Systems and Control

This field offers a program of study which includes a basic, methodology-oriented curriculum in dynamic systems. The curriculum covers basic engineering principles and methods of applied mathematics common to continuous-time and discrete-time dynamic system modeling, analysis, and design. The emphasis is on the properties of dynamic systems models, control and feedback principles and properties, and practical computer solution methods.

Summary of Major Field Body of Knowledge:

Students should master the major field body of knowledge covered in the following courses:
MAE M171A, 270A, 270B, 271A, 271B
and a selection of 2 courses from:
MAE 270C, 271C, M272A, 273A, 275A, 277, 279

The written qualifying (preliminary) examination covers the following subset of the major field body of knowledge:
MAE 171A, 270A, 270B, 271A, 271B.

More details concerning the major field body of knowledge can be found in the **Syllabus for the Major Field**, on the next page.

Minimum Requirements for Ph.D. Major Field Students:

The student must pass a written examination in the major field and satisfy other program requirements for the Ph.D. in the MAE Department besides completing all other formal University requirements.

Format of Written Qualifying Examination:

The exam consists of a 4-hour closed book part and a 4-hour open book part.

Timing of Written Qualifying Examination:

Offered every Spring quarter.

Link to old exams:

http://stdntsvcs.mae.ucla.edu/exam/index.htm

Ph.D. Minor Field Requirements:

Three courses including at least two graduate classes from the courses listed in the Major Field Body of Knowledge. The undergraduate class may be selected from MAE 171A, 171B, 172.

Syllabus for the Major Field in Systems and Control

The undergraduate classes listed below provide background for the graduate classes, and one can be used toward a minor in Systems and Control.

I. Systems, Feedback and Control Fundamentals [171A]

a) Mathematical modeling of dynamic systems in the frequency domain (Laplace transforms, transfer functions)
b) Block diagram manipulations
c) Stability; Routh Hurwitz Criterion
d) Transient response; transient performance specifications (overshoot, rise time, settling time)
e) Steady state errors; final value theorem; system type; steady state performance specifications
f) Root locus analysis and design; closed loop root locations and transient performance
g) Frequency response methods (bode, nyquist); frequency response performance specifications (gain margin, phase margin, band width)
h) Frequency response design
i) Compensator design using PID controllers, lead, lag and integral action
j) Disturbance rejection

II. Digital Control of Physical Systems [171B]

a) Analysis and design of digital control systems.
b) Sampling theory. Z-transformation.
c) Discrete-time system representation.
d) Design using classical methods: performance specifications, root locus, frequency response, loop-shaping compensation.
e) Design using state-space methods: state feedback, state estimator, state estimator feedback control.
f) Simulation of sampled data systems and practical aspects: roundoff errors, sampling rate selection, computation delay

III. Control System Design Laboratory [172]

a) Application of frequency domain design techniques for control of mechanical systems.
b) Controller design: formulate performance measures for control problem, experimentally identify mechanical systems, and develop uncertainty descriptions for design models.
c) Exploration of issues concerning model uncertainty and sensor/actuator placement.
d) Implementation of control designs on flexible structures, rate gyroscope, and inverted pendulum.
e) Detailed laboratory reports.

IV. Linear Systems [270A]

a) State-space representation of continuous-time and discrete-time control systems
b) Relevant methods and results from linear algebra, such as eigenvalues and eigenvectors, singular values, the Cayley-Hamilton theorem, Jordan form
c) Matrix exponentials, state-transition matrices, impulse-response functions

d) Stability of linear systems, Lyapunov functions and Lyapunov equations
e) Controllability, stabilizability, observability, detectability; controllability, and observability diagrams
f) Control and observer canonical forms, companion form
g) Stabilization and pole-placement by feedback
h) Reconstruction of state vector and functionals by observers
i) Relationships between state-space representations and frequency-domain representations

V. Linear Optimal Control [270B]

a) Existence and uniqueness of solutions to linear-quadratic optimal control problems for continuous-time and discrete-time systems; finite-time and infinite-time problems
b) Hamiltonian systems and optimal control
c) Relationships between optimal feedback control and Riccati equations (Riccati differential, difference, and algebraic equations)
d) Relationships between Hamiltonian matrices and Riccati equations; numerical solution of Riccati equations
e) Properties of the optimal linear-quadratic regulator: stability, phase and gain margins
f) Implications of controllability, stabilizability, and detectability for existence and uniqueness of solutions to optimal control problems, for properties of optimal closed-loop systems, and for Riccati matrices
g) Linear-quadratic optimal control with constrained final state vector
h) Linear-quadratic optimal tracking
i) Lyapunov equations and quadratic performance indices

VI. Optimal Control Theory [270C]

a) First-order necessary conditions for weak and strong optimality
b) Global optimality and the Hamilton-Jacobi- Bellman equation
c) The second variations in the calculus of variations
d) The Riccati matrix differential equation
e) Necessary and sufficient conditions for positive definiteness of the second variation (the Jacobi condition)
f) The strongly positive condition and necessary and sufficient conditions for a local weak minimum
g) Linear-quadratic differential games with partial information
h) The singular problem in the calculus-of-variations
i) State variable inequality constraints

VII. Stochastic Processes in Dynamical Systems [271A]

a) Probability space
b) Random variables and the expectation operation
c) Independence and condition probabilities
d) Brownian motion process
e) Markov process
f) Mean-square calculus
g) Second order processes

h) Stochastic differential equations and stochastic integrals
i) Itô integrals and Itô differentials
j) Itô stochastic calculus
k) Kolmogorov equations

VIII. Stochastic Estimation [271B]

a) Estimation Theory: Discrete Time
  1. Bayes' theorem
  2. The orthogonal projection lemma
  3. Properties of the minimum variance filters (Kalman Filter)
  4. Linear-exponential-Gaussian estimator
  5. Worst case filter design
  6. Extended Kalman Filter
  7. The modified gain extended Kalman filter

b) Estimation Theory: Continuous Time
  1. Continuous time Kalman filter
  2. Properties of Kalman filter
  3. Continuous extended Kalman filter (EKF)
  4. Linear minimum variance filter

IX. Stochastic Optimal Control [271C]

a) Stochastic Control and the Linear Quadratic Gaussian Control Problem
  1. Dynamic Programming: An Illustration
  2. Stochastic Dynamical System
  3. Dynamic Programming Algorithm
  4. Stochastic LQ Problems With Perfect Information
  5. Dynamic Programming with Partial Information
  6. Sufficient Statistics
  7. The Discrete-Time LQG Problem with Partial Information
  8. The Continuous-Time LQG Problem
  9. Dynamic Programming for Continuous-Time Markov Processes
  10. The Linear-Quadratic Gaussian Problem with Partial Information
  11. Stationary Optimal Control
  12. Linear Quadratic Gaussian Control with Loop Transfer Recovery

b) Linear Exponential Gaussian Control and Estimation 385
  1. Discrete-Time Linear Exponential Gaussian (LEG) Control
  2. The LEG Estimator
  3. The Optimality of the Stochastic Estimator
  4. Continuous Time Linear Exponential Gaussian Control
  5. Linear Exponential Gaussian Controllers and its relationship with the Disturbance Attenuation and H-infinity syntheses

X. Nonlinear Dynamic Systems [M272A]

a) State-space techniques for studying solutions of time-invariant and time-varying nonlinear dynamic systems with emphasis on stability.
b) Lyapunov theory (including converse theorems).
c) Invariance, center manifold theorem.
d) Input-to-state stability
e) Small-gain theorem.

XI. Robust Control System Analysis and Design [273A]

a) Graduate-level introduction to analysis and design of multivariable control systems.
b) Multivariable loop-shaping, performance requirements, model uncertainty representations, and robustness covered in detail from frequency domain perspective.
c) Structured singular value and its application to controller synthesis.

XII. System Identification [275A]

a) Methods for identification of dynamical systems from input/output data, with emphasis on identification of discrete-time (digital) models of sampled-data systems.
b) Conversion to continuous-time models.
c) Models identified include transfer functions and state-space models.
d) Discussion of applications in mechanical and aerospace engineering, including identification of flexible structures, microelectromechanical systems (MEMS) devices, and acoustic ducts.

XIII. Advanced Digital Control for Mechatronic Systems [277]

a) Digital signal processing and control analysis of mechatronic systems.
b) System inversion-based digital control algorithms and robustness properties,
c) Youla parameterization of stabilizing controllers,
d) Previewed optimal feedforward compensator,
e) Repetitive and learning control.
f) Real-time control investigation of topics to selected mechatronic systems.

XIV. Dynamics and Control of Biological Oscillations [279]

a) Neuronal dynamics as planar nonlinear oscillators and their phase plane analysis
b) Analysis and design of central pattern generators (CPGs) via multivariable harmonic balance
c) Design of coupled nonlinear oscillators via Froquet analysis, coordinate transformations, and averaging
d) Dynamical models of robotic vehicle systems inspired by animal locomotion
e) Optimal periodic motion of mechanical rectifiers
f) Feedback control for stable coordinated oscillations by eigenstructure assignment

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