NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

SCHEME OF INSTRUCTION AND SYLLABI

for M.Tech. Systems and Control Engineering Program

(Effective from 2021-22)

DEPARTMENT OF CHEMICAL ENGINEERING

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

Department of Chemical Engineering

VISION

To attain global recognition in research and training students for meeting the challenging needs of chemical & allied industries and society.

MISSION

- Providing high quality undergraduate and graduate education in tune with changing needs of industry.
- Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.
- Fostering industry-academia relationship for mutual benefit and growth.

Department of Chemical Engineering:

Brief about the Department:

The department was started in the year 1964 and since then it has come a long way in educating budding chemical engineers and scholars. The department celebrated its Golden Jubilee in 2014-15. The department is operating in a new building spanning around 8000 sq. m with ample space in class rooms and laboratories since 2018. The building of the department with green ambience having aesthetic landscaping and gardening has secured first place based on its architectural elegance.

The department of Chemical Engineering offers B.Tech., M.Tech. and Ph.D programs. The department has well qualified faculty dedicated to teaching and doing research in fundamental and advanced areas. The department houses various laboratories catering to the needs of the curriculum. The Department has good experimental as well as simulation based research facilities. The faculty are actively engaged in industrial consultancy and sponsored research projects. The department has inked MoUs with some of the leading industries and Universities in India and abroad. The graduating students are absorbed into reputed firms through campus placements and good number of students are going for higher studies. The department aims at inculcating lifelong learning skills in the students. The alumni of the department are shouldering high positions in multifarious organizations.

Both B.Tech. and M.Tech. programs in Chemical Engineering have been fully accredited for 5 years by National Board of Accreditation (NBA) in June 2015.

Brief about the Programme:

This is an interdisciplinary program admitting students with different backgrounds such as Instrumentation & Control Engineering, Electrical Engineering, Electronics and Instrumentation, Chemical Engineering, etc…The students are exposed to core and advanced areas of Systems and Control in the first two semesters consisting of a well-structured palette of core subjects. A wide range of electives are offered, which provides an opportunity to explore the branch in a desired perspective. As a part of the curriculum, students get hands on experience on software packages MATLAB/SIMULINK, Python. Students devote their entire second year for the Master's dissertation Project. Education and research are closely integrated within this Master's program in the field of Control and Automation. The department is equipped with good Control Laboratory with different experimental facilities for understanding Systems Modeling, Control and Automation concepts.

List of Programs offered by the Department:

Program	Title of the Program
B.Tech.	Chemical Engineering
M.Tech.	Chemical Engineering
	Systems and Control Engineering
PG Diploma	Systems and Control Engineering
Ph.D.	

Note: Refer to the Rules and Regulations for M.Tech. program (weblink) given on the institute website.

M.Tech. – Systems and Control Engineering

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 systems and control engineering to meet contemporary needs of industry and research.
PEO-3	Attain professional competency to address the technological needs of society and industry.
PEO-4	Demonstrate leadership and initiative to advance organizational goals with commitment to ethical standards, team work and respect for diverse cultural backgrounds.
PEO-5	Engage in ongoing learning and professional development through pursuance of higher education and self-study.

Program Articulation Matrix

PEO / **Mission Statements**	**PEO1**	**PEO2**	**PEO3**	**PEO4**	**PEO-5**
Providing high quality education in tune with changing needs of industry.	3	3	3	2	1
Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.	3	3	2	1	1
Fostering industry-academia relationship for mutual benefit and growth.	3	3	2	2	2

1-Slightly; **2-Moderately;** **3-Substantially**

M.Tech. – Systems and Control Engineering

Program Outcomes

PO-1	Independently carry out research / investigation and development work to solve practical problems
PO-2	Write and present a substantial technical report/document
PO-3	Apply modern experimental, computational, simulation and design tools to address the challenges faced in industries from a control perspective
PO-4	Implement control engineering and automation in a contemporary, global, economic, environmental and societal contexts for sustainable development.
PO-5	Contribute effectively in a team and demonstrate leadership skills with professional ethics.
PO-6	Pursue life-long learning, updating knowledge and skills for professional and societal development.

SCHEME OF INSTRUCTION

M.Tech. Systems and Control Engineering – Course Structure

I - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH5201	System Identification	3	0	0	3	PCC
2	CH5202	Advanced Process Control	3	0	0	3	PCC
3	CH5103	Engineering Optimization	3	0	0	3	PCC
4	MA5036	Computational Techniques	3	0	0	3	PCC
5		Elective - I	3	0	0	3	PEC
6		Elective – II	3	0	0	3	PEC
7	MA5046	Computational Laboratory	0	1	2	2	PCC
8	CH5203	Process Control Laboratory	0	1	2	2	PCC
9	CH5248	Seminar - I	0	0	2	1	SEM
		Total	**18**	**2**	**6**	**23**	

I - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH5251	Intelligent Control	3	0	0	3	PCC
2	CH5252	Data Analytics	3	0	0	3	PCC
3	EE5153	Digital Control Systems	3	0	0	3	PCC
4		Elective – III	3	0	0	3	PEC
5		Elective – IV	3	0	0	3	PEC
6		Elective – V	3	0	0	3	PEC
7	CH5253	Systems and Control Laboratory	0	1	2	2	PCC
8	CH5254	Digital and Intelligent Control Laboratory	0	1	2	2	PCC
9	CH5298	Seminar - II	0	0	2	1	SEM
		Total	**18**	**2**	**6**	**23**	

SCHEME OF INSTRUCTION

M.Tech. Systems and Control Engineering – Course Structure

II - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH6247	Comprehensive Viva-voce				2	CVV
2	CH6249	Dissertation Part - A				12	DW
		Total				**14**	

II - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH6299	Dissertation Part – B				20	DW
		Total				**20**	

Credits in Each Semester					
Cat. Code	**Sem-I**	**Sem-II**	**Sem-III**	**Sem-IV**	**Total**
PCC	16	13	-	-	29
PEC	6	9	-	-	15
SEM	1	1	-	-	2
CVV	-	-	2	-	2
DW	-	-	12	20	32
Total	**23**	**23**	**14**	**20**	**80**

Note: PCC – Professional Core Courses
PEC – Professional Elective Courses
CVV - Comprehensive Viva-voce
DW – Dissertation Work

Program Elective Courses

Elective – I, II (I Year, I Semester)		
S. No.	**Course Code**	**Course Title**
1	CH5211	Modern Control Theory and Analysis
2	CH5212	Performance Assessment & Plant-wide Control
3	CH5213	Random and Stochastic Processes
4	CH5214	Industrial Instrumentation
5	CH5215	Design of PID Controllers
6	CH5216	Networked Control Systems
7	CH5217	Statistical Process Control
8	CH5218	Quantitative Feedback Theory
Electives – III, IV, V (II Year, II Semester)		
S. No.	**Course Code**	**Course Title**
1	CH5261	Industrial Automation
2	CH5262	Nonlinear Control
3	CH5263	Estimation and Filtering Techniques
4	CH5264	Learning based Control Systems
5	CH5265	Bioprocess and Biomedical Instrumentation
6	CH5266	Multi Sensor Data Fusion
7	CH5267	Data-Driven Control
8	CH5268	Real Time Embedded Systems
9	CH5269	Intelligent Instrumentation and Applications
10	CH5270	Guidance Strategies for Autonomous Vehicles
11	CH5271	Optimal and Adaptive Control
12	CH5272	Hybrid Systems
13	CH5273	Sliding Mode Control

Note: In addition to the above listed electives, a student can also register one elective per semester from other departments and two electives per semester from other specializations of the same department, based on suitability of timetable.

DETAILED SYLLABUS

M.Tech. – Systems and Control Engineering

Course Code: CH 5201	SYSTEM IDENTIFICATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Apply system identification concepts
CO2	Develop Parametric, Non-parametric and disturbance models
CO3	Estimate parameters using regression analysis
CO4	Perform residual analysis

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	-	2
CO2	3	1	3	3	-	2
CO3	3	1	3	3	-	2
CO4	3	1	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

System Identification - Motivation and Overview. Models of Discrete-Time LTI Systems – Convolution equation. Difference equations, Transfer functions, State-space models, Discretization, Sampling and Hold operations, Sampling theorem.

Non-parametric models - impulse response, step response and frequency response models.

Disturbance models - random processes, representation of stationary processes, white-noise process, auto-covariance function (ACF), cross-covariance function (CCF), ARMA and ARIMA models. Parametric model structures - ARX, ARMAX, OE, BJ models.

Regression techniques, statistical properties.

Estimation of non-parametric models - impulse / step response coefficients, frequency response models. Estimation of parametric models - notions of prediction and simulation, predictors for parametric models, prediction-error methods, Instrumental Variable method.

Model Structure Selection and Diagnostics - estimation of delay and order, residual checks, properties of parameter estimates, model comparison and selection, model validation.

Learning Resources:

Text Books:

1. Principles of System Identification: Theory and Practice, Arun K. Tangirala, CRC Press, 2015.
2. Nonlinear System Identification, Oliver Nelles, Springer, 2020, 2nd Edition.

Reference Books:

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

Online Resources:

1. NPTEL course link: https://nptel.ac.in/courses/103/106/103106149/
2. MATLAB SysID tool webinar by Prof. Ljung: https://in.mathworks.com/videos/introduction-to-system-identification-81796.html

Course Code: CH 5202	ADVANCED PROCESS CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Identify controlled and manipulated variables
CO2	Design regulatory control scheme for a given process
CO3	Analyse the controlled and manipulated variables in multivariable processes.
CO4	Apply linear and nonlinear model predictive control.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	1	3	3	-	2
CO2	3	1	3	3	-	2
CO3	3	1	3	3	-	2
CO4	3	1	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to control; Hierarchy of control layers, review of basics. Selection of controlled and manipulated variables. System linearization; state space and transfer function models.

Advanced 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.

Model Predictive Control (MPC) - Concepts; Theory and implementation; Relation with LQ-control. Implementation of MPC, State update and model prediction. Receding Horizon implementation; Issues and Challenges.

Economic MPC, Nonlinear Model Predictive Control (NMPC) – Theory and implementation.

Introduction to controller performance assessment and diagnosis – minimum variance benchmark.

Learning Resources:

Text Books:

1. Process Dynamics and Control, Seborg, D. E., Edgar, T. F., Millechamp, D. A., Doyle III, F. J., Wiley, 2014, 3rd Edition.
2. Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, Raghunathan Rengaswamy, Babji Srinivasan, Nirav Pravinbhai Bhatt, CRC Press, 2020.

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

Reference Books:

1. Predictive Control for Linear and Hybrid Systems, Francesco Borrelli, Alberto Bemporad, Manfred Morari, Cambridge University Press, 2017.
2. Process Control: Theory and Applications, Jean-Pierre Corriou, Springer, 2018, Second Edition.
3. Process Dynamics and Control, B. Roffel and B. Betlem, Wiley, 2006.
4. Advanced Process Control, Cecil L. Smith, Wiley, 2010.
5. Process Control: Principles and Applications, Surekha Bhanot, Oxford, 2008.

Online Resources:

Prof. Niket Kaisare, IIT Madras Course on MPC:
https://onlinecourses.nptel.ac.in/noc21_ge01/preview

Course Code: CH 5103	ENGINEERING OPTIMIZATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Formulate objective function for a given problem
CO2	Solve unconstrained single and multi-variable optimization problems
CO3	Apply linear programming and nonlinear programming techniques
CO4	Use dynamic programming for optimization

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	3	-	1
CO2	3	2	3	3	-	1
CO3	3	2	3	3	-	1
CO4	3	2	3	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 Optimization Problems, 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 its Quadratic Approximation.

Optimization of Unconstrained Functions: One Dimensional search Numerical Methods for Optimizing 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 to integer and mixed integer programming, Assignment problem (Hungarian method)

Metaheuristic optimization methods: bio-inspired approaches

Learning Resources:

Text Books:

1. Optimization of Chemical Processes, Edgar T.F. and D. M. Himmelblau, McGraw Hill, 2001, 2nd Edition.
2. Engineering Optimization: Theory and Practice, Singiresu S Rao, John Wiley & Sons Ltd., 2019, 5th Edition.

Reference Books:

1. Optimization: Theory and Practice, Mohan C. Joshi and Kannan M. Moudgalya, Alpha Science International Limited, 2004.
2. Convex optimization, Stephen Boyd, Lieven Vandenberghe, Cambridge University Press, 2004.
3. Applied Optimization with MATLAB Programming, Venkataraman P., Wiley, 2009, 2nd Edition.
4. Design of Thermal Systems, Stoecker W. F., McGraw-Hill, 2011, 3rd Edition.

Online Resources:

Course Code: MA5036	COMPUTATIONAL TECHNIQUES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Implement linear algebra concepts for solving engineering problems
CO2	Solve ordinary differential equations and differential algebraic equations
CO3	Apply probability theory
CO4	Employ Statistical techniques to solve engineering problems

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	2	-	1
CO2	3	1	3	2	-	1
CO3	3	1	3	2	-	1
CO4	3	1	3	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Linear Algebra: Solving linear equations, Vector spaces and Subspaces, Orthogonality, Determinants, Eigenvalues and Eigen vectors, Function spaces. Cayley-Hamilton theorem, Polynomials and functions defined on matrices, Similarity transformations, Jordan forms, quadratic forms.

Review of solution methods for system of linear and nonlinear algebraic equations.

Linear Ordinary Differential Equations and Solution Methods.

Nonlinear Ordinary Differential Equations: Autonomous / non-autonomous systems of odes, Differential-Algebraic equations - Solution methods.

Partial differential equations – Solution methods for parabolic, hyperbolic and elliptic equations.

Introduction to Probability: Sets, fields, sample space and events. Combinatorics: Probability on finite sample spaces. Joint and conditional probabilities, independence; Bayes' rule and applications.

Continuous and discrete random variables, cumulative distribution function (cdf); probability mass function (pmf); probability density functions (pdf) and properties. Jointly distributed random variables, conditional and joint density and distribution functions, independence. Central limit theorem and its significance.

Applications to different engineering systems.

Learning Resources:

Text Books:

1. Introduction to Linear Algebra, Gilbert Strang, Wellesley-Cambridge Press, 2009, Fourth Edition.
2. Differential Equations and Linear Algebra, Gilbert Strang, Wellesley-Cambridge Press, 2014.
3. Nonlinear ordinary differential equations, an introduction for scientists and engineers, D.W.Jordan, P. Smith, Oxford University Press, 2007.
4. Intuitive Probability and Random Processes using MATLAB, Steven M. Kay, Springer, 2006.

Reference Books:

1. Applied Numerical Methods. Gourdin, A. and M Boumhrat; Prentice Hall India, 2000.
2. Numerical Methods for Engineers, Gupta, S. K.; New Age International, 2015, 3rd Edition.
3. Applied Numerical Methods for Engineers and Scientists, Singiresu S. Rao, Prentice Hall, 2001.
4. Probability, Random Variables and Stochastic Processes, Athanasios Papoulis, S. Unnikrishna Pillai, Tata Mc-Graw Hill, 2002, 4th Edition.

Online Resources:

1. http://www-math.mit.edu/~gs/index.html

Course Code: MA5046	COMPUTATIONAL LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Apply numerical methods for solving engineering problems
CO2	Apply statistical methods for data analysis
CO3	Solve unconstrained and constrained optimization problems
CO4	Use programming tools such as MATLAB / SIMULINK / EXCEL / CASADI

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	2	3	1
CO2	2	2	3	2	3	1
CO3	2	2	3	2	3	1
CO4	2	2	3	2	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

The students will be using MATLAB / SIMULINK / EXCEL / CASADI.

The list of computational experiments (Examples relevant to engineering systems):

1. Solution of linear algebraic equations
2. Solutions of non-linear algebraic equations
3. Solution of linear ODEs
4. Solution of non-linear ODEs
5. Solution of PDEs
6. Linear Regression and Non-linear Regression Methods
7. Statistical analysis of data – mean, variance, distribution characteristics
8. Probability density functions (PDFs)
9. Optimization of unconstrained optimization problems
10. Optimization of constrained optimization problems

Learning Resources:

Text Books:

1. Lab Manuals / Exercise sheets

Course Code: CH5203	PROCESS CONTROL LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None.

Course Outcomes:

At the end of the course, the student will be able to

CO1	Apply the identification concepts for systems.
CO2	Design controllers for linear systems.
CO3	Identify and control nonlinear processes.
CO4	Apply feed-forward and ratio control schemes on the given process.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	3	2	2	1	2
CO2	3	3	2	2	1	2
CO3	3	3	2	2	1	2
CO4	3	3	2	2	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

In this lab, experiments are given to the students like mini projects. Students need to apply the concepts in a systematic manner in order to perform these experiments. The experiment need to be performed with the given operating conditions in the respective session.

1. Feed forward control for temperature process.
2. Ratio control
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:

Text Books:

1. Lab manuals and Online Journal

Reference Books:

1. Jean-Pierre Corriou, Process Control: Theory and Applications, Second Edition, Springer, 2018.
2. Raghunathan Rengaswamy, Babji Srinivasan, Nirav Pravinbhai Bhatt, Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, CRC Press, 2020.

Online Resources:

Course Code: CH5248	SEMINAR - I	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Select a topic from extensive literature review
CO2	Communicate orally with a group of people
CO3	Demonstrate comprehension of the topic
CO4	Prepare a consolidated seminar report

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	-	3
CO2	2	2	1	1	3	3
CO3	2	1	2	3	2	2
CO4	2	3	1	-	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to systems and control engineering and allied areas.

Leading journals and conferences, paper referencing and critiquing, ethics and plagiarism, improving presentation and communication skills, Technical paper and report writing.

Learning Resources:

1. Systems, Control Engineering and Automation Journals and Conference proceedings.
2. Technical communication, Mike Markel, S.A. Selber, Bedford/St. Martin's, 2017, 12th Edition.
3. The essentials of Technical Communication, E. Tebeaux, Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical writing process, K. Morgan, S. Spajic, Better on Paper publications, 2015, 1st Edition.
5. Managing your documentation projects, J.T. Hackos, Wiley, 1994, 1st Edition.

Text Books:

Reference Books:

Online Resources:

Course Code: CH5251	INTELLIGNET CONTROL	Credits: 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand the concept of neural networks
CO2	Apply neural networks to control the process plants
CO3	Develop fuzzy logic based controllers
CO4	Design controllers using genetic algorithms

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	2	2	3	-	1
CO2	3	2	2	3	-	1
CO3	3	2	2	3	-	1
CO4	3	2	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Neural Networks: 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, control structures – supervised control, Model reference control, Internal model control, Predictive control.

Introduction to reinforcement learning and deep learning.

Introduction to Fuzzy Logic: 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. Artificial Neural Networks, Bose and Liang, Tata McGraw Hill, 1996.

2. Fuzzy Modeling and Fuzzy Control, Huaguang Zhang, Derong Liu, Birkhauser Publishers, 2006.
3. Principles of Soft Computing, S. N. Sivanandam and S. N. Deepa, John Wiley & Sons, 2007.

Reference Books:

1. Neural Networks for Modelling and Control of Dynamic Systems, M. Nørgaard, O. Ravn, N. K. Poulsen, L. K. Hansen, Springer-Verlag, 2000
2. Intelligent Systems and Control, Laxmidhar Behera and Indrani Kar, Oxford, 2009
3. Neural Networks and Fuzzy Systems: A Dynamic Approach to Machine Intelligence, Kosco B, Prentice Hall of India, New Delhi, 1992.
4. Fusion of Neural Networks, Fuzzy Systems and Genetic Algorithms: Industrial Applications, Lakshmi C. Jain, N. M. Martin, CRC Press, 1998.
5. Fuzzy Controller Design, Zdenko Kovacic and Stjepan Bogdan, Taylor & Francis, 2006

Online Resources:

1. Prof. Kevin M. Passino resources of MATLAB codes (http://eewww.eng.ohio-state.edu/~passino/ICbook/ic_code.html)

Course Code: CH5252	DATA ANALYTICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Demonstrate proficiency with statistical analysis of data
CO2	Use inferential statistics for decision making
CO3	Apply supervised learning for classification and regression problems
CO4	Apply unsupervised learning for clustering

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	2	2	2	1	2
CO2	3	2	2	2	1	2
CO3	3	2	2	2	1	2
CO4	3	2	2	2	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to data analytics, Python fundamentals.

Data Quality and Pre-processing: Distance measures, dimensionality reduction, principal component analysis (PCA).

Descriptive Statistics:

Graphical approach - Frequency tables, relative frequency tables, grouped data, pie chart, bar chart, histograms, ogives, stem and leaf plots, box plots, dot diagram, scatter plots, Pareto diagram.

Measure of Central Tendency and Dispersion **-** Arithmetic mean, median and mode, variance, standard deviation, quartiles, range, mean absolute deviation, coefficient of variation, Z scores, normal distribution, confidence interval estimation.

Probability Distribution and Inferential Statistics: Random variables, probability distributions, hypothesis testing, single sample test, two sample test, Type I error, Type II error, Analysis of Variance (ANOVA).

Supervised learning: Linear regression, ridge regression, Lasso regression, logistic regression, multiple linear regression, goodness of fit, bias–variance trade off, k-nearest neighbors algorithm, linear discriminant analysis, classification and regression trees and pruning, support vector machines, random forest, Naive Bayes, Introduction to deep learning.

Unsupervised learning: Cluster analysis – K Means, hierarchical, DBSCAN.

Applications to different engineering systems.

Learning Resources:

Text Books:

1. Applied Statistics and Probability for Engineers, Douglas C. Montgomery, George C. Runger, 6th Edition, John Wiley & Sons Inc., 2016.
2. The Elements of Statistical Learning, Trevor Hastie, Robert Tibshirani, Jerome Friedman, 2nd Edition, Springer, 2009.
3. Introduction to Machine Learning, Ethem Alpaydın,3rd Edition, MIT Press, 2014

Reference Books:

1. A General Introduction to Data Analytics, João Mendes Moreira , André C. P. L. F. de Carvalho, Tomáš Horváth, Wiley, 2019.
2. Introduction to Data Mining, Pang-Ning Tan, Michael Steinbach, Anuj Karpatne, Vipin Kumar, 2nd Edition, Pearson, 2019.

Online Resources:

1. https://nptel.ac.in/courses/106/107/106107220/
2. https://nptel.ac.in/courses/110/106/110106072/

Course Code: EE5153	DIGITAL CONTROL SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Apply Z transforms.
CO2	Analyze stability for discrete time processes.
CO3	Design controllers for discrete time processes.
CO4	Develop discrete state space models.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	-	1
CO2	3	1	3	3	-	1
CO3	3	1	3	3	-	1
CO4	3	1	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Digital control systems - Quantizing and quantization error, Data acquisition, Conversion and distribution system

Z-Transform: 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: State space representation of digital control systems - Solution of discrete time state space equations, Pulse transfer function matrix, Discretization of continuous time state space equations, Lyapunov stability analysis

Pole Placement & Observer Design: Controllability, Observability

Quadratic Optimal Control Systems: Design via pole placement, State observers, Quadratic optimal control, Steady state quadratic optimal control, Quadratic optimal control of a servo system.

Learning Resources:

Text Books:

1. Digital control engineering, M. Gopal, New Age Int. Ltd., 2nd Edition, 2014.
2. Discrete time control systems, K. Ogata, Pearson Education, 2nd Edition, 2006.

Reference Books:

1. Modern control Engineering, Katsuhiko Ogata, Pearson Education India, 5th Edition, 2015.
2. Digital Control Systems, B.C. Kuo, Oxford University Press, 2nd Edition, 2012.
3. Discrete Time Control Problems using MATLAB, Joe H. Chow, Dean K. Frederick, Nicholas W. Chbat, Thomson Brooks, 2003.

Online Resources:

Course Code: CH5253	SYSTEMS AND CONTROL LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Design controllers for unstable processes
CO2	Design controllers for interacting systems
CO3	Identify and control nonlinear processes
CO4	Design controllers for MIMO processes

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	3	1	1
CO2	3	2	3	3	1	1
CO3	3	2	3	3	1	1
CO4	3	2	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:
In this lab, experiments are given to the students like mini projects. Students need to apply the concepts in a systematic manner in order to perform these experiments. The experiment need to be performed with the given operating conditions in the respective session.

1. Control of unstable inverted pendulum system.
2. Programmable logic controller implementation on (i) bottle filling unit (ii) conveyer belt system (iii) level control
3. Data based model development for MIMO conical tank process
4. LQR/MPC application to a coupled four tank system
5. Control of level in an MIMO conical tank process
6. Data acquisition using standard add-on cards/remote I-O modules
7. Identification and control of liquid level in non-interacting cylindrical tank systems.
8. Identification and control of level in cylindrical tanks operated in interacting mode
9. Identification and control of level in a three tank process

Learning Resources:

Text Books:
1. Lab manuals / Exercise sheets

Reference Books:
1. Jean-Pierre Corriou, Process Control: Theory and Applications, Second Edition, Springer, 2018.
2. Raghunathan Rengaswamy, Babji Srinivasan, Nirav Pravinbhai Bhatt, Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, CRC Press, 2020.

Online Resources:

Course Code: CH5254	DIGITAL AND INTELLIGENT CONTROL LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Apply discrete control tools for processes
CO2	Design controllers and simulate its performance on MIMO systems.
CO3	Estimate states using filtering techniques
CO4	Understand PLC programming

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	3	2	2
CO2	3	2	3	3	2	2
CO3	3	2	3	3	2	2
CO4	3	2	3	3	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:
The student will carry out simulation studies using appropriate programming tools (MATLAB/SIMULINK/Python/Siemens-TIA. The list of case studies include

1. PID controller design in Laplace domain
2. Discrete PID controller design and analysis
3. Stability analysis in discrete domain
4. Discrete controllers for MIMO systems
5. Model predictive control
6. Neural networks based control design
7. Fuzzy logic control design
8. Controller design using genetic algorithms
9. State estimation using Kalman filter / Extended Kalman filter
10. PLC programming (Siemens-TIA)

Learning Resources:

Text Books:

Reference Books:

1. M. Gopal: Digital control engineering, New Age Int. Ltd., 2nd Edition, 2014
2. Bose and Liang, Artificial Neural Networks, Tata McGraw Hill, 1996.
3. Huaguang Zhang, Derong Liu, Fuzzy Modeling and Fuzzy Control, Birkhauser Publishers, 2006.

Online Resources:

Course Code: CH5298	SEMINAR - II	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Select a topic from extensive literature review
CO2	Communicate orally with a group of people
CO3	Demonstrate comprehension of the topic
CO4	Prepare a consolidated seminar report

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	-	3
CO2	2	2	1	1	3	3
CO3	2	1	2	3	2	2
CO4	2	3	1	-	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to systems and control engineering and allied areas.

Leading journals and conferences, paper referencing and critiquing, ethics and plagiarism, improving presentation and communication skills, Technical paper and report writing.

Learning Resources:

1. Systems, Control Engineering and Automation Journals and Conference proceedings.
2. Technical communication, Mike Markel, S.A. Selber, Bedford/St. Martin’s, 2017, 12th Edition.
3. The essentials of Technical Communication, E. Tebeaux, Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical writing process, K. Morgan, S. Spajic, Better on Paper publications, 2015, 1st Edition.
5. Managing your documentation projects, J.T. Hackos, Wiley, 1994, 1st Edition.

Text Books:

Reference Books:

Online Resources:

Course Code: CH6247	COMPREHENSIVE VIVA-VOCE	Credits 0-0-0: 2

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Demonstrate an understanding of the courses studied.
CO2	Explain the principles, phenomena and their applications.
CO3	Communicate effectively.
CO4	Comprehend the concepts for solving practical issues.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	1	1	1	1	2	1
CO2	1	1	1	1	2	1
CO3	1	1	1	1	1	1
CO4	1	1	2	2	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

All the courses of I year.

Course Code: CH6249	DISSERTATION PART - A	Credits 0-0-0: 12

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Identify the problem based on literature survey
CO2	Formulate the problem by defining objectives
CO3	Develop an effective solution methodology
CO4	Prepare a technical report
CO5	Demonstrate the progress of dissertation work

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	3	3	3	1	2
CO2	3	3	3	3	1	2
CO3	3	3	3	3	1	2
CO4	3	3	3	3	1	2
CO5	3	3	3	3	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Course Code: CH6299	DISSERTATION PART - B	Credits 0-0-0: 20

Pre-Requisites: CH6149 Dissertation Part - A

Course Outcomes:

At the end of the course, the student will be able to

CO1	Implement the methodology identified in dissertation part-A
CO2	Analyze and interpret the results
CO3	Draw conclusions from the results
CO4	Prepare a comprehensive dissertation report following ethical principles
CO5	Demonstrate the outcomes of dissertation work

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	3	3	3	1	1
CO2	3	3	3	3	1	1
CO3	3	3	3	2	1	1
CO4	3	3	3	3	1	1
CO5	3	3	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Elective Courses Offered in First Semester

Course Code: CH5211	MODERN CONTROL THEORY AND ANALYSIS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand state-space models and their representations.
CO2	Solve the state equations.
CO3	Design control systems using state-space models.
CO4	Estimate the states using Kalman filter.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	2	-	1
CO2	3	-	3	3	-	1
CO3	3	-	3	3	-	1
CO4	3	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

State-Space Representation: The State-Space, Linear Transformation of State-Space Representations, System Characteristics from State-Space Representation, Special State-Space Representations: The Canonical Forms.

Solving the State-Equations: Solution of the Linear Time Invariant State Equations, Calculation of the State-Transition Matrix, Understanding the Stability Criteria through the State-Transition Matrix. Numerical Solution of Linear Time-Invariant State-Equations. Numerical Solution of Linear Time-Varying State-Equations. Numerical Solution of Nonlinear State-Equations. Applications to different processes.

Control System Design in State-Space: Design: Classical vs. Modern. Controllability and observability, Pole-Placement Design Using Full-State Feedback, Pole-placement regulator design.

Optimal control and optimal observers: Hamilton-Jacobi-Bellman equation, Linear Quadratic Regulator Problem,

Kalman Filter: Importance, Analytical form, limitations and extensions.

Learning Resources:

Text Books:

1. Modern Control Engineering, Ogata, K, 5th Edition, Prentice-Hall, 2010.
2. Modern Control Design - with MATLAB & SIMULINK, Ashish Tewari Wiley & Sons, 2002.
3. Computer Controlled Systems: Theory and Design, K.J. Astrom and B. Wittenmark, Prentice-Hall, 2000.
4. Modern Control Systems Theory, M. Gopal 3rd Edition, New Age International, 2014.

Reference Books:

1. Modern Control Theory, Brogan W. L, 3rd Edition, Prentice Hall, 1991.
2. Applied Nonlinear Control, Jean-Jacques E. Slotine, Weiping Li Prentice Hall, 1991.

Online Resources:

Course Code: CH5212	PERFORMANCE ASSESSMENT & PLANT WIDE CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand minimum variance bench mark
CO2	Estimate and use interactor matrices
CO3	Apply unified approach for performance assessment
CO4	Carry out degrees of freedom
CO5	Understand plant wide control

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	3	3	-	2
CO2	2	-	3	3	-	2
CO3	2	-	3	3	-	2
CO4	2	-	3	3	-	2
CO5	2	-	3	3	-	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.

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. Process Control Performance Assessment: From Theory to Implementation, Andrzej Ordys, Damien Uduehi, Michael A Johnson, Springer, 2007.
2. Control Performance Management in Industrial Automation, Mohieddine Jelali, Springer, 2013.
3. Plant-wide Process Control, William L. Luyben, Bjorn D. Tyreus, Michael L. Luyben, McGraw Hill, 1998.

Reference Books:

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

Online Resources:

Course Code: CH5213	RANDOM AND STOCHASTIC PROCESSES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Describe a random event in terms of procedure, observation, and probability
CO2	Characterize probability models for discrete and continuous random variables
CO3	Understand the convergence of random variables
CO4	Characterize stochastic processes with an emphasis on random processes

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	3	-	1
CO2	3	-	2	3	-	1
CO3	3	-	2	3	-	1
CO4	3	-	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Probability: Definitions, scope and history; limitation of classical and relative-frequency-based definitions. Sets, fields, sample space and events; axiomatic definition of probability. Combinatorics: Probability on finite sample spaces. Joint and conditional probabilities, independence, total probability; Bayes' rule and applications.

Continuous and discrete random variables, cumulative distribution function (cdf); probability mass function (pmf); probability density functions (pdf) and properties. Jointly distributed random variables, conditional and joint density and distribution functions, independence. Expectation: mean, variance and moments of a random variable. Joint moments, conditional expectation; covariance and correlation; independent, uncorrelated and orthogonal random variables. Random vector: mean vector, covariance matrix and properties. Special distributions. Vector-space representation, linear independence, inner product, Schwarz Inequality. Estimation theory and orthogonality principle.

Sequence of random variables and convergence: Almost sure (a.s.) convergence and strong law of large numbers; convergence in mean square sense from parameter estimation; convergence in probability; convergence in distribution. Central limit theorem and its significance.

Random process: realizations, sample paths, discrete and continuous time processes, examples. Probabilistic structure. Stationarity: strict-sense stationary (SSS) and wide-sense stationary (WSS) processes. Ergodicity and its importance. Power spectral density, properties;

cross-power spectral density, auto-correlation. LTI system with a WSS process as an input: stationarity of the output, auto-correlation and power-spectral density of the output.

Learning Resources:

Text Books:

1. Intuitive Probability and Random Processes using MATLAB, Steven M. Kay, Springer, 2006.
2. Probability, Random Variables and Stochastic Processes, Athanasios Papoulis, S. Unnikrishna Pillai, 4th Edition, Tata Mc-Graw Hill, 2002.
3. Introduction to Random Signals and Applied Kalman Filtering, Robert G. Brown, Patrick Y. C. Hwang, John Wiley & Sons, 1997.

Reference Books:

1. Probability and Random Variables: A Beginner's Guide, Stirzaker DC, ambridge University Press, 2003.
2. Probability and Radom Variables, G. P. Beaumont, Woodhead Publishers, 2005.

Online Resources:

Course Code: CH5214	INDUSTRIAL INSTRUMENTATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand techniques for measurement of level, pressure.
CO2	Measure temperature using contact / non-contact techniques.
CO3	Analyze methods for torque and velocity.
CO4	Select methods for acceleration, vibration and density measurement.
CO5	Identify a suitable technique for flow measurement.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	-	1
CO2	2	-	2	3	-	1
CO3	2	-	2	3	-	1
CO4	2	-	2	3	-	1
CO5	2	-	2	3	-	1

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. Fundamentals of Industrial Instrumentation and Process Control, William C. Dunn, McGraw-Hill, 2005.
2. Mechanical and Industrial Measurements, R. K. Jain, Khanna Publishers, New Delhi, 1999.
3. Fluid Flow Measurement, E. L. Upp, Paul J. LaNasa, 2nd Edition, Gulf Professional Publishers, 2002.

Reference Books:

1. Instruments Engineers Handbook, Bela G. Liptak, 4th Edition, CRC Press, 2003.
2. Principles of Industrial Instrumentation, D. Patranabis, Tata McGraw Hill, 1999.

Online Resources:

Course Code: CH5215	DESIGN OF PID CONTROLLERS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Design PID controllers using different methods
CO2	Design PID controllers for MIMO systems
CO3	Automate the control at plant level
CO4	Design PID controllers for nonlinear processes

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	3	3	-	2
CO2	3	-	3	3	-	2
CO3	3	-	3	3	-	2
CO4	3	-	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to design of PID controllers. Classifications of PID design methods. Open loop and closed loop tuning methods.

Ziegler–Nichols, Cohen-Coon Methods. Advantages and disadvantages. Model based design methods – direct synthesis and IMC methods for different types and orders of processes. Optimization based approaches for PID design.

Model reduction. Frequency domain based design methods. Design for desired robustness levels using sensitivity analysis.

Anti-wind up, measurement noise attenuation.

Set-point filters and set-point weighting. Design approaches.

Multivariable PID controller design – Decentralized, decoupled and centralized PID controllers design – advantages and disadvantages of each method.

Relay based tuning of PID controllers.

Auto tuning for Plant wide Control Systems - Recycle Plant, Control Structure Design, Unbalanced Schemes, Balanced Scheme, Controllability, Operability, Controller Tuning for Entire Plant. Guidelines for Auto tune Procedure. Applications to case studies.

Introduction to nonlinear PID controller design.

Learning Resources:

Text Books:

1. Process Identification and PID Control, S. W. Sung, Jietae Lee, In-Beum Lee, Wiley, 2009.
2. Process Dynamics and Control, Seborg, D. E., Edgar, T. F., Millechamp, D. A., Doyle III, F. J., 3rd Edition, Wiley, 2014.
3. Autotuning of PID controllers: Relay feedback approach, Cheng-Ching Yu, 2nd edition, Springer, 2006

Reference Books:

1. Model-Reference Robust Tuning of PID Controllers, Alfaro, Victor M., Vilanova, Ramon, Springer, 2016.
2. PID Controller Design in the Third Millennium: Lessons Learned and New Approaches, Ramon Vilanova, A. Visioli, Springer, 2013.
3. PID Control: New Identification and Design Methods, Michael A. Johnson, Mohammad H. Moradi, Springer, 2005.

Online Resources:

Course Code: CH5216	NETWORKED CONTROL SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand the serial communication and parallel communication standards
CO2	Understand the protocols used with internet
CO3	Understand routers, modems and cryptography for communicating the measured data
CO4	Understand web based calibration and data acquisition
CO5	Perform control of plants using virtual laboratories, wireless sensors and internet.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	-	1
CO2	2	-	2	3	-	1
CO3	2	-	2	3	-	1
CO4	2	-	2	3	-	1
CO5	2	-	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Industrial communication systems: Interface - Introduction, Principles of interface, serial interface and its standards. Parallel interfaces and buses

Introduction to Internet: Origin of Internet – Overview of TCP / IP layers – IP addressing – DNS – Packet switching – Routing – SMTP, POP, MIME, NNTP, ftp, Telnet, HTML, HTTP, URL, SNMP, RFCs, FYIs – STDs.
Physical Layer Aspects: Backbone network – Trunks, Routers, Bridges – Access network – MODEMs, WILL, ISDN, XDSL, VSAT.

Network Layer Aspects and Network Security: IPVG, Mobile IP – IPSEC – IPSO – Public key cryptography – digital signature standard – firewall – Secure socket Layer SSL – Secure Data Network System SDNS – Network layer security Protocol NLSP – Point to point Tunneling Protocol PPTP – SHTTP.

Measurements through Internet: Web based data acquisition – Monitoring of plant parameters through Internet – Calibration of measuring instruments through Internet.
Internet based Control: Virtual laboratory – Web based Control – Tuning of controllers through Internet. Wireless sensors for measurement and feedback control.
Internet of Things (IoT) – communication and feedback control Demonstration using appropriate tools in the laboratory.

Learning Resources:

Text Books:

1. Internet Based Control Systems, Shuang-Hua Yang, Springer, 2011.
2. Internet Working with TCP/IP, Douglas E. Camer, 3rd Edition, Prentice Hall, 1999.

Reference Books:

1. TCP/IP Illustrated, Richard Stevens, Addison Wesley, 1999.
2. Internet Cryptography, Richard E. Smith, Addison Wesley, 1999.

Online Resources:

Course Code: CH5217	STATISITCAL PROCESS CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Apply statistical methods for process control
CO2	Use univariate charts and cumulative sum charts
CO3	Control the processes with attribute based charts
CO4	Use multivariate statistical process control methods
CO5	Use process monitoring charts

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	2	3	3	-	1
CO2	2	1	2	2	-	1
CO3	2	1	3	3	-	1
CO4	2	1	2	2	-	1
CO5	2	1	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to 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. Introduction to Statistical Process Control, Peihua Qiu, CRC Press, 2014.
2. Statistical Process Control, John Oakland, 6th Edition, Elsevier, B-H Publications, 2008.

Reference Books:

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

Online Resources:

Course Code: CH5218	QUANTITATIVE FEEDBACK THOERY	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand the importance of Quantitative feedback theory based robust control
CO2	Model and design the robust QFT controller and prefilter for the Single input single output uncertain system
CO3	Design the QFT controller/prefilter for unstable and non-minimum phase system using the loop-shaping methods
CO4	Perform the QFT synthesis for cascade control systems and for discrete time system
CO5	Synthesis the QFT based multivariable controller for uncertain system

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	-	3	3	-	1
CO2	2	-	2	2	-	1
CO3	2	-	3	3	-	1
CO4	2	-	2	2	-	1
CO5	2	-	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Fundamentals

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 (QFT) Preliminaries

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. Quantitative Feedback Theory: Fundamentals and Applications, C. H. Houpis, S.J. Rasmussen, Mario Garcia-Sanz, 2nd Edition, CRC Press, 2018.
2. Robust Control Engineering: Practical QFT Solution, Mario Garcia-Sanz, 1st Edition, CRC Press, 2017.
3. Quantitative feedback design of Linear and Nonlinear Control Systems, Oded Yaniv, 1st Edition, Springer, 1999.

Reference Books:

1. Design of Robust Control Systems: From Classical to Modern Practical Approaches, Marcel J. Sidi, 1st Edition, Krieger Publishing Company, 2001.
2. Quantitative Feedback Design Theory (QFT), Horowitz, 1st Edition, QFT Publishers, Denver, CO. 1993.
3. Synthesis of feedback systems, Horowitz, 1st Edition, Academic Press, 1963.
4. Robust control: Theory and Applications, K-Z. Liu, Y. Yao, 1st Edition, 2016.

Online Resources

Elective Courses Offered in Second Semester

Course Code: CH5261	INDUSTRIAL AUTOMATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand process automation technologies.
CO2	Understand Piping & Instrumentation Diagrams.
CO3	Design PLC programming for processes.
CO4	Apply distributed control systems (DCS) for processes.
CO5	Understand security design approaches.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	3	3	-	2
CO2	3	-	3	3	-	2
CO3	3	-	3	3	-	2
CO4	3	-	3	3	-	2
CO5	3	-	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction, 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, controller software.

Piping and Instrumentation Diagrams(P&ID): P&ID symbols, Components, Line numbering, Valve numbering, Equipment identification, Interpreting P&IDs - valves, equipment, Vessels Pumps, Heat exchangers, Compressors, control & safety systems.

Programmable logic controller (PLC): Definition, overview of PLC systems, input/output modules, power supplies, isolators. General PLC programming procedures, 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. HART protocol: Method of operation, structure, operating conditions and applications.

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. Industrial Automation using PLC, SCADA and DCS, Jamkar, R. G., Global press, 2018
2. Programmable Controllers, E. A. Parr, 3rd Edition, Newnes, 2003.
3. Programmable Logic Controllers - Principles and Applications, John. W. Webb, Ronald A Reis, 3rd Edition, Prentice Hall, 1995.

Reference Books:

1. Computer Control of Processes, Chidambaram M, Narosa Publishers, 2002.
2. Introduction to Programmable logic controller, Dunning, G. A., Cengage Learning, 2005.
3. Industrial Instrumentation and Control, Singh, S, McGraw hill, 3rd Edition, Prentice Hall, 2008.
4. Process Control Instrumentation Technology, Johnson, C D., 8th Edition, Pearson, 2014.

Online Resources:

Course Code: CH5262	NONLINEAR CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand nonlinear systems and their dynamics
CO2	Apply realization theory to linear systems and stability concepts
CO3	Determine controllability and observability
CO4	Analyze stability of linear and nonlinear systems using Lyapunov method

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	3	3	-	1
CO2	2	-	3	3	-	1
CO3	2	-	3	3	-	1
CO4	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to nonlinear systems, Phase plane analysis – generalization of phase plane behavior. Limit cycle behavior of nonlinear systems.

Realization theory – Realization of LTI systems, realization of bilinear systems, examples. Stability and the Lyapunov method – local stability, Lyapunov theory.

Singular perturbation theory, Properties of ODE systems with small parameters, Nonstandard singularly perturbed systems with two time scales, Singularly perturbed systems with three or more time scales.

Local Controllability and Observability of Nonlinear Systems. Stability and The Lyapunov Method: Stability Notions, BIBO (Bounded-input-bounded-output)Stability Conditions for LTI Systems, L_2-gain of Linear and Nonlinear Systems, the Small-gain Theorem, Asymptotic or Internal Stability of Nonlinear Systems.

Feedback and Input-output Linearization of Nonlinear Systems. Exact Linearization via State Feedback.

Sliding-mode control, input-output stability, dissipativity, passivity, and passivity based controller design.

Applications to different engineering systems.

Learning Resources:

Text Books:

1. Nonlinear Systems, H. K. Khalil, 3rd Edition, Englewood Cliffs, NJ: Prentice Hall, 2001.
2. Analysis and Control of Nonlinear Process Systems, K.M. Hangos, J. Bokor, G. Szederkényi, Springer, 2004.

Reference Books:

1. Feedback Systems: Input-Output Properties, C. A. Desoer and M. Vidyasagar, Academic Press, 2009
2. Nonlinear and Adaptive Control Design, M. Krstic, I. Kanaellakopoulos and P. Kokotovic, Wiley, 1995.
3. Applied Nonlinear Control, Jean-Jacques E Slotine, Weiping Li, Prentice-hall, 1991.
4. Analysis and Design of Nonlinear Control Systems, Daizhan Cheng Xiaoming Hu Tielong Shen, Springer, 2010.
5. Constructive Nonlinear Control, R. Sepulchre, Springer-Verlag, 1997
6. Control Systems Theory with Engineering Applications, Sergey Edward Lyshevski, Birkhauser, 2001.

Online Resources:

Course Code: CH5263	ESTIMATION AND FILTERING TECHNIQUES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Estimate the states using statistical and fundamental theories
CO2	Develop Kalman filter algorithms for state estimation
CO3	Use particle filters for state estimation
CO4	Apply optimization techniques for state estimation

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	2	-	1
CO2	3	-	3	3	-	1
CO3	3	-	2	2	-	1
CO4	3	-	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to State Estimation – Introduction to statistical theory. Introduction to state and parameter estimation - Steady-state perspective, State-space model formulation from fundamental theories. Observers. Continues and discrete state space model and relationships.

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.

Extended and Unscented Kalman Filters – Extensions to handle Non-Linearity and Non-Gaussianity in processes. Predictor-Corrector form. Unscented Kalman Filter - Concept of unscented sampling, 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.

Introduction to Particle Filters - State Estimation, Enhancements to handle Delayed or infrequent measurements. Differential Algebraic Equation systems. Difficulties to use particle filters.

Optimization based approaches to 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. Optimal State Estimation, Dan Simon, John Wiley & sons, 2006.
2. Kalman Filtering: Theory and Practice Using MATLAB, Mohinder S. Grewal and Angus P. Andrews, 3rd Edition, John Wiley & sons, 2008.
3. Advanced Kalman Filtering, Least-Squares and Modeling, Bruce P. Gibbs, Wiley, 2011.

Reference Books:

1. Classification, Parameter Estimation and State Estimation: An Engineering Approach Using MATLAB, F. Vander Heijden, R.P.W. Duin, D. de Ridder, D.M.J. Tax, John Wiley & Sons, 2004.
2. Introduction to Random Signals and Applied Kalman Filtering, Robert G. Brown and P.Y.C. Hwang, 4th Edition, John Wiley & Sons, 2012.

Online Resources:

Course Code: CH5264	LEARNING BASED CONTROL SYSTEMS	Credits 3-0-0: 3

Pre-requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the theoretical and implementation aspects of optimal control and model-based reinforcement learning
CO2	Apply optimal control techniques to optimize the operations of physical, social, and economic processes
CO3	Design model based reinforcement learning control schemes
CO4	Design model-free reinforcement learning control schemes
CO5	Implement learning based control schemes on different processes

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	1	2	-	1
CO2	3	-	1	3	-	1
CO3	3	-	3	3	-	1
CO4	3	-	3	3	-	1
CO5	3	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

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

Unconstrained optimization, constrained optimization; convex optimization and optimization tools. Dynamic programming, discrete LQR, Stochastic DP, value iteration, policy iteration, Automatic differentiation and Jax

LQG, dual control, introduction to reinforcement learning

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. Dynamic Programming and Optimal Control, D. P. Bertsekas. Vol. I and II, Athena Scientific, 2012.
2. Nonlinear Programming, D. P. Bertsekas. Athena Scientific, 2016.
3. Reinforcement Learning and Optimal Control, Athena Scientific, D. P. Bertsekas. 2019. (Dimitri P. Bertsekas web resources: http://www.mit.edu/~dimitrib/RLbook.html)

Reference Books:

1. Predictive Control for Linear and Hybrid Systems, F. Borrelli, A. Bemporad, M. Morari. 2017.
2. Reinforcement Learning and Approximate Dynamic Programming for Feedback Control, Lewis and Derong Liu, editors, John Wiley/IEEE Press, Computational Intelligence Series. 2012
3. Optimal Control Theory: An Introduction, D. K. Kirk. Dover Publications, 2004.
4. Model Predictive Control: Theory, Computation, and Design, J. B. Rawlings, D. Q. Mayne, M. M. Diehl. 2nd Edition, Nob Hill Publishing LLC, 2017.
5. Reinforcement Learning: An Introduction. R. S. Sutton and A. G. Barto, MIT Press, 2018, Available online at: http://www.incompleteideas.net/book/RLbook2018.pdf

Online Resources:

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

Course Code: CH5265	BIOPROCESS & BIOMEDICAL INSTRUMENTATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand the techniques to handle biomass and monitor bio-processes
CO2	Understand on-line sensors for measuring bio-process parameters
CO3	Understand bio signals; their generation and processing
CO4	Apply different instrumentation techniques in medical field

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	-	1	2	-	1
CO2	2	-	1	2	-	1
CO3	2	-	1	2	-	1
CO4	2	-	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to bioprocesses. Bio-process Monitoring Requirements: Standard Techniques for Biomass, Substrates, Products, Intermediates and Effectors.

On-Line Sensing Devices: In Situ Instruments for Temperature, pH, Pressure, Oxygen, Carbon Dioxide, Culture Fluorescence, Redox Potential, Biomass, Comparability of Sensors, Optical Density.

Sampling: Sampling of Culture Fluid Containing Cells, Sampling of Culture Supernatant Without Cells, Interfaces, Flow Injection Analysis (FIA), Chromatography such as GC, HPLC. Mass Spectrometry (MS). Biosensors, Electrochemical Biosensors, Fiber Optic Sensors, Calorimetric Sensors, Acoustic/Mechanical Sensors.

Nature and complexities of biomedical measurements, Medical equipment standards-organization, classification and regulation. Biocompatibility - Human and Equipment safety – Physiological effects of electricity, Micro and macro shocks, and thermal effects.

Modeling and simulation in biomedical instrumentation – Difference in modeling engineering systems and physiological systems – Model based analysis of Action Potentials - cardiac output – respiratory mechanism - Blood glucose regulation and neuromuscular function.

Types and Classification of biological signals – Signal transactions – Noise and artifacts and their management - Biopotential electrodes- types and characteristics - Origin, recording schemes and analysis of biomedical signals with typical examples of Electrocardiography(ECG), Electroencephalography(EEG), and Electromyography (EMG)–

Processing and transformation of signals-applications of wavelet transforms in signal compression and denoising.

Learning Resources:

Text Books:

1. Advanced Instrumentation, Data Interpretation and Control of Biotechnological Processes, J. F. Van impe, P. A. Vanrolleghem, D. M. Iserentant, Springer, 2010.
2. Biomedical Instrumentation and Measurements, Cromwell l., Prentice Hall of India, 1995.
3. Biomedical Signal Analysis, Rangaraj M. Rangayan, 2nd Edition, John Wiley & Sons, 2015.

Reference Books:

1. Process Computations in Biotechnology, T. K. Ghose, Tata McGraw Hill, 1994.
2. Bioinstrumentation, John G. Webster, John Wiley & Sons, 2005.
3. Biomedical Signal and Image Processing, Kayvan Najarian and Robert Splinter, CRC Press, 2005.

Online Resources:

Course Code: CH5266	MULTI SENSOR DATA FUSION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Infer the data collected from multiple sensors
CO2	Understand the models and architectures used for data fusion
CO3	Develop mathematical models and algorithms for multi sensor data fusion
CO4	Understand the variety of methods available for data fusion and sensor fusion
CO5	Use data structures for implementing data fusion systems

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	1	2	-	1
CO2	3	-	1	2	-	1
CO3	3	-	3	3	-	1
CO4	3	-	1	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Multi sensor data fusion: 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

Benefits of data fusion, Mathematical tools used: 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 and Other Methods: 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. Multi Sensor Data Fusion, H. B. Mitchell, Springer, 2007.
2. Multi Sensor Data Fusion with MATLAB, Jitendra R. Raol, CRC Press, 2009.
3. Sensor and Data Fusion, Lawrence A. Klein, 2nd Edition, SPIE Press, 2012.

Reference Books:

1. Mathematical Techniques in Multi Sensor Data Fusion, David L. Hall, Artech House, Boston, 1992.
2. Data Fusion and Sensor Management: An Information-Theoretic Approach, J. Manyika, H.F. Durrant-Whyte, Prentice Hall, 1994.
3. Handbook of Multi Sensor Data Fusion: Theory and Practice, Martin Liggins, David Hall, James Llinas, 2nd Edition, CRC Press, 2008.

Online Resources:

Course Code: CH5267	DATA-DRIVEN CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Analyze the input-output data
CO2	Develop iterative learning control
CO3	Develop virtual reference feedback control
CO4	Design control for parameter varying systems

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	2	-	1
CO2	3	-	2	2	-	1
CO3	3	-	3	3	-	1
CO4	3	-	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction. Limitations of model-based control when the model is uncertain. Joint design of identification and control. Taxonomy.

Iterative Feedback Tuning, Virtual Reference Feedback Tuning, 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 direct data-driven tuning of multivariable controllers. PID controller design directly based on data. Advantages and limitations.

Nonparametric control design and regularization. Optimal experiment design. The receding horizon approach. Data-driven selection of control specifications.

Direct data-driven control of 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 nonlinear systems.

Learning Resources:

Text Books/Research Articles:

1. Model Free Adaptive Control: Theory and Applications, Zhongsheng Hou, ShangtaiJin, CRC Press, 2014.

2. Learning-based Adaptive Control: An Extremum Seeking Approach, Mouhacine Benosman Butterworth-Heinemann, 2016.

Reference Books:

1. From experiment design to closed-loop control, H. Hjalmarsson. Automatica 2005; 41(3):393–438.
2. Noniterative direct data-driven tuning of multivariable controllers: theory and application, S. Formentin, S. M. Savaresi, L. Del Re. IET control theory and applications, 2012; 6(9): 1250-1257.
3. On identification methods for direct data-driven controller tuning, K. van Heusden, A. Karimi, T. Söderström. International Journal of Adaptive Control and Signal Processing, 2011; 25(5): 448–465
4. Identification for control: From the early achievements to the revival of experiment design, M. Gevers, European journal of control, 2005; 11(4): 335-352.
5. Virtual reference feedback tuning: a direct method for the design of feedback controllers, M.C. Campi, A. Lecchini, S.M. Savaresi. Automatica 2002; 38:1337–1346

Online Resources:

Course Code: CH5268	REALTIME AND EMBEDDED SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand microprocessors, microcontrollers and digital signal processors
CO2	Understand the pc based data acquisition; analog to digital signal conversion and vice versa
CO3	Understand the digital logic circuits used with embedded systems
CO4	Design embedded systems
CO5	Use real time operating systems

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	-	1	2	-	1
CO2	3	-	1	2	-	1
CO3	3	-	1	2	-	1
CO4	2	-	3	3	-	1
CO5	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

System Design: Definitions, Classifications and brief overview of micro-controllers, microprocessors and DSPs. 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 of S/W 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 state4s, task scheduling, interrupt processing, clocking communication and synchronization, control blocks, memory requirements and control, kernel services.

Case Studies: Discussion of specific examples of complete embedded systems using mc68 HC11, mc8051, ADSP2181, PIC series of microcontroller.

Learning Resources:

Text Books:

1. Embedded Microprocessor Systems – Real World Design, Ball S.R, Prentice Hall, 1996.
2. Real Time Systems – Design for Distributed Embedded Applications, Herma K, Kluwer Academic, 1997.
3. Art of Programming Embedded Systems, Gassle J, Academic Press, 1992.

Reference Books:

1. Specification and Design of Embedded Systems, Gajski D.D, Vahid F, Narayan S, PRT Prentice Hall, 1994.
2. Real Time Systems, C.M. Krishna, Kang G. Shin, McGraw Hill, 1997.
3. An Introduction to Real Time Systems, Raymond J.A. Buhr, Donald L. Bailey, Prentice Hall, 1999.

Online Resources:

Course Code: CH5269	INTELLIGENT INSTRUMENTATION and APPLICATIONS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Develop design methodologies for measurement and instrumentation of real world problems
CO2	Understand the concepts of intelligent sensor devices, their performance characteristics and signal and system dynamics
CO3	Understand the issues in dealing signal conditioning operations
CO4	Use artificial intelligence in sensor signal processing to solve real world problems
CO5	Develop interfacing protocols in wireless networking platform

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	-	1	2	-	1
CO2	3	-	1	2	-	1
CO3	3	-	1	2	-	1
CO4	3	-	3	3	-	1
CO5	3	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: intelligent instrumentation, definition, types of instruments, static and dynamic characteristics of instruments, Historical Perspective, Current status, software based instruments.

Intelligent Sensors: Classification, Smart sensors , Monolithic Integrated Smart Sensors, Hybrid Integrated Smart Sensors, Cogent Sensors, Soft or Virtual sensors, self-adaptive, self-validating sensors, Soft Sensor Secondary Variable Selection, Rough Set Theory , Model Structures. Self-Adaptive Sensors, Self-Validating Sensors, VLSI Sensors, Temperature Compensating Intelligent Sensors, Pressure Sensor.

Linearization, Calibration, and Compensation: Analog Linearization of Positive and Negative Coefficient Resistive Sensors. Higher-Order Linearization , Quadratic Linearization , Third-Order Linearization Circuit, Nonlinear ADC- and Amplifier-Based Linearization, Interpolation, Piecewise Linearization, Microcontroller-Based Linearization, Lookup Table Method, Artificial Neural Network–Based Linearization, Nonlinear Adaptive Filter–Based Linearization, Sensor Calibration, Conventional Calibration Circuits , Offset Compensation, Error and Drift Compensation, Lead Wire Compensation.

Sensors with Artificial Intelligence: Artificial Intelligence, Sensors with Artificial Intelligence, Multidimensional Intelligent Sensors, AI for Prognostic Instrumentation, ANN-Based Intelligent Sensors, Fuzzy Logic–Based Intelligent Sensors.

Intelligent Sensor Standards and Protocols.

Learning Resources:

Text Books:

1. Intelligent Sensing, Instrumentation and Measurements, Subhas Chandra Mukhopadhyay, Springer, 2013.
2. Intelligent Instrumentation: Principles and Applications, Manabendra Bhuyan, CRC Press, 2010.
3. Intelligent Instrumentation, G. C. Barney, Prentice Hall, 1995.

Reference Books:

1. Instrumentation, Measurement, Circuits and Systems, R. Saravanan, P. Vivekananth, Tianbiao Zhang, Springer, 2012.

Online Resources:

Course Code: CH5270	GUIDANCE STRATEGIES FOR AUTONOMOUS VEHICLES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand missile guidance laws
CO2	Analyze cooperative control
CO3	Describe unmanned aircraft systems
CO4	Develop control strategies for autonomous operation

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	2	-	1
CO2	3	-	2	2	-	1
CO3	3	-	2	2	-	1
CO4	3	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Basics of missile guidance - Introduction to missiles, missile guidance laws(pursuit, line-of-sight, proportional navigation), capturability analysis form aneuvering and non-maneuvering targets (8 weeks)

Applications of guidance strategies to cooperative control - multi-vehicle path planning, collision avoidance, rendezvous/docking problems.

Introduction to the unmanned aircraft systems (UAS). UAS design parameters, UAS components: mechanical & electrical, Overview of UAS Guidance & Navigation.

Overview of dynamics of motion, 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, Classical and state space control design for UAS.

Learning Resources:

Text Books:

1. Missile guidance and pursuit: Kinematics, Dynamics and Control, N.A.Shneydor: Harwood Publishing, 1998
2. Formation Control of Multiple Autonomous Vehicle Systems, Hugh H.T. Liu, Bo Zhu, Wiley, 2018.

3. Aircraft Control and Simulation, Brian L. Stevens, Frank L. Lewis, Eric N. Johnson, Third Edition, Wiley, 2016.

Reference Books:

1. Autonomous Guided Vehicles: Methods and Models for Optimal Path Planning, Hamed Fazlollahtabar, Mohammad Saidi-Mehrabad, Springer, 2015.
2. Autonomous Control Systems and Vehicles: Intelligent Unmanned Systems, Kenzo Nonami, Muljowidodo Kartidjo, Kwang-Joon Yoon, Agus Budiyono, Springer, 2013.
3. Multilayer Control of Networked Cyber-Physical Systems Application to Monitoring, Autonomous and Robot Systems, Sabato Manfredi, Springer, 2017.

Online Resources:

Course Code: CH5271	OPTIMAL AND ADAPTIVE CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Formulate an optimal control problem
CO2	Determine optimal trajectories
CO3	Design robust control strategies for the given system
CO4	Identify suitable adaptive control scheme
CO5	Design self-tuning regulators for real-time applications

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	1	2	-	1
CO2	3	-	1	2	-	1
CO3	3	-	1	2	-	1
CO4	2	-	3	3	-	1
CO5	2	-	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Problem formulation – Performance measure Optimal control problem. Dynamic Programming – Optimal control law– computational procedure. Characteristics of dynamic programming solution. Variational approach to optimal control problems – Necessary conditions for optimal control – Linear regulator problems. Linear tracking problems.

Modeling 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 Approach: Introduction, preliminary Theorems, Kharitonov Theorem, Control Design Using Kharitonov Theorem.

H_∞ and H_2 Control: Introduction, Function Space, Computation of H_2 and H_∞ Norms. Robust Control Problem as H_2 and H_∞ Control. H_2/H_∞ Control Synthesis.

Adaptive Control versus Conventional Feedback Control. Fundamental Hypothesis in Adaptive Control. Basic Adaptive Control Schemes - Open-Loop Adaptive Control, Direct Adaptive Control, Indirect Adaptive Control.

Deterministic self-tuning regulators (STR) – pole placement design.Model reference adaptive schemes (MRAS) – the MIT rule, determination of adaptation gain, Gain scheduling – the principle, design of gain scheduling controllers, nonlinear transformations, applications of gain scheduling.

Learning Resources:

Text Books:

1. Optimal Control, Frank L. Lewis, Draguna Vrabie, Vassilis L. Syrmos, John Wiley & Sons, 2012.
2. Adaptive Control, Astrom .K. J., Wittenmark B., 2nd Edition, Pearson Education, 2008.

Reference Books:

1. Multivariable Feedback Control: Analysis and Design, Sigurd Skogestad, Ian Postlethwaite, 2nd Edition, John Wiley & Sons, 2007.
2. Optimal Control Theory: An Introduction, Donald E. Kirk, Dover Publications, 2004
3. Adaptive Control: Algorithms, Analysis and Application, Loan Doré Landau, Rogelio Lozano, Mohammed M'Saad, Alireza Karimi, 2nd Edition, Springer, 2011.
4. Loop-shaping Robust Control, Philippe Feyel, Wiley, 2013.
5. Robust Control Design: an Optimal Control Approach, Feng Lin, John Wiley & Sons, 2007.

Online Resources:

1. Optimal control @Cleveland University: https://academic.csuohio.edu/simond/courses/eec644/
2. Prof.Kostas Tsakalisclass :http://tsakalis.faculty.asu.edu/686.htm

Course Code: CH5272	HYBRID SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand continuous and discrete dynamic nature of systems
CO2	Develop hybrid models
CO3	Analyze stability of hybrid systems
CO4	Design control strategies for the given hybrid system

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	2	-	1
CO2	3	-	2	2	-	1
CO3	3	-	2	2	-	1
CO4	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Hybrid Systems: Examples and modeling frameworks of hybrid systems, Basic nonsmooth analysis, differential inclusion, Hybrid state trajectory, Filippov solution, zeno phenomena

Stability Analysis and Stabilization: Lyapunov theory, Linear Matrix Inequality, Stability under arbitrary switching, stability under constrained switching, Multiple-Lyapunov function, LMI based synthesis using multiple-Lyapunov function

Discrete Time Optimal Control: Switched LQR problem, MPC of switched Piecewise Affine Systems, Infinite-horizon optimal control and its connection to stability/stabilization.

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

Continuous Time Optimal Control: Hilbert space, weak topology, chattering lemma, basic calculus of variation, Theory of numerical optimization in infinite-dimensional space, Optimality functions and master algorithms, Epi-convergence and consistent approximation, Applications to optimal control of switched nonlinear systems.

Learning Resources:

Text Books:

1. Hybrid Dynamical Systems: modeling, stability, and robustness, R. Goebel, R. G. Sanfelice and A. R. Teel, Princeton University Press, 2012.
2. Predictive Control for Linear and Hybrid Systems, Francesco Borrelli, Alberto Bemporad, Manfred Morari, , Cambridge University Press, 2017.
3. Switching in systems and control, D. Liberzon, Springer, 2003.

Reference Books:

1. Hybrid Systems: Foundations, advanced topics and applications, J. Lygeros, S. Sastry and C. Tomlin, Springer, 2012.

Online Resources:

1. Wei Zhang course@ The Ohio State University: http://www2.ece.ohio-state.edu/~zhang/HybridSystemsClass/index.html

Course Code: CH5273	SLIDING MODE CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcome: At the end of course, the student will be able to

CO1	Formulate and design the sliding mode controller for an application at hand
CO2	Understand the need for special sliding mode controllers and its design
CO3	Design the different discrete time sliding mode controllers
CO4	Understand and synthesis the stable higher order sliding mode controllers

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	2	-	1
CO2	2	-	1	2	-	1
CO3	2	-	1	2	-	1
CO4	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Sliding mode control basics

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- Design Examples.

Higher Order Sliding Modes

Concept of relative degree- Order of sliding mode- New features in HOSM- Twisting and Super-twisting algorithms- Majorant curve and Lyapunov proofs- Design Examples.

Learning Resources:

Text Books:

1. Sliding Mode Control: Theory and Applications, C. Edwards, S. Spurgeon, 1st Edition, Taylor and Francis, 1998.

2. Sliding Mode Control and Observation,Y. Shtessel, C. Edwards, L. Fridman, A. Levant, 1st Edition, Springer Birkhauser, 2014.
3. Discrete-time Sliding Mode Control: A Multirate Output Feedback Approach, Bandyopadhyay B. and Janardhanan S., 1st Ed., Springer. 2006

Reference Books:

1. Sliding Mode Control in Electromechanical Systems, Utkin V., Guldner J. and Shi J., 2nd Edition., Taylor and Francis, 2009
2. Sliding mode control using novel sliding surfaces, B. Bandyopadhyay, Fulwani Deepak, Kyung-Soo Kim, “1st Edition, Springer, 2009.
3. Recent Trends in Sliding Mode Control, L. Fridman, J-P Barbot, Frank Plestan, 1st Edition, IET Publisher, 2016.

Online Resources: