Mastersweek

CONTROL AND AUTOMATION

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01

Linear Systems Theory

Review of matrix algebra, state variable modelling of continuous and discrete time systems, linearization of state equations, solution of state equations of linear time-invariant and timevarying systems, Controllability and observability of dynamical systems, Minimal realization of linear systems and canonical forms, Liapunov's stability theory for linear dynamical systems, State Feedback controllers, Observer and Controller design

02

Mathematical Methods in Control

Linear Spaces – Vectors and Matrices, Transformations, Norms - Vector and Matrix norms, Matrix factorization, Eigenvalues and Eigenvectors and Applications, Singular Value Decomposition and its Applications, Projections, Least Square Solutions. Probability, Random Variables, Probability distribution and density functions, Joint density and Conditional distribution, Functions of random variables, Moments, characteristic functions, sequence of random variables, Correlation matrices and their properties, Random processes and their properties, Response of Linear systems to stochastic inputs, PSD theorem.

03

Nonlinear Systems

Introduction to nonlinear systems: Examples of phenomena, models & derivation of system equations. Fundamental properties: Existence & uniqueness, Dependence on initial conditions & parameters. Phase plane analysis. Limit cycles & oscillations. Describing function method and applications. Circle criterion. Lyapunov stability of autonomous systems. Perturbation theory & Averaging. Singular perturbation model and stability analysis. Basic results on Lie algebra. Controllability and Observability of nonlinear systems. Bifurcations. Chaos. Synchronization.

04

Optimal Control Theory

Maximization of functionals of a single and several functions using calculus of variations, Constrained extremals, Euler-Lagrange Equation, Necessary conditions for optimal control, Pontryagin's minimum principle and state inequality constraints, Minimum time problems, Minimum control effort problems, Linear quadratic regulator problems, Riccati Equation, Singular intervals in optimal control problems, The principle of optimality, Application of the principle of optimality to decision making, Dynamic programming applied to routing problems, Solving optimal control problems using dynamic programming, Discrete linear regulator problem, Hamilton -Jacobi -Bellman Equation, Numerical Techniques to determine optimal trajectories.

05

Stochastic Filtering and Identification

MMSE estimation including LMS, Gaussian case. Wiener filtering & prediction. Kalman filtering & prediction. Extended Kalman filtering. Predictors for difference equation based models including ARMA, Box Jenkins & others. Statistical properties of Least Squares estimation and its relationship with Bayes estimation (ML, MAP), convergence analysis, CR bound. Recursive Least Squares, Iterative methods for nonlinear Least Squares. Identification problem: Different approaches for linear dynamical systems. Offline identification methods including Least Squares, Prediction error framework, Pseudo-linear regression (PLR) & Instrument variable methods. Recursive Identification of linear dynamical system: RLS, PLR, Prediction error framework & its application to ARMA & Innovations representation. Convergence Analysis of Recursive Identification methods: Associated ODE, Martingale. Nonlinear system identification. Subspace based method of system identification. Applications including LQG and adaptive control.

06

Control Systems Laboratory

Basics of Sensors and Actuators, Study of AC and DC Motors, Linear Systems, Analog and Digital Motors, Synchros, Temperature Control.

07

Advanced Control Laboratory

Magnetic Levitation System, Twin Rotor MIMO System, Gyroscope, Ball and Beam System, Embedded Control System, Mobile Robotic System.

08

Advanced Robotics

Review of Coordinate Transformations, D-H parameters and kinematics. Velocity kinematics and Jacobian, Singularity analysis, Robot Dynamics. Motion planning, Robot control: linear methods – feedforward control, state feedback, observers; Nonlinear Control methods – Computed Torque Control, Feedback linearization, Sliding Mode control; Vision based Robotic Control. Holonomic and Non-Holonomic Systems, Mobile Robots : Modeling and Control, Odometry Analysis, Navigation problems with obstacle avoidance, motion capturing systems.

09

Numerical Optimization

Unconstrained optimization techniques - one dimensional methods like Fibonacci method, Golden section method; higher dimension methods: pattern search method, Nelder and Meed method; gradient based methods: Steepest descent method, Newton method, Conjugate direction and gradient method, Quasi-Newton methods. Constrained optimization techniques - penalty method, barrier method, cutting plane method, projection gradient method. Heuristic technique: like Genetic programming method to solve non-convex programs.

10

Systems Biology

MODELS : Variables and parameters, Law of mass action, Representations : Deterministic vs stochastic, Spatial aspects, Examples of core processes: Gene expression, Protein degradation, Phosphorylation.DYNAMICS : Equilibrium solutions, Bifurcations, Switches, Bistability, Pulses and Oscillations, Circadian Rhythms and Clocks, Spatial
patterns. Morphogenesis and Development. CONTROL MECHANISMS : Performance Goals, Integral Feedback Control, Homeostasis and Perfect Adaptation, Bacterial Chemotaxis, Feedforward Loops, Fold Change Detection, Robustness to Perturbations, Tradeoffs, Internal Model Principle.

11

Selected Topics in Systems and Control

To be decided by the instructorTo be decided by the Instructor when floating this course: It can be anything that is related to systems and control engineering, but is not covered in any of the established courses.

12

Design Aspects in Control

System Modeling – model structures (Process model, ARX model), Review of concepts of stability, feedback and feedforward control. Classical control – First-Order Plus Dead-Time model (FOPDT), process reaction curves, Second-Order Plus Dead-Time model (SOPDT), relay feedback process identification; Smith Predictor and its variations, PID controllers and their tuning, Ziegler-Nichols and Cohen-Coon techniques. Reliable State Feedback design – pole placement, eigenstructure assignment, region based eigenvalue assignment, eigenstructure-time response relationships. Controller gain selection – noise sensitivity. Controller robustness. Disturbance rejection. Frequency Domain Loop Shaping. Output feedback control – compensator design, review of Lead, Lag and Lag-Lead compensators, Zero dynamics – significance in servo control design, design for unstable zero dynamics. Observers – concept and design philosophy. Applications in practical Controller design scenarios

13

Signal Theory

Discrete random variables (Bernoulli, binomial, Poisson, geometric, negative binomial, etc.) and their properties like PDF, CDF, MGF.Continuous random variables: Gaussian, multivariate Gaussian; whitening of the Gaussian random vector; complex Gaussian random vector, circularity; Rayleigh and Rician; exponential; chi-squared; gamma. Signal spaces: convergence and continuity; linear spaces, inner product spaces; basis, Gram-Scmidt orthogonalization.Stochastic convergence, law of large numbers, central limit theorem.Random processes: stationarity; mean, correlation, and covariance functions, WSS random process; autocorrelation and cross-correlation functions; transmission of a random process through a linear filter; power spectral density; white random process; Gaussian process; Poisson process.

14

Sensors and Transducers

Transducer Fundamentals: Transducer terminology Design and performance characteristics, --- criteria for transducer selection, Case Studies – Transducers principles of representative cases with emphasis on special “Electronic Conditioning requirements” of different type of sensors-- Resistive transducer; Inductive transducers; capacitive transducers; piezoelectric transducer; semiconductor and other sensing structures. Displacement transducers; tachometers and velocity transducers; accelerometers and gyros; strain gauges; force and torque transducers; flow meters and level sensors; pressure transducers; sound and ultrasonic transducer. Phototubes and photodiodes; photovoltaic and photoconductive cells, photoemission, photo electromagnetic, detectors pressure actuated photoelectric detectors, design and operation of optical detectors, detector characteristics.Brief Introduction -- Smart Intelligent Sensors, MEMS, Nano.Transducer Performance: Static and dynamic performance parameters Standards: Electrical tests, measurement unit, measurement standards of of voltage, current, frequency, impedance etc .Errors and noise: types of errors, Effect of noise and errors on resolution and threshold. Dynamic range.Testing: Calibration, dynamic tests, environmental test, life test. Case Studies in Application of transducers: displacement, velocity, acceleration, force, stress, strain, pressure and temperature measurement. Angular and linear encoders, Radar, laser and sonar distance measurement, Tachometers, Viscometer, densitometer

15

Basic Information Theory

Introduction to entropy, relative entropy, mutual information, fundamental inequalities like Jensen’s inequality and log sum inequality. Proof of asymptotic equipartition property and its usage in data compression. Study of entropy rates of the stochastic process following Markov chains. Study of data compression: Kraft inequality and optimal source coding. Channel capacity: symmetric channels, channel coding theorem, Fano’s inequality, feedback capacity. Differential entropy. The Gaussian channel: bandlimited channels, channels with colored noise, Gaussian channels with feedback. Detailed study of the rate-distortion theory: rate distortion function, strongly typical sequences, computation of channel capacity. Joint source channel coding/separation theorem. There are no laboratory or design activities involved with this course.

16

Advanced Digital Signal Processing

Review of Signals and Systems, Sampling and data reconstruction processes. Z transforms. Discrete linear systems. Frequency domain design of digital filters. Quantization effects in digital filters. Discrete Fourier transform and FFT algorithms. High speed convolution and its application to digital filtering. Introduction to Multirate signal processing, Multirate filtering and Filterbanks: including Polyphase decomposition and perfect reconstruction, Cyclostationarity and LPTV filters, Introduction to

17

Introduction to Chaotic Dynamical Systems

Topics to be covered include chaos, elementary bifurcations. Sarkovski’s theorem, recurrence and equidistribution, codes, symbolic dynamics and chaotic behaviour. Higher dimensional dynamics, including horseshoes, Henon map. Stability of systems.

18

Intelligent Motor Controllers

Fundamental concepts in control of electric drive systems. Intelligent Control algorithms used for electric drive systems. Application of Fuzzy Logic, Neural Networks, Genetic Algorithm, Hybrid Fuzzy and Nonlinear Control of Power Converters and Drives. Other recent topics on Intelligent Control of Drives.

19

Smart Grid Technology

Introduction:- Smart Grid an Overview; Components of Smart Grid; Intelligent Appliances; Smart Substations; Smart Distributions-Generations; Smart Power meters; Universal Access (wind, solar, hydro etc.) Smart Grid Technologies: Integrated Communications; Sensing and Measurement; Advance Control Methods; Advance components and Improved Interfaces and Decision Support. Benefits of Smart Grid: Self-Healing; Power Quality Improvement; Utilization of all generation and storage options; Optimized use of assets and efficient Operation. Miscellaneous: Smart Grid Challenges; Smart Grid Projects; Contribution of Microgrid in development of Smart Grid.Wavelet Transform.
The self-study component will consist of design problems in the above to be implemented on MATLAB.

20 Mechatronics

Introduction to mechatronics systems. Various parts of mechatronics systems. Analog-to-digital-conversion (A/D) and its implementation using a microcontroller and DSPs. Study of the underlying operationalprinciples and construction of electromagnetic actuators such as DC, AC, and stepping motors. Study of various transducers their working principles. Selection of best electrical machines for a given motion control application considering system inertia, external forces or torques, and motion profiles. Design and analysis for basic power controllers for various applications.

21 Power System Dynamics

Dynamic models of synchronous machines, excitation system, turbines, governors, loads. Modelling of single-machine-infinite bus system. Mathematical modelling of multimachine system. Dynamic and transient stability analysis of single machine and multi-machine systems. Power system stabilizer design for ultimachine systems. Dynamic equivalencing. Voltage stability Techniques for the improvement of stability. Direct method of transient stability analysis: Transient energy function approach.

22 Dynamic Modelling And Control of Sustainable

Microgrids and distributed generation; Introduction to renewable energy technologies; electrical systems and generators used in wind energy conversion systems,diesel generators, combined heat cycle plants, inverter based generation, solar PV based systems, fuel cell and aqua-electrolyzer, battery and flywheel based storage system; Voltage and frequency control in a microgrid; Grid connection interface issues.

23 Automation in Manufacturing

Introduction to Automation of different manufacturing processes. Types of systems - mechanical, electrical, electronics; Data conversion devices, transducers, signal processing devices, relays, contactors and timers. Sensors and their interfaces; Hydraulics & Pneumatic Systems design and their application to manufacturing equipment; Sequence operation of hydraulic and pneumatic cylinders and motors; Electro Pneumatic & Electro Hydraulic Systems design, Relay Logic circuits, Feedback control systems, PID Controller; Drives and mechanisms of an automated system: stepper motors, servo drives. Ball screws, linear motion bearings, electronic caming and gearing, indexing mechanisms, tool magazines, and transfer systems. Programmable Logic Controllers, I/Os, system interfacing, ladder logic, functional blocks, structured text, and applications. Human Machine Interface & SCADA; Motion controller and their programming, PLCOpen Motion Control blocks, multi axes coordinated motion, CNC control; RFID technology and its application; Machine vision and control applications. Modular Production Systems – Distribution, Conveying, Pick & Place etc. Laboratory work will be hands-on design and operation of automatic systems.

24 Introduction to Machine Learning

Introduction to Machine intelligence and learning; linear learning models; Artificial Neural Networks: Single Layer Networks, LTUs, Capacity of a Single Layer LTU, Nonlinear Dichotomies, Multilayer Networks, Growth networks, Backpropagation and some variants; Support Vector Machines: Origin, Formulation of the L1 norm SVM, Solution methods (SMO, etc.), L2 norm SVM, Regression, Variants of the SVM; Complexity: Origin, Notion of the VC dimension, Derivation for an LTU, PAC learning, bounds, VC dimension for SVMS, Learning low complexity machines - Structural Risk Minimisation; Unsupervised learning: PCA, KPCA; Clustering: Origin, Exposition with some selected methods; Feature Selection: Origin, Filter and Wrapper methods, State of the art - FCBF, Relief, etc; Semi-supervised learning: introduction; Assignments/Short project on these topics.

25 Embedded Systems and Applications

Introduction to embedded system. Architectural Issues: CISC, RISC, DSP Architectures.Component Interfacing, Software for Embedded Systems : Program Design and Optimisation techniques, O.S for Embedded Systems, Real-time Issues. Designing Embedded Systems : Design Issues, Hardware- Software Co-design, Use of UML. Embedded Control Applications, Networked Embedded Systems : Distributed Embedded Architectures, Protocol Design issues, wireless network. Embedded Multimedia and Telecommunication Applications: Digital Camera, Digital TV, Set-top Box, Voice and Video telephony.

26 Intelligent Systems

Introduction, Search, Markov Decision Process, Game Playing, Constraint Satisfaction, Bayesian Network, Logic, Planning, Searching with non-deterministic action.

27 Neural Systems and Learning Machines

Introduction to biological neural systems, artificial neural network models, feed forward models, recurrent systems, analysis and applications.

28 Computer Vision

Link between Computer Vision, Computer Graphics, Image Processing and related fields; feature extraction; camera models; multi-view geometry; applications of Computer Vision in day-to-day life.

29 Swarm Intelligence

Swarm intelligence, distributed optimization, ant colony algorithms, PSO, firefly, bee, and related methods, applications and implementation issues.

30 Signals and Systems in Biology

Introduction to Cell Biology (DNA and Proteins); Introduction to Evolution; Modelling Evolution (Genetic Algorithms, Quasispecies); Genomic Signal Processing; Transcriptomic/Proteomic signals; Regulatory networks and dynamics; Protein interaction networks; Signal transduction and metabolic networks; Evolvability and Learning. Project activities on these topics (involving the use of online biological databases and bioinformatics software tools); Student presentations and Journal Club

31 Numerical Linear Algebra and Optimization in Engineering

Basics of Linear Algebra; Matrix decomposition - LU, LDU, QR and Cholesky factorization; Householder reflection, Givens rotation; Numerical implications of SVD; Numerical Solution for Linear Systems; Algorithm Stability; Problem Conditioning; Pivoting and scaling; Least Square Solutions; Numerical Matrix eigenvalue methods; Sparse Systems; Iterative methods for large systems; Krylov, Arnoldi, Lanczos methods; Numerical Optimization techniques - Conjugate gradient method, Linear and quadratic programming, Spectral and Pseudo-spectral methods.

32 Nonlinear Control

Overview of nonlinear control, Lyapunov stability for autonomous and non-autonomous systems, Input-Output Stability and Input-to-State Stability, Passivity analysis and applications, Absolute Stability, Incremental stability analysis, Lyapunov-based feedback control design, Feedback linearization and backstepping, Sliding mode control, Nonlinear observer design.

33 Adaptive and Learning Control

Introduction to adaptive control, Review of Lyapunov stability theory, Direct and indirect adaptive control, Model reference adaptive control, Parameter convergence, persistence of excitation, Adaptive backstepping, Adaptive control of nonlinear systems, Composite adaptation, Neural Network-based control, Repetitive learning control, Reinforcement learning-based control, Predictive control, Robust adaptive control.

34 Model Reduction in Control

Introduction to Model Reduction; Sources of Large Models - Circuits, Electromagnetic Systems, Mechanical Systems; Discretization Methods - Finite Difference Method (FDM), Finite Element Method (FEM); Classical Model Reduction Methods - Pade Approximation, Moment matching, Routh Approximants; Modern Methods - Modal Model Reduction Methods, SVD (Grammian) based methods, Krylov based methods, SVD-Krylov based methods; MOR for Nonlinear Systems – SVD & POD Methods; Model Reduction in Control; Control Design on Reduced Models – Sub- optimal

35

Robust Control

Modeling of uncertain systems, Signals and Norms, Lyapunov theory for LTI systems Passive systems – frequency domain, Passive systems – time domain, Robust Stability and performance, Stabilizing controllers – Coprime factorization, LQR, LQG problems Ricatti equations and solutions, H-infinity control and mu-synthesis, Linear matrix inequalities for robust control, Ricatti equation solution through LMI.

36

Networked and Multi-Agent Control Systems

Overview of networked systems, Graph Theory Fundamentals, Graphbased Network Models, Network Optimization, Consensus Problem: cooperative control, leader-follower architecture.Control under Communication Constraints, Formation Control, Swarming and Flocking Collision Avoidance, Game Theoretic Control of Multi-Agent Systems, Applications: Multi-robot/vehicle coordination, Sensor Networks, Social Networks, Smart Grids, Biological Networks.

37

Modeling and Control of Distributed Parameter Systems

Overview: Motivation and examples (wave propagation, fluid flow, network traffic, electromagnetism), Modeling of Distributed Parameter Systems (DPS): Parabolic and Hyperbolic PDEs, Analytic and Numerical Solution of PDEs, Lyapunov stability of DPS Boundary control and Observer Design of DPS, Discretization of Distributed Parameter Models: Finite Difference, Finite Element and Boundary Elements, Reduction of FEM models, Applications: Control of systems with time delays, control of fluid flow, network control.

38

Stochastic Control

Overview of stochastic systems with examples, Modeling of Stochastic Systems: Continuous and discrete-time models subjected to noise, Markov Decision Processes, Introduction to Stochastic Calculus and Stochastic Differential Equations, Stochastic Stability, Stochastic Optimal Control with complete and partial observations, finite and infinite horizon problems, Linear and nonlinear Filtering, Separation Principle, Linear quadratic Gaussian Problem, Stochastic Dynamic Programming, Stochastic Adaptive Control, Applications: Finance, operations research, biology.

39

Advanced Topics in Systems and Control

To be decided by the Instructor when floating this course: Can be anything that is related to systems and control engineering but is not covered in any of the established courses.

40

Advanced Robotics

Review of different robotic systems; Types of wheeled mobile robots and walking machines; Jacobian; Forward and inverse kinematic algorithms; Non-recursive and recursive dynamic algorithms; Dynamics of mobile robots and walking machines; Kinematic design of robotic systems based on singularity, manipulability, etc.; Control of robots. Mechanical design of links.

41

Digital Control of Power Electronics and Drive Systems

Review of Digital signal processors, Laplace transforms, Theory of sampling, z-transformations, sampling techniques, Digital PWM generation schemes, Realization of different PWM's using DSP's, Control of DC-DC Converters, Inverters, DC and Ac Machines.

42

Embedded Intelligence

Basics of embedded, learning, and adaptive systems; sensors, nature of dynamic environments, hardware aspects.

43

Advanced Machine Learning

Advanced topics in machine learning, including Nonlinear Dimension Reduction, Maximum Entropy, Exponential Family Models, Graphical Models; Computational Learning Theory, Structured Support Vector Machines, Feature Selection, Kernel Selection, Meta-Learning, Multi-Task Learning, Semi-Supervised Learning, Reinforcement Learning, Approximate Inference, Clustering, and Boosting.

44

Computational Neuroscience

Fundamentals of brain anatomy and physiology, signals of brain, Brain signal recording and imaging techniques, Human experimentation study design, Processing the X-D neural data, Machine learning approaches, Graph theory and neural networks, Multivariate pattern analysis in 4D Imaging data, Statistical inferences, student projects and presentations.

45

Cyber-Physical Systems

Introduction: core principles behind CPSs; Specification of CPS, CPS models: Continuous, Discrete, Hybrid, Compositional; Abstraction and System Architecture, Design by Invariants, Sensing and Fusion, Cloud of Robots/CPS; Case Studies: Healthcare, Smart Grid, Transportation.

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Special Module in Systems and Control

Pre-requisites: to be decided by the instructor. To provide exposure in specialized topics in systems and control.