USC Viterbi

School of Engineering

Ming Hsieh Department of Electrical Engineering

Fall 2017 – EE 585: Linear Systems Theory

- **Instructor:** Mihailo Jovanović, EEB 324, ee.usc.edu/mihailo/
- **Class schedule:** TuTh, 9:30 - 10:50am, OHE 100B, Aug 21 - Dec 1, 2017
- **Target audience:** graduate students with interests in control and dynamical systems, artificial intelligence and machine learning, signal and image processing, communications, computer science and engineering, optimization, robotics, power systems, systems biology, and financial engineering
- **Texts and software:**
  - **Primary text:** Mohammed Dahleh, Munther Dahleh, George Verghese, "Lectures on dynamic systems and control", available on the class webpage
  - **Supplementary text:** Joao P. Hespanha, "Linear Systems Theory", Princeton University Press, First Edition, ISBN-10: 0-691-14021-9
  - **Supplementary material 1:** Stephen Boyd, "EE 263: Introduction to linear dynamical systems", http://www.stanford.edu/class/ee263/
  - **Supplementary material 2:** Stephen Boyd, "EE 363: Linear dynamical systems", http://www.stanford.edu/class/ee363/
  - **Software:** Homework sets will make a use of Matlab or Simulink
- **Grading policy:** Homework (40%), Midterm exam (30%), Final exam (30%)
- **Tentative exam schedule:** Midterm: Oct 12; Final: during exam week
- **Course description:** Introduction to dynamic systems and control. Fundamentals of matrix theory. Basic system properties: causality, linearity, time-invariance. Description of dynamic systems. State-space models. Solution to dynamics systems (discrete time, continuous time). Properties of state transition matrix. Similarity transformations. Modes of LTI systems. Normal vs. non-normal matrices. Laplace and Z transforms. Transfer functions. Lyapunov stability. Linearization. Lyapunov stability for LTI systems. Signal measures and input-output stability. Frequency responses of LTI systems. Singular Value Decomposition. Input-output norms. Interconnections: stability and performance. Controllability – basic ideas, standard and canonical forms, modal tests. Observability, observability tests. Minimality. Realization theory for LTI systems. Kalman decomposition. Multivariable poles and zeros. Interconnections: minimality, well-posedness, stability. State-feedback design. Pole placement. Linear Quadratic Regulator. Algebraic Riccati Equation. Observer design and filtering. Observer-based controllers. Separation principle.

ee.usc.edu/mihailo/courses/ee585/f17/

USC Viterbi School of Engineering

Course ID and Title:
EE 585: Linear Systems Theory
Units: 3
Term—Day—Time: Fall 2017—TuTh—9:30-10:50am

Location: OHE 100B

Instructor: Mihailo Jovanovic
Office: EEB 324
Office Hours: Tu, 2:00-3:00pm
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Instructor Webpage: ee.usc.edu/mihailo/

Course Webpage: ee.usc.edu/mihailo//courses/ee585/f17/

Teaching Assistant: TBA
Office: TBA
Office Hours: TBA
Contact Info: TBA

IT Help: N/A
Hours of Service: N/A
Contact Info: N/A

Course Description
The intent of this course is to provide the students with the basic tools of modern linear systems theory. We will establish a balance between state-space methods for analysis/synthesis of linear dynamical systems and frequency domain methods for studying input-output properties of multivariable linear systems. The course content will be motivated by examples from different application domains and it will be presented in such a way to make it of interest to students with background in control and dynamical systems, communications, signal and image processing, computer science and engineering, optimization, robotics, power systems, systems biology, and financial engineering.

Learning Objectives
The course objective is to equip students with the working knowledge of modern linear systems theory.

Prerequisite(s): EE 441
Co-Requisite(s): None
Concurrent Enrollment: None
Recommended Preparation: Even though I plan to cover everything from scratch, the students would benefit from a solid background in linear algebra (EE 441 or an equivalent course). Those interested should contact the instructor.

Course Notes
Letter Grade. Lecture notes and other relevant class information will be posted on the course webpage.

Technological Proficiency and Hardware/Software Required
Homework sets will make a use of Matlab.

Required Readings and Supplementary Materials
Mohammed Dahleh, Munther Dahleh, and George Verghese, "Lectures on Dynamic Systems and Control"

Please refer to the course webpage for information about additional references and supplementary materials.

Description and Assessment of Assignments
Homework is intended as a vehicle for learning, not as a test. Moderate collaboration with your classmates is encouraged. However, I urge you to invest enough time alone to understand each homework problem, and independently write the solutions that you turn in. Homework is generally handed out every other Thursday, and it is due at the beginning of the class a week. Late homework will not be accepted. Start early!

Assignment Submission Policy
Please see "Description and Assessment of Assignments".

Grading Timeline
One week after submission.

Additional Policies
Attendance of the lectures is expected.

Grading Breakdown

Including the above detailed assignments, how will students be graded overall? Participation should be no more than 15%, unless justified for a higher amount. All must total 100%.

Assignment	Points	% of Grade
Homework	40	40
Midterm exam	30	30
Final exam	30	30
TOTAL	100	100

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1	Course mechanics; What is the course about? Basic system properties	Homework 1 assigned.	
Week 2	State-space models; Equilibrium points; Linearization; Solution to discrete time systems; State transition matrix		Homework 1 due.
Week 3	Z transform; Resolvent; Transfer function; Impulse and frequency responses of DT LTI systems; State transition matrix of CT systems; Variation of constants formula	Homework 2 assigned.	
Week 4	Numerical computation of the state transition matrix; Matrix exponential; Laplace transform; Impulse response and transfer function of CT LTI systems; A double-integrator example		Homework 2 due.
Week 5	Eigenvalue decomposition; Diagonalization of a matrix; Jordan canonical form	Homework 3 assigned.	
Week 6	Modal decomposition of LTI systems; Normal vs. non-normal matrices; Modal conditions for stability of LTI systems		Homework 3 due.
Week 7	Stability of equilibrium points of nonlinear systems; Stability via linearization	Homework 4 assigned.	

Week 8	Lyapunov functions for LTI systems; Algebraic Lyapunov Equation		Homework 4 due.
Week 9	Signal norms; Frequency responses of LTI systems	Homework 5 assigned.	
Week 10	Singular Value Decomposition; System norms; Reachability of discrete-time systems; Kalman rank test		Homework 5 assigned.
Week 11	Reachability gramian; Minimum energy state transfer; Reachability ellipsoid	Homework 6 assigned.	
Week 12	Canonical form of unreachable systems; Modal tests for reachability		Homework 6 due.
Week 13	Controllability of continuous-time systems; Observability	Homework 7 assigned.	
Week 14 (Thanksgiving)	Pole placement; State estimation; Kalman filter; Observer-based controller	Homework 8 assigned.	Homework 7 due.
Week 15	Linear Quadratic Regulator		Homework 8 due.
FINAL	Final Exam		For the date and time of the final exam please consult the USC Schedule of Classes at classes.usc.edu

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, "Behavior Violating University Standards" https://policy.usc.edu/student/scampus/part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, intimate partner violence, stalking, and harassment are prohibited by the university. You are encouraged to report all incidents to the *Office of Equity and Diversity*/*Title IX Office* http://equity.usc.edu and/or to the *Department of Public Safety* http://dps.usc.edu. This is important for the health and safety of the whole USC community. Faculty and staff must report any information regarding an incident to the Title IX Coordinator who will provide outreach and information to the affected party. The sexual assault resource center webpage http://sarc.usc.edu fully describes reporting options. Relationship and Sexual Violence Services https://engemannshc.usc.edu/rsvp provides 24/7 confidential support.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://ali.usc.edu, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://dsp.usc.edu provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* http://emergency.usc.edu will provide safety and other updates, including ways in which instruction will be continued by means of Blackboard, teleconferencing, and other technology.