AME 541:Linear Control Systems II

Time:	*Tu,Th 4-5:50pm*
Instructor:	*H. Flashner*
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Homework: Will be assigned every Thursday and **must be submitted** the following Thursday

Grading: The final grade will be assigned according to the following weightings :

Homework:	20%
Midterm (October 5):	30%
Final (December 7, 4:30pm):	50%

Textbook

J.P. Hespanha, *Linear Systems Theory*, Second EditionPrinceton Press, 2018.

Reference books

1. C.T. Chen, *Linear Systems Theory and Design, 3rd Edition*, Oxford University Press, 1999.
2. W. J. Rugh, *Linear Systems Theory*, Prentice-Hall, 1993.
3. T. Kailath, *Linear Systems,* Prentice-Hall, 1980.

Outline

1. **Mathematical Representation of Systems** (Notes)
   (a) Modeling of dynamical systems
2. **Linear Systems Modeling** (Chapters 1- 2)
   (a) State representation
      i. Nonlinear systems
      ii. Linear systems
   (b) Linearization
      i. Linearization about an equilibrium point
      ii. Linearization about a trajectory
3. Characteristics of Linear Systems (Chapters 3-4)
   (a) Causality, time invariance, lineaity
   (b) Impulse response
   (c) Transfer function
   (d) Impulse response znd transfer of state-space systems
   (e) Equivalent state-space systems systems

4. **Solution of State Equations** (ChaCpter 5-7)
    (a) Solution homogeneous and non-homogeneos LTV linear systems
        i. Properties of transition matrix
    (b) Matrix exponential
        i. Properties of matrix exponential
        ii. Computation of matrix exponential using Laplace transform
    (c) Computation of matrix exponential using eigenvalue analysis
        i. Jordan canonical form
5. **Stability Analysis** (Chapters 8-9)
    (a) Internal stability
        i. Lyapunov linear stability theorem
        ii. Stability of linearized systems
    (b) Input-output stability
        i. Bounded-input, bounded output (BIBO) stability
        ii. Time domain conditions for BIBO stabilty
        iii. Frequency domain conditions for BIBO stabilty
    (c) BIBO stability versus Lyapunov stability
6. **Controllability** (Chapter 11-12)
    (a) Controllability and reachability
        i. Controllability and reachability Grammians
        ii. Tests for controllability of LTI systems
    (b) Feedback stabilization
        i. Feedback stabilization using Lyapunov test
        ii. Eigenvalue assignment
7. **Controllable decompositions and stabilizability**
    (a) Controllable decomposition
        i. Invariance with respect to similarity transformation
        ii. Block diagram interpretation
        iii. Transfer function
    (b) Tests for stabilizability
    (c) Feedback stabilization
8. **Observability and State Observation** (Chapter 15-16)
    (a) Observability and constructability Grammians
    (b) Observability tests for LTI systems
    (c) Duality for LTI systems
    (d) Observable decomposition
    (e) Kalman decomposition
9. **State Estimation and Output Feedback** (Chapter 16)
    (a) Detectability
        i. Detectability tests
    (b) State estimation

i. Full order state observer
ii. Reduced order state observer

(c) Stabilization via output feedback

10. **Minimal Realizations** (Chapter 17)

(a) Implications of of coprimness
(b) Markov parameters
(c) Minimal realization of SISO systems
(d) Balanced realization of SISO systems

11. **Poles and Zeros of MIMO Systems** (chapters 18-19)

(a) Polynomial matrices: Smith form
(b) Rational matrices: Smith-McMillan form
(c) McMillan degree, poles and zeros
(d) Transmission zeros and invariant zeros
(e) Minimal realization of MIMO systems

12. **Linear Optimal Control and Its Characteristics** (Chapter 21-23)

(a) Linear quadratic regulation
(b) Optimal state feedback
(c) Riccati equation
(d) Hamiltonian matrix
(e) Frequency domain properties of single input systems
(f) Loop shaping using LQR for single input system

13. **Output Feedback**

(a) Deterministic minimum energy estimation (MEE)
(b) Stochastic linear quadratic Gaussian (LQG) estimation
(c) LQR/LQG output feedback
(d) Optimal set point control