Indian Institute of Space Science and Technology
Department of Space, Government of India
Thiruvananthapuram

Curriculum and Syllabus for
M.TECH
Control Systems– R2014

FIRST SEMESTER

Code	Course Title	Lecture Hours	Tutorial Hours	Practical Credits	Total Credits
AVC 611	Mathematics for Control	3	0	0	3
AVC 612	Linear Control System	3	0	0	3
AVC 613	Digital Control and Embedded Systems	3	0	0	3
AVC 614	Principles of Feedback Control	3	0	0	3
EO1	Elective I	3	0	0	3
EO2	Elective II	3	0	0	3
AVC 631	Digital Control and Embedded Systems Lab	0	3	1	1
	Total	**18**	**3**	**1**	**19**

SECOND SEMESTER

Code	Course Title	Lecture Hours	Tutorial Hours	Practical Credits	Total Credits
AVC 621	Optimal Control Systems	3	0	0	3
AVC 622	Non Linear Dynamical Systems	3	0	0	3
AVC 623	Robust Control Design	3	0	0	3
E03	Elective III	3	0	0	3
E04	Elective IV	3	0	0	3
	Total	**15**	**0**	**0**	**15**

Summer Project (During Summer Vacations)

Code	Course Title	Lecture Hours	Tutorial Hours	Practical Credits	Total Credits
AVC 851	Design Project	1	6	2	3

THIRD SEMESTER

Code	Course title	Lecture Hours	Tutorial Hours	Practical Credits	Total Credits
AVC 852	Seminar	0	0	0	3
AVC 853	Project Work Phase I	0	0	0	15
Total		**0**	**0**	**0**	**18**

FOURTH SEMESTER

Code	Course Title	Lecture Hours	Tutorial Hours	Practical Credits	Total Credits
AVC 854	Project Work Phase II	0	0	0	18
Total		**0**	**0**	**0**	**18**

ELECTIVE COURSES

Course Code	Course Name
AVC 861	Introduction to Robotic Systems
AVC 862	Mobile Robotics and Visual Servoing
AVC 863	Adaptive Control
AVC 864	Modelling of Launch Vehicle and Space Craft Dynamics
AVC 865	Machine Learning and Control
AVC 866	Fractional Calculus and Control
AVC 867	Optimization
AVC 868	Geometric Approach to Mechanics and Control
AVC 869	System Identification and Parameter Estimation
AVC 870	Modelling and Control of Power Electronics Converters
	Open elective from DSP related to Filtering
	Open elective from Aerospace Engineering related to Space and Flight Mechanics

AVC611 Mathematics For Control (3- 0 - 0) 3 credits

Matrix Operations, Geometry of linear equations, Gaussian elimination, Triangular factorization, Inverses and Transposes.

Vector Spaces: Linear independence, Basis ,Dimension, Four fundamental subspaces, Linear transformations.

Orthogonality: Orthogonal vectors, orthogonality, normed vector spaces.

Least squares: Orthogonal projections and least squares fitting, applications to data analysis Orthogonilization and orthonormalization: the Gram-Schimddt process, linear functional, dual spaces and dual bases.
Determinants: Determinant calculation, relation to linear transformations.

Eigenvalues and eigenvectors: Definition, significance, calculation of eigenvalues and eigenvectors.

Similarity of matrices: Definition, properties, and consequences of similarity; invariants under similarity transformation; similarity classes. Congruence transformations, diagonalization and invariants: Invariants of congruence, reduction to congruence Normal Form".

Introduction to Probablity and Random Variables: distribution functions, binomial, geometric, hypergeometric, and Poisson distributions, uniform, exponential, normal, gamma and beta distributions; conditional probability; Bayes theorem; joint distributions; Chebyshev inequality; law of large numbers; and central limit theorem.

Texts/References:

1. Gilbert Strang ,Linear Algebra and its Applications, 4th ed., Thomson Learning Co., Belmont CA, 2006.
2. Kenneth Hoffman and Ray Kunze, Linear Algebra, 2nd ed., , Prentice- Hall 1971.
3. Roger Horn and Charles Johnson, Matrix analysis, Cambridge University Press, 1990.
4. Athanasios Papoulis, Probability, Random Variables and Stochastic Processes,McGraw-Hill Science, 2001.
5. David S. Watkins, Fundamentals of Matrix Computations, Wiley Interscience, 2002.
6. Gene H. Golub, Charles F. Van Loan, Matrix Computations, JHU Press, 1996.
7. Ross, Sheldon, A First Course in Probability. 8th ed. Upper Saddle River, NJ: Prentice Hall, 2009.

AVC612 Linear Control System (3- 0 - 0) 3 credits

Introduction to Modern Control Theory : Introduction to state-space versus transform methods in linear systems; internal versus input/output formulation; discrete-time and continuous- time systems;. Fundamental concepts of linearity, causality, time-invariance, Solution to LTI and LTV systems, Solutions to homogeneous and non homogeneous cases. Computation of matrix exponentials using Laplace transforms and Jordan Normal form, positive definite matrices, quadratic forms

Stability: Internal or Lyapunov stability, Lyapunov stability theorem, Eigen value conditions for Lyapunov stability, Continuous and Discrete time cases, Input-Output stability: BIBO stability, Time domain conditions for BIBO stability. Frequency domain conditions for BIBO stability. BIBO versus Lyapunov stability.

Controllability and Stabilizability: Controllable and reachable subspaces, Physical examples and system interconnections, Reachabilty and controllability Grammians, Open loop minimum energy control, Controllabilty matrix(LTI), Eigen vector test for controllability, Lyapunov test for controllability, Controllable decomposition and block diagram interpretation, Stabilizable system, Eigen vector test for stabilizabilty, Popov-Belevitch_Hautus (PBH) Test for stabilizabilty, Lyapunov test for stabilizabilty. Feedback stabilization based on Lyapunov test.

Observabilty and Detectability: Unobservable and unconstructable subspaces, Physical examples, observabilty and Constructabilty Grammians, Gramian based reconstruction, Duality (LTI), Observable decompositions, Kalman decomposition theorem, Detectability, detectability tests, State estimation, Eigen value assignment by output injection, Stabilization through output feedback.

Texts/References:

1. Joao P. Hespanaha, Linear Systems Theory. Princeton University Press, 2009.
2. Chi-Tsong Chen, Linear System Theory and Design, 3rd ed., Oxford,1999.
3. P. Antsaklis and A. Michel, Linear Systems Theory, McGraw Hill, 1997.
4. Wilson J. Rugh, Linear System Theory, Prentice Hall, 1996.
5. Chi-Tsong Chen, Linear System Theory and Design, Holt, Rinehart and Winston, 1970.
6. T. Kailath, Linear Systems, Prentice Hall, 1980.
7. F.M. Callier and C.A. Desoer, Linear System Theory, Springer- Verlag, 1991.
8. W. S. Levine,, The Control Handbook, CRC press, 1996.
9. W. M Wonham, Linear multivariable control - A geometric approach, New York, Springer-Verlag New York, Inc. (Applications of Mathematics. Volume 10), 1979.

AVC613 Digital Control and Embedded systems (3- 0 - 0) 3 credits

Introduction, Overview of design approaches, continuous versus digital control, Sampling theorem, ZOH, effect of sampling rate, Calculus of difference equations, z-transform, Frequency domain analysis, Signal flow graphs. State space approach: Controllability, Observability, Discretization of continuous transfer functions; Digital filter properties. Controller design using transformation techniques: z-plane specifications. Design in the w, w' domain. PID controller, deadbeat controller. State space methods: Pole placement design, stabilization and all stabilizing controllers, Quantization effects: limit cycles and dither.

The concept of embedded systems design, Embedded microcontroller cores, embedded memories, Examples of embedded systems, Technological aspects of embedded systems: interfacing between analog and digital blocks, signal conditioning, digital signal processing, sub-system interfacing, interfacing with external systems, user interfacing, Software aspects of embedded systems: real time programming languages and operating systems for embedded systems.

A brief introduction to cyber physical systems, DSP processors and pulse width modulation.

Texts/References:

1. Kannan M. Moudgalya, Digital Control, Wiley India, 2007.
2. J.W. Valvano, "Embedded Microcomputor System: Real Time Interfacing", Brooks/Cole, 2000.
3. Jack Ganssle, "The Art of Designing Embedded Systems", Newnes, 1999.
4. David Simon, "An Embedded Software Primer", Addison Wesley, 2000.
5. K.J. Ayala, "The 8051 Microcontroller: Architecture, Programming, and Applications", Penram Intl, 1996.
6. Karl Johan Åström, Björn Wittenmark, Computer-controlled systems: theory and design, Prentice Hall, 1996.
7. Gene Franklin, Ellis-Kagle Press, J. David Powell, Digital Control of Dynamic Systems, Pearson Education, 2005.

AVC614 Principles of Feedback Control (3- 0 - 0) 3 credits

Basics of feedback control: History and motivation for feedback; terminologies, Frequency response, Stability concepts, Bandwidth, Transient response, Closed loop design specifications w.r.t tracking and disturbance rejection, Sensitivity to parameter variations.

Limitations of performance in SISO Feedback systems: Four closed loop transfer functions, Time domain design limitations- Integrators and overshoots, Open RHP poles and overshoots, Open RHP zeros and undershoots, Frequency domain design specifications, Algebraic design tradeoffs, Analytic design tradeoffs, The Bode gain-phase relation, The Bode sensitivity integral, The Poisson sensitivity integral, The Middleton Complementary sensitivity integral, The Poisson complementary sensitivity integral, Sensor noise vs. plant disturbance tradeoffs, uncertainty and other factors which impose fundamental limits on feedback performance.

Uncertainty and Robustness for SISO Feedback systems: Stability robustness & performance robustness; real uncertainty; complex uncertainty; multiplicative and additive uncertainty, Bandwidth limitations, examples.

Properties of MIMO Feedback systems: SISO Analysis of MIMO stability robustness, MIMO stability robustness, MIMO generalization of the stability radius, Singular values and gain of a MIMO system, Singular values and Control authority.

Set point tracking for MIMO systems: Pre compensation and integral control for and MIMO system, Feasibility of set point tracking- Zeros of MIMO system, Zeros and feasibility, Integral control and state estimation, Feed forward with integral control, Tracking vs. Disturbance rejection.

Limitations on Performance in MIMO Feedback systems: Sensitivity and complementary sensitivity matrices and tradeoffs; zeros and poles, disturbance tradeoffs, uncertainty and other factors which impose fundamental limits on feedback performance in the MIMO case. The role and use of singular values.

Texts/References:

1. J.S. Freudenberg with C.V.Hollot and D.P. Looze, A first graduate course in feedback control, ebook.

2. S Skogestad and I. Postlethwaite, Multivariable Feedback Control, Analysis and design, second edition. New York: Wiley, 2005
3. J. M. Maceijowski, Multi-Variable Feedback Design, Addision-Wesely Pub, 1989.
4. L. Greensite, Analysis and Design of Space Vehicle Flight Control Systems - Vol 1- Short Period Dynamics, NASA.

AVC621 Optimal Control Systems (3- 0 - 0) 3 credits

Basic mathematical concepts: Finite dimensional optimization, Infinite dimensional optimization, Conditions for optimality, Performance measures for optimal control problems.

Dynamic programming: The optimal control law, The principle of optimality, Dynamic programming concept, Recurrence relation, computational procedure, The Hamilton-Jacobi-Bellman equations.

Calculus of variations: Examples of variational problems, Basic calculus of variations problem, Weak and strong extrema, Variable end point problems, Hamiltonian formalism and mechanics: Hamilton’s canonical equations.

From Calculus of variations to Optimal control: Necessary conditions for strong extrema, Calculus of variations versus optimal control, optimal control problem formulation and assumptions, Variational approach to the fixed time, free end point problem.

The Pontryagin’s Minimum principle: Statement of Minimum principle for basic fixed end point and variable end point control problems, Proof of the minimum principle, Properties of the Hamiltonian, Time optimal control problems.

The Linear Quadratic Regulator: Finite horizon LQR problem- Candidate optimal feedback law, Ricatti differential equations (RDE), Global existence of solution for the RDE. Infinite horizon LQR problem- Existence and properties of the limit, solution, closed loop stability. Examples: Minimum energy control of a DC motor, Active suspension with optimal linear state feedback, Frequency shaped LQ Control.

LQR using output feedback: Output feedback LQR design equations, Closed loop stability, Solution of design equations, example.

Linear Quadratic tracking control: Tracking a reference input with compensators of known structure, Tracking by regulator redesign, Command generator tracker, Explicit model following design.

Linear-Quadratic-Guassian controller (LQG) and Kalman-Bucy Filter: LQG control equations, estimator in feedback loop, steady state filter gain, constraints and minimizing control, state estimation using Kalman-Bucy Filter, constraints and optimal control

Text/References:

1. D.E.Kirk, Optimal Control Theory- An Introduction, Dover Publications, New York, 2004.
2. Alok Sinha, Linear Systems- Optimal and Robust Controls, CRC Press, 2007.
3. Daniel Liberzone, Calculus of variations and Optimal control theory, Princiton University
4. press, 2012.

5. Frank L. Lewis, Applied optimal control & Estimation- Digital design and implementation,Prentice Hall and Digital Signal Processing Series, Texas Instruments, 1992.
6. Jason L. Speyer, David H. Jacobson, Primer on Optimal Control Theory , SIAM,2010.
7. Ben-Asher, Joseph Z, Optimal Control Theory with Aerospace Applications, American Institute of Aeronautics and Astronautics, 2010
8. IT course notes on Principles of optimal control, 2008.
9. Brian D. O. Anderson, John Barratt Moore, Optimal control: linear quadratic methods,
10. Dover, 2007.
11. Brian D. O. Anderson, John Barratt Moore, Optimal filtering, Dover, 2005.
12. Frank L. Lewis, Optimal estimation: with an introduction to stochastic control theory, Wiley Interscience, 1986.

AVC622 Nonlinear Dynamical System (3- 0 -0) 3 credits

Introduction: Nonlinear system behavior, Nonlinear control.

Nonlinear system analysis:

Phase plane analysis: Concepts of phase plane analysis, Phase plane analysis of linear and nonlinear systems, Existence of limit cycles.

Fundamentals of Liapunov theory: Nonlinear systems and equilibrium points, Concepts of stability, Linearization and local stability, Lyapunov's direct method, Invariant set theorems, Lyapunov analysis of LTI systems, Krasovskii's method, Variable gradient method, Physically motivated Lyapunov functions, Performance analysis. Control design based on Liapunov's direct method.

Advanced stability theory: Concepts of stability for Non-autonomous systems, Lyapunov analysis of non autonomous systems, instability theorems, Existence of Lyapunov functions, Barbalat's Lemma and stability analysis, Positive real systems: PR and SPR Transfer functions, The Kalman-Yakubovich Lemma, The passivity Formalism: passivity in linear systems., Absolute stability, Establishing boundedness of signals, Existence and Unicity of solutions

Nonlinear Control systems design:

Feedback Linearization and the canonical form, Input-state Linearization of SISO systems, Input-output Linearization of SISO systems, multi input systems Sliding Control: Sliding surfaces, Filippov's construction of the equivalent dynamics, direct implementations of switching control laws, Continuous approximations of switching control laws, modeling and performance trade offs Lie derivative, Lie Bracket, Back stepping method for non-feedback linearizable systems.

Texts/References:

1. Jean- Jacques Slotine and Weiping Li, Applied nonlinear Control, Prentice Hall,1991, ISBN: 0-13-040890.
2. H.K. Khalil, Nonlinear Systems, 3rd ed., Prentice hall, 2002.
3. D. Elliott, Bilinear Systems, Springer, 2009.
4. Shankar Sastry, Nonlinear Systems; Analysis, Stability and Control, Springer. 1999
5. P. LaSalle, Solomon Lefschetz, Stability by Liapunov's direct method: with applications, Joseph Academic Press, 1961
6. Mathukumalli Vidyasagar, Nonlinear syste.ms analysis, SIAM, 2002.

7. Alberto Isidori, Nonlinear Control Systems - Volume 1, Springer, 1995.
8. Alberto Isidori, Nonlinear Control Systems – Volume 2, Springer, 1999.

AVC623 Robust Control Design (3- 0 -0) 3 credits

Basics: Control system representations, System stabilities, Coprime factorization and stabilizing controllers, Signals and system norms

Modelling of uncertain systems: Unstructured Uncertainties, Parametric uncertainty, Linear fractional transformation, Structured uncertainties.

Robust design specifications: Small gain theorem and robust stabilization, Performance considerations, Structured singular values.

Design: Mixed sensitivity optimization, 2-Degree of freedom design, Sub-optimal solutions, Formulae for discrete time cases.

Loop- shaping design procedures: Robust stabilization against Normalized coprime factor perturbation, Loop shaping design procedures, Formulae for discrete time cases.

m- Analysis and Synthesis: Consideration of robust performance, m-synthesis: D-K iteration method, m-synthesis: m -K iteration method.

Lower-order controllers: Absolute error approximation methods like Balanced truncation, Singular perturbation approximation and Hankel-norm approximation, Reduction via fractional factors, Relative error approximation and frequency weighted approximation methods.

Design case studies: Robust Control of a mass damper spring system, A triple inverted pendulum control system, Robust control of a hard disk drive.

Linear Matrix Inequalities: Some standard LMI problems – eigen-value problems,generaliszed eigen-value problems; Algorithms to solve LMI problems – Ellipsoid algorithm, interior point methods.

Texts/References:

1. D.-W.Gu, P.Hr.Petkov and M.M.Konstantinov, Robust Control Design with MATLAB, Springer, 2005.
2. Alok Sinha, Linear Systems- Optimal and Robust Controls, CRC Press, 2007.
3. S. Skogestad and Ian Postlethwaite, Multivariable feedback control,John Wiley & Sons, Ltd, 2005.
4. G.E. Dullerud, F. Paganini, A course in Robust control theory- A convex approach, Springer, 2000.
5. Kemin Zhou with J.C. Doyle and K. Glover, Robust and Optimal control, Prentice Hall, 1996.
6. G Balsa, R.Y. Chiang, A.K.Packard and M.G.Safonov, Robust Control Toolbox (Ver. 3.0) User’s
7. Guide. Natick, MA: The Mathworks, 2005. http://www.mathworks.com/access/helpdesk/hellp/toolbox/robust

8. Kemin Zhou, John Comstock Doyle, Keith Glover, Robust and optimal control, Prentice Hall, 1996.
9. Kemin Zhou, John Comstock Doyle, Essentials of robust control, Prentice Hall, 1998.
10. Stephen Boyd, Laurent El Ghaoul, Eric Feron, Linear Matrix Inequalities in System and ControlTheory, SIAM, 1994.

Elective Courses

AVC861 Introduction to Robotic systems (3- 0 -0) 3 credits

Introduction: Components and mechanisms of a robotic system, Robot Manipulators, Mobile Robots , Applications, trajectory planning.

Kinematics: Rotation matrix, Euler angles, Quaternions, Homogeneous transformation, DH Convention, Typical examples, Joint space and Operational space, Inverse Kinematics problem, Rodrigues parameters.

Differential Kinematics and Statics: Geometric Jacobian, Jacobian Computation, kinematic singularities, Analysis of redundancy, Analytical Jacobian, Inverse Kinematics algorithms, Satics, Kineto-static duality, Velocity and force transformations.

Dynamics: Lagrange formulation, Computation of kinetic and potential energies, Dynamical model of simple manipulator structures, Direct dynamics and inverse dynamics, Operational space dynamic model.

Motion control: The control problem, Joint space control, Decentralized control, Computed torque feedforward control, Centralized control, PD Control with gravity compensation, Inverse dynamics control, Operational space control.

Force Control: Manipulator interaction with environment, Compliance control, Impedence control, Force control, Constrained motion, Hybrid force/motion control, estimation related to robotics.

Texts/References

1. B.Siciliano, L. Sciavicco, L. Villani, G.Oriolo, Robotics- Modelling, Planning and Control, Springer, 2009.
2. Reza N. Jazar, Theory of Applied Robotics- Kinematics, Dynamics, and Control , Springer, 2007.
3. M.W.Spong, S.Hutchinson and M. Vidyasagar, Robot Modelling and Control,2006.
4. B. Siciliano, O. Khatib (Eds), Springer Handbook of Robotics, Springer, 2008.
5. Mark W Spong, M Vidyasagar, Robot Dynamics And Control, John Wiley and Sons, 2008.
6. Richard M. Murray, Zexiang Li, S. S. Sastry, A Mathematical Introduction to Robotic Manipulation,CRC Press, 1994.
7. James R. Wertz, Spacecraft Attitude Determination and Control, Kluwer Academic Publishers,Dordrecht, 1980.

AVC862 Mobile Robotics and Visual Servoing (3- 0 -0) 3 credits

Mobile Robotics

Introduction to mobile robots, Nonholonomic constraints, Kinematic models, Unicycle, Bicycle, Chained form, Dynamic model of mobile robots.

Trajectory Planning: Path and Timing laws, Flat outputs, Path planning, Trajectory planning, Optimal trajectories.

Motion Control: Trajectory tracking, Cartisian regulation, Posture regulation, Odometric localization.

Obstacle avoidance and Motion planning: The canonical problem, Configuration space, Different types of obstacles, Planning via retraction, Planning via cell decomposition, Probabilistic planning, Planning via artificial potentials, Motion planning for manipulators.

Visual Servoing: Vision for control, Different types of configuration, Image processing, Pose estimation, Interaction matrix, Stereo vision, Camera calibration

Visual servoing problem: Position based visual servoing, Image based visual servoing, Hybrid visual servoing

Texts/References:

1. B.Siciliano, L. Sciavicco, L. Villani, G.Oriolo, Robotics- Modelling, Planning and Control, Springer, 2009.
2. M.W.Spong, S.Hutchinson and M. Vidyasagar, Robot Modelling and Control, 2006.
3. B. Siciliano, O. Khatib (Eds), Springer Handbook of Robotics, Springer, 2008.

AVC863 Adaptive Control (3- 0 -0) 3 credits

Introduction: Parametric models of dynamical systems, Adaptive control problem

Real time parameter estimation: Least squares and regression models, Estimating parameters in Dynamical Systems, Experimental conditions, Prior information, MLE, RLS,Instrument variable method.

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

Stochastic and Predictive Self tuning regulators: Design of Minimum variance and Moving average controllers, Stochastic self tuning regulators, Unification of direct self tuning regulators. Linear quadratic STR, adaptive predictive control.

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

Properties of Adaptive systems: Nonlinear dynamics, Analysis of Indirect discrete timeself tuners, Stabilty of direct discrete time algorithms, Averaging, Application of averaging techniques, Averaging in stochastic systems, Robust adaptive controllers.

Texts/References

1. K.J. Astrom and B. Wittenmark, Adaptive Control, 2nd ed., Pearson Education, 1995.
2. Petros Ioannou and Baris Fidan, Adaptive Control Tutorial, SIAM, 2006.
3. P.A. Ioannou and J. Sun, Robust Adaptive Control, Prentice Hall, 1995.
4. Sankar Sastry and Marc Bodson, Adaptive Control- Stability, Convergence and Robustness, Springer, 2011.
5. M. Krstic, I. Kanellakopoulos and P. Kokotovic, Nonlinear and Adaptive Control Design, Wiley-Interscience, 1995.
6. H.K. Khalil, Nonlinear Systems, Prentice Hall, 3rd ed., 2002.
7. Jean- Jacques Slotine and Weiping Li, Applied nonlinear Control, Prentice Hall,1991.
8. Torsten Söderström, Instrumental variable estimation, Springer, 1983.
9. Harold Wayne Sorenson, Parameter estimation: principles and problems, M Dekker, 1980.

AVC 864 Modelling of Launch Vehicle and Spacecraft dynamics (3- 0 -0) 3 credits

Coordinate systems, Attitude dynamics and control, Rotational kinematics, Direction cosine matrix, Euler angles, Euler's eigen axis rotation, Quaternions, Rigid body dynamics of launch vehicle, Angular momentum, Inertia matrix, Principal axes, Effect of aerodynamics, Generalized equations of motion, derivation of dynamic equations, structural dynamics and flexibility, propellant sloshing, actuator dynamics, gimballed engine dynamics, External forces and moments, Linear model for Aero-structure-control-slosh interaction studies.

Space craft dynamics, Natural motions of rigid space craft, Translational motion in space, Translational motions in circular orbit, Rotational motion in space, rotational motion in circular orbit, Disturbances, Space craft sensors and attitude determination, Attitude control with thrusters and reaction wheels, Attitude stabilization with spin and generalized momentum wheels.

Texts/References:

1. J.H.Blakelock, Automatic control of Aircraft and Missiles, Wiley India,1991.
2. A.L.Greensite, Control Theory Vol. II- Analysis and Design of Space Vehicle Flight Control Systems, Spartan Books, 1970.
3. N V Kadam ,Practical design of flight control systems for launch vehicles and Missiles , Allied Publishers Pvt. Ltd., 2009.
4. Brian L. Stevens, Frank L. Lewis, Aircraft Control and Simulation, Wiley, 2003.
5. K. J. Ball, G. F. Osborne, Space vehicle dynamics, Clarendon P., 1967.
6. L. Greensite, Analysis and Design of Space Vehicle Flight Control Systems – Short Period Dynamics, Vol 1, NASA.
7. L. Greensite, Analysis and Design of Space Vehicle Flight Control Systems, -- Trajectory Equations Vol 2, 1967, NASA.

AVC 865 Machine learning and Control (3- 0 -0) 3 credits

Machine learning fundamentals: supervised learning – artificial neural networks, support vector machines, kernel methods, statistical techniques, recurrent (or feedback) neural networks; unsupervised learning – clustering, self organizing map, competitive learning, pre-processing techniques (principal component analysis, singular value decomposition, independent component analysis); semisupervised learning – reinforcement learning

Applications to Control Problems: State estimation using neuro observer (single layer and multi layer), kalman filter and reinforcement learning;Identification of non-linear dynamical systems using neural networks (state space models and input-output models), support vector machines and reinforcement learning Modelling and (approximate solutions to) Optimal control problems using support vector machines, regression methods, monte-carlo method, model predictive control and adaptive reinforcement learning

Robust control using differential neural networks, support vector machines and reinforcement learningPath planning using dynamic neural networks, density based machine learning techinques, support vector machines

Adaptive control using self organizing map or RBF networks, Trajectory tracking using dynamic (recurrent) neural networks,

Texts/References:

1. Frank Leroy Lewis, Suresh Jagannathan, A. Yeşildirek, Neural Network Control of Robot Manipulators And Non-Linear Systems, Taylor and Francis group, 1999.
2. Frank L. Lewis, Derong Liu, Reinforcement Learning and Approximate Dynamic Programming for Feedback Control, Wiley and IEEE press, 2013
3. Zi-Xing Cai, Intelligent Control: Principles, Techniques and Applications World Scientific, 1997.
4. Bishop, C. M., Pattern Recognition and Machine Learning, Springer, 2006.
5. Alexander S. Poznyak, Edgar N. Sanchez, Wen Yu, Differential Neural Networks for Robust Nonlinear Control Identification, State Estimation and Trajectory tracking, World Scientific, 2001.
6. Alex Smola, S.V.N. Vishwanathan, Introduction to Machine Learning, Cambridge University Press, 2010.
7. Simon Haykins, Neural Networks and Learning Machines, Prentice Hall, 2009.
8. Related Research Articles from Journals and Conferences.

AVC 866 Fractional Calculus and Control (3- 0 -0) 3 credits

Fractional Calculus: Review of basic definitions of integer-order (IO) derivatives and integrals and their geometric and physical interpretations, Definition of Riemann-Liouville (RL) integration, Definitions of RL, Caputo and Grunwald-Letnikov (GL) fractional derivatives (FDs), Variousgeometrical and physical interpretations of these FDs, Computation of these FDs for some basic functions like constant, ramp, exponential, sine, cosine, etc., Laplace and Fourier transforms of FDs.

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

Fractional-order Modeling: Concepts of 'memory' and 'non-locality' in real-world and engineeringsystems, non-exponential relaxation , 'Mittag-Leffler' type decay and rise, Detailed analysis of fractional-order (FO) modeling of: electrical circuit elements like inductor, capacitor, electrical machines like transformer, induction motorand transmission lines, FO modeling of viscoelastic materials, concept of fractionaldamping, Models of basic circuits and mechanical systems using FO elements, Concept of anomalous diffusion, non- Gaussian probability density function and the development of corresponding FO model, FO models of heat transfer, A brief overview of FO models of biological systems.

Linear Fractional-order Systems: Review of basic concepts of complex analysis, Concepts of multivalued functions, branch points, branch cuts, Riemann surface and sheets, Fractional-order transfer function (FOTF) representation, Concepts like commensurate and non-commensurate TFs, stability, impulse, step and ramp response, Frequency response, nonminimum phase systems, Root locus, FO pseudo state-space (PSS) representation and the associated concepts like solution of PSS model, controllability, observability, etc.

Fractional-order Control: Detailed discussion and analysis of superiority of FO control over the conventional IO control in terms of closed-loop performance, robustness, stability, etc., FO lead-lag compensators, FO PID control, design of FO state-feedback, Realization and implementation issues for FO controllers, survey of various realization methods and the comparative study.

Texts/References:

1. K. B. Oldham and J. Spanier. The Fractional Calculus . Dover Publications, USA, 2006.
2. Kilbas, H. M. Srivastava, and J. J. Trujillo. Theory and Applications of Fractional Differential Equations, Elsevier, Netherlands, 2006.
3. Podlubny. Fractional Differential Equations . Academic Press, USA, 1999.
4. C. A. Monje, Y. Q. Chen, B. M. Vinagre, D. Xue, and V. Feliu. Fractional-order Systems and Control: Fundamentals and Applications Springer-Verlag London Limited, UK, 2010.
5. R. L. Magin. Fractional Calculus in Bioengineering. Begell House Publishers, USA, 2006.
6. R. Caponetto, G. Dongola, L. Fortuna, and I. Petras. Fractional Order Systems: Modeling and Control Applications. World Scientific, Singapore, 2010.
7. K. S. Miller and B. Ross. An Introduction to the Fractional Calculus and Fractional Differential Equations. John Wiley & Sons, USA, 1993.
8. S. Das. Functional Fractional Calculus for System Identification and Controls, Springer, Germany, 2011.
9. M. D. Ortigueira. Fractional Calculus for Scientists and Engineers. Springer, Germany, 2011.
10. Petras. Fractional-Order Nonlinear Systems: Modeling, Analysis and Simulation Springer, USA, 2011.

AVC 867 Optimization (3- 0 -0) 3 credits

Motivation, mathematical review , matrix factorizations, sets and sequences, convex sets and functions, linear programming and simplex method, Weierstrass' theorem, Karush Kuhn Tucker optimality conditions, algorithms, convergence, unconstrained optimization, Line search methods, method of multidimensional search, steepest descent methods, Newton's method, modifications to Newton's method , trust region methods, conjugate gradient method:s, quasi-

Newton's methods. Constrained optimization, penalty and barrier function methods, augmented Lagrangian methods, polynomial time algorithm for linear programming, successive linear programming, successive quadratic programming.

Heuristic methods, evolutionary computing, genetic, bee, and ant algorithms

Texts/References:

1. R. Fletcher Practical Optimization (2nd Edition) John Wiley & Sons, New York, 1987.
2. M.S.Bazaraa , H.D.Sherali and C.Shetty , Nonlinear Programming, Theory and Algorithms, JohnWiley and Sons, New York, 1993.
3. David G. Luenberger, Optimization by Vector Space Methods, John Wiley and Sons, 1969.
4. David G. Luenberger, Linear and Nonlinear Programming, Springer 2008.
5. Stephen P. Boyd, Lieven Vandenberghe, Convex Optimization, Cambridge University Press, 2004.

AVC 868 Geometric Approach to Mechanics and Control (3- 0 -0) 3 credits

Prerequisites: Vector Spaces (Linear Algebra)

An introduction to differentiable manifolds, tangent ff vectors, vector fields, co vector fields, immersions and submersions, Lie groups, actions of groups, Lie algebras, adjoint co-adjoint maps, symmetries. Vector fields, integral curves, push-forward and pull-back, differential forms and Riemannian geometry.

Euler Poincare reduction for the rigid body and heavy top, satellite dynamics and control with coordinate free models, inverted pendulum on a cart.

Texts/References:

1. D .D. Holm, T. Schmah and C. Stoica, Geometric Mechanics and Symmetry, Oxford University Press, 2009.
2. J. Marsden and T. Ratiu, Introduction to Mechanics and Symmetry, Springer-Verlag, 1994.

A. Agrachev and Y. Sachkov, Control Theory from the Geometric Viewpoint Springer, 2004.

3. L. W. Tu, An Introduction to Manifolds Springer 2008.
4. V. Arnold, Ordinary Differential Equations Springer, 1992.
5. J. A. Thorpe, Elementary Topics in Differential Geometry, Springer 2004.
6. M. Spivak, A Comprehensive Introduction to Differential Geometry, Publish or Perish, 1999.

AVC 869 System Identification and Parameter Estimation (3- 0 -0) 3 credits

Introduction, discrete systems, basic signal theory , Open-loop LTI SISO systems, time domain, frequency domain

Least Squares Estimation, Covariance in Stationary, Ergodic Processes, White Noise, Detection of Periodicity and Transmission Delays, ARMA Processes.

Non-parametric identification: correlations and spectral analysis, Subspace identification, Identification with “Prediction Error”-methods: prediction, model structure, approximate models, order selection, validation, ARX and ARMAX Input Models, Ourput Error Model, Box-Jenkins Model

Non-linear model equations, Linearity in the parameters, Identifiability of parameters, Error propagation, MIMO-systems, Identification in the frequency domain, Identification of closed loop systems, Non-linear optimization

Texts/References:

1. Karl Johan Åström, Lectures on system identification - Part 3, Department of Automatic Control, .Lund Institute of Technology, 1975
2. T. Söderström and P. Stoica, System Identification, Prentice Hall, 1989.
3. L Ljung, System identification – Theory for the user, Pearson Education, 1998.
4. Jerry M. Mendel, Lessons in Digital Estimation Theory, Prentice Hall, 1987.
5. Steven M. Kay, Fundamentals of Statistical Signal Processing, Prentice Hall, 2013.

AVC 870 Modelling and Control of Power Electronics Converters (3- 0 -0) 3 credits

Steady state analysis of converters: buck, boost, buck boost, cuk, sepic in continuous and discontinuous conduction modes.

Isolated converter circuits and operations

Converter dynamics and control: AC equivalent circuit model – small signal modeling. State-Space Averaging, Important Converter Transfer functions in CCM and DCM modes.

Controller designs methods: Voltage feedback control. Current programmed control – Unstable operation for duty cycle greater than 0.5, stabilization. Converter and controller models in Current - Programmed Controller Model. Sliding mode control.

Resonant Converters, DC-AC, AC-DC converters.

Texts/References:

1. Robert W. Erickson and Dragan Maksimovic, Fundamentals of Power Electronics, 2nd Edition, Springer, 2001.
2. Journal papers from IEEE/IET and other web based resources.