sensor Data Fusion with MATLAB, Jitendra R. Raol, CRC Press, 2009, 1st Edition.

Other Suggested Readings:

1. R. M. Abdelmoneem, E. Shaaban and A. Benslimane, "A Survey on Multi-Sensor Fusion Techniques in IoT for Healthcare," *2018 13th International Conference on Computer Engineering and Systems (ICCES)*, Cairo, Egypt, 2018, pp. 157-162.

https://ieeexplore.ieee.org/abstract/document/8639188

2. F. Alam, R. Mehmood, I. Katib, N. Albogami and A. Albeshri, "Data fusion and IoT for smart ubiquitous environments: A survey", ***IEEE Access***, vol. 5, pp. 9533-9554, 2017.

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7911293

3. Deepak sharma, Anuj kumar, Nitin Tyagi, Sunil S. Chavan, “Towards intelligent industrial systems: A comprehensive survey of sensor fusion techniques in IIoT”,Measurement: Sensors, Volume 32, 100944, 2024.

https://www.sciencedirect.com/science/article/pii/S2665917423002805

CH16070 **3-0-0 (3)**

Learning based Control Systems

Pre-Requisites: None

Course Outcomes:

CO-1	Understand the theoretical and implementation aspects of optimal control and model based reinforcement learning
CO-2	Apply optimal control techniques to optimize the operations of physical, social, and economic processes
CO-3	Design reinforcement learning control schemes
CO-4	Implement learning based control schemes on different processes

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	3	2	2	1
CO-2	3	-	3	2	2	1
CO-3	3	-	3	2	2	1
CO-4	3	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Control, stability, and metrics, Introduction to learning; System identification and adaptive control

Optimization: Unconstrained optimization, constrained optimization; convex optimization and optimization tools. Dynamic programming, discrete LQR, Stochastic DP, value iteration, policy iteration, Automatic differentiation, LQG, dual control, introduction to reinforcement learning

Nonlinear optimization: Nonlinearity; Tracking LQR, iterative LQR, DDP, Regression models.

Direct methods for optimal control: sequential convex programming, HJB, HJI, reachability, analysis, Training neural networks and Python/R/MATLAB.

Model predictive control: Feasibility and stability of MPC, Adaptive and learning MPC, Model-based RL Model-free RL: policy gradient and actor critic, Model-based policy learning, Model-based policy learning, calculus of variations. Indirect methods for optimal control: Pontryagin's maximum principle, wrap up, recent work, and future directions.

Learning Resources:

Text Books:

1. D. P. Bertsekas, Dynamic Programming and Optimal Control, Vol. I and II, Athena Scientific, 2012.
2. D. P. Bertsekas, Nonlinear Programming, Athena Scientific, 2016.

3. Liuping Wang, Model Predictive Control System Design and Implementation using MATLAB, Springer, 2009.

Reference Books:

1. F. Borrelli, A. Bemporad, M. Morari, Predictive Control for Linear and Hybrid Systems, 2017.
2. Lewis and Derong Liu, Reinforcement Learning and Approximate Dynamic Programming for Feedback Control, John Wiley/IEEE Press, Computational Intelligence Series, 2012
3. D. K. Kirk, Optimal Control Theory: An Introduction, Dover Publications, 2004.
4. J. B. Rawlings, D. Q. Mayne, M. M. Diehl, Model Predictive Control: Theory, Computation, and Design, Nob Hill Publishing LLC, 2017, 2nd Edition
5. R. S. Sutton and A. G. Barto, Reinforcement Learning: An Introduction. MIT Press, 2018.

Other Suggested Readings:

1. David Silver's class @UCL: Reinforcement learning: https://www.davidsilver.uk/teaching/
2. Rich Sutton's class: Reinforcement Learning: http://incompleteideas.net/
3. John Schulman's and Pieter Abeel's class: Deep Reinforcement Learning: https://rll.berkeley.edu/deeprlcourse-fa15/
4. Sergey Levine's, Chelsea Finn's and John Schulman's class: Deep Reinforcement Learning: http://rail.eecs.berkeley.edu/deeprlcourse/
5. Katerina Fragkiadaki, Tom Mitchell @CMU, Deep Reinforcement Learning and Control: http://www.andrew.cmu.edu/course/10-703/
6. Prof. F. L. Lewis research https://lewisgroup.uta.edu/code/Software%20from%20Research.htm

CH16072 **3-0-0 (3)**

Intelligent Control

Pre-Requisites: None

Course Outcomes:

CO-1	Development of the neural networks and analyse the computational complexity
CO-2	Apply neural networks to control the systems using different control structures
CO-3	Analyse and design a fuzzy logic based controllers for different systems
CO-4	Design controllers using genetic algorithms for different engineering systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	2	2	2	1
CO-2	3	-	2	2	2	1
CO-3	3	-	3	2	2	1
CO-4	3	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Artificial Neural Networks: Basic properties of Neurons, Neuron Models, Feed-forward networks. Computational complexity of ANNs.

Neural Networks Based Control: ANN based control: Introduction: Representation and identification, modeling the plant, Radial Basis Function, control structures – supervised control, Model reference control, Internal model control, Predictive control.

Fuzzy Logic Basics: Fuzzy Controllers: Preliminaries – Fuzzy sets and Basic notions – Fuzzy relation calculations – Fuzzy members – Indices of Fuzziness – comparison of Fuzzy quantities – Methods of determination of membership functions.

Fuzzy Logic Based Control: Fuzzy Controllers: Preliminaries – Fuzzy sets in commercial products – basic construction of fuzzy controller – Analysis of static and dynamic properties of fuzzy controller.

Neuro – Fuzzy and Fuzzy – Neural Controllers: Neuro – fuzzy systems: A unified approximate reasoning approach – Construction of role bases by self-learning: System structure and learning.

Introduction to Genetic algorithms. Controller design using genetic algorithms. Applications to different engineering systems.

Learning Resources:

Text Books:

1. Z.Kovacic, S Bogdan,Fuzzy Controller Design, Taylor & Francis, 2017, 1st Edition.
2. L. Behera, S. Kumar, P.K. Patchaikani, R.R. Nair, S. Dutta, Intelligent Control of Robotics systems, CRC Press, 2020, 1st Edition.

Reference Books:

1. J. Liu, Radial Basis function neural network control for mechanical systems, Springer-Verlag Berlin, 2015, 1st Edition.
2. M. Nørgaard, O. Ravn, N. K. Poulsen, L. K. Hansen, Neural Networks for Modelling and Control of Dynamic Systems, Springer-Verlag, 2003, 1st Edition.
3. S. N. Sivanandam and S. N. Deepa,Principles of Soft Computing, Wiley, 2018, 3rd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108104049