USC Viterbi School of Engineering

Course ID and Title:
EE 585: Linear Systems Theory
Units: 4
Term: Fall, every year
Day: Tu, Th
Time: 9:00-11:50am

Instructor: Mihailo Jovanovic
Office: EEB 324
Office Hours:
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Instructor Webpage: https://viterbi-web.usc.edu/~mihailo/

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IT Help: Distance Education Network (DEN)
Hours of Service: N/A
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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, machine learning, artificial intelligence, power systems, systems biology, and financial engineering.

Topics: Course mechanics; What is the course about? Basic system properties: linearity, time invariance, memory, causality; State-space models; Equilibrium points; Linearization; Examples of electrical and mechanical systems; Solution to discrete time (DT) systems; State transition matrix; Z transform; Resolvent; Transfer function; Impulse and frequency responses of DT LTI systems; State transition matrix of continuous time (CT) systems; Variation of constants formula; Numerical computation of the state transition matrix; Matrix exponential; Laplace transform; Impulse response and transfer function of CT LTI systems; A double-integrator example; Eigenvalue decomposition; Diagonalization of a matrix; Jordan canonical form; Modal decomposition of LTI systems; Normal vs. non-normal matrices; Modal conditions for stability of LTI systems; Stability of equilibrium points of nonlinear systems; Stability via linearization; Lyapunov functions for LTI systems; Algebraic Lyapunov Equation; Signal norms; System norms; Singular Value Decomposition; Frequency responses of LTI systems; Reachability of discrete time systems; Kalman rank test; Reachability gramian; Minimum energy state transfer; Reachability ellipsoid; Canonical form of unreachable systems; Modal tests for reachability; Popov–Belevitch–Hautus (PBH) reachability test; Controllability of continuous time systems; Observability; Observability gramian; Observability ellipsoid; Infinite horizon uncertainty ellipsoid; Balanced realization; Balanced truncation; Introduction to system identification; Kalman-Ho algorithm; Pole placement; State estimation; Kalman filter; Separation principle; Observer-based controller; Introduction to optimal control of linear systems; Linear Quadratic Regulator; Algebraic Riccati Equation

Learning Objectives

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

Prerequisite(s): EE 510
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 510 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: linearity, time invariance, memory, causality	Homework 1 assigned. Reading: Handouts.	
Week 2	State-space models; Equilibrium points; Linearization; Examples of electrical and mechanical systems	Reading: Chapters 6 and 7.	Homework 1 due.
Week 3	Solution to discrete time (DT) systems; State transition matrix; Z transform; Resolvent; Transfer function; Impulse and frequency responses of DT LTI systems	Homework 2 assigned. Reading: Chapter 10.	
Week 4	State transition matrix of continuous time (CT) systems; Variation of constants formula; Numerical computation of the state	Reading: Chapter 11.	Homework 2 due.

	transition matrix; Matrix exponential; Laplace transform; Impulse response and transfer function of CT LTI systems; A double-integrator example		
Week 5	Eigenvalue decomposition; Diagonalization of a matrix; Jordan canonical form	Homework 3 assigned. Reading: Handouts.	
Week 6	Modal decomposition of LTI systems; Normal vs. non-normal matrices; Modal conditions for stability of LTI systems	Reading: Chapter 12.	Homework 3 due.
Week 7	Stability of equilibrium points of nonlinear systems; Stability via linearization	Homework 4 assigned. Reading: Chapter 13.	
Week 8	Lyapunov functions for LTI systems; Algebraic Lyapunov Equation	Reading: Chapter 14.	Homework 4 due.
Week 9	Signal norms; System norms; Singular Value Decomposition; Frequency responses of LTI systems	Homework 5 assigned. Reading: Chapters 15 and 16.	
Week 10	Reachability of discrete time systems; Kalman rank test; Reachability gramian; Minimum energy state transfer; Reachability ellipsoid	Reading: Chapter 22.	Homework 5 assigned.
Week 11	Canonical form of unreachable systems; Modal tests for reachability; Popov–Belevitch–Hautus (PBH) reachability test; Controllability of continuous time systems	Homework 6 assigned. Reading: Chapter 23.	
Week 12	Observability; Observability gramian; Observability ellipsoid; Infinite horizon uncertainty ellipsoid	Reading: Chapter 24.	Homework 6 due.
Week 13	Balanced realization; Balanced truncation; Introduction to system identification; Kalman-Ho algorithm	Homework 7 assigned. Reading: Chapter 26.	
Week 14 (Thanksgiving)	Pole placement; State estimation; Kalman filter; Separation principle; Observer-based controller	Homework 8 assigned. Reading: Chapters 28 and 29.	Homework 7 due.
Week 15	Introduction to optimal control of linear systems; Linear Quadratic Regulator; Algebraic Riccati Equation	Reading: Handouts.	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.