Syllabus – Linear Systems Analysis
ECE 8010, Sections 001, 843, 500
Fall 2024

Meeting Time and Location

MWF, 1:25-2:15
Riggs Hall, Room 223 (Sec. 1, Clemson), and
Zucker, Room 302 (Sec. 843, Charleston)

Instructor

Richard Groff,
Office: Riggs Hall, Room 302
Phone: 864-656-5906

Student Hours

Office hours are held simultaneously in my physical office and/or via Zoom. See the "Student Hours and Contact Info" page under Modules on Canvas for the office hours schedule and Zoom link. Appointments outside of office hours may be arranged via email. Any changes in office hours will be posted on the Canvas page. Please check the page for any updates before attending in person.

Course Modality in-person (Sec 001), hybrid (Sec 843)

Email Contact

regroff@clemson.edu In the subject line of any email related to the course, please use "ECE8010:" as a prefix to your specific subject and include a short, useful subject description. For example, a good subject line might be "ECE8010: Question regarding HW4 P3". I will attempt to respond to email inquiries within 48 hours.

Canvas

Canvas (http://www.clemson.edu/canvas/ or https://clemson.instructure.com/) is an electronic course management system that will be used to post notes, assignments and solutions, homework clarifications and hints, supplemental readings, links to other resources, and grades.

Prerequisites & Corequisites

This course requires knowledge of matrix operations and ordinary differential equations, including Laplace transform techniques. Coursework in linear algebra (e.g. MTHSC 3110) and classical controls (e.g. ECE4090) is helpful, but **not** required.

Course Description

In this course, we will use linear algebra and linear analysis to derive fundamental results for linear dynamical systems in state space form and apply the results to understand the behavior of physical systems. This course will primarily focus on theory, with specific attention to deriving (proving) results. Homework problems will often require interpretation of theoretical results in numerical application settings. A complete survey of linear systems and linear control in a single semester is infeasible. Instead, the goal is to establish a strong understanding of the fundamentals of linear systems and mathematical proof in preparation for advanced coursework as well as independent research and exploration.

Textbook

The course notes are mostly self-contained and do not match up precisely with the required text (Brogan) or the supplementary texts. Reading a text is helpful for reinforcing the concepts from the course notes. The texts listed below have been placed on reserve at Cooper Library. To check availability, go to https://libraries.clemson.edu/find/course-reserves/.

Suggested Text: (do not purchase before attending class)

- William L. Brogan, *Modern Control Theory*, 3rd ed., Prentice Hall, 1991.

Supplementary Texts:

- Chi-Tsong Chen, *Linear System Theory and Design*, 4th ed., Oxford University Press, 2012.
- Panos J. Antsaklis and Anthony N. Michel, *Linear Systems*, Birkhäuser Boston, 2005.
- Robert L. Williams II and Douglas A. Lawrence, *Linear State-Space Control Systems*, Wiley, 2007. https://onlinelibrary-wiley-com.libproxy.clemson.edu/doi/book/10.1002/9780470117873
- Wilson J. Rugh, *Linear System Theory*, 2nd ed., Prentice Hall, 1995.
- David G. Luenberger, *Optimization by Vector Space Methods*, Wiley, 1969.
- Gene F. Franklin, J. David Powell, and Abbas Emami-Naeini, *Feedback Control of Dynamic Systems*, Prentice Hall, 2019.
- S. Boyd and L. Vandenberghe, *Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares*, Cambridge University Press, 2018. (legal, free pdf available from http://vmls-book.stanford.edu/)

Software

MATLAB and Simulink will be used regularly on homework assignments, especially in the latter half of the semester. MATLAB/Simulink may be downloaded and installed on a personal computer using the Clemson license www.cecas.clemson.edu/matlab. You can also use Matlab Online https://matlab.mathworks.com/. Note that MATLAB will not be explicitly taught in this course. Resources will be provided so that you can learn MATLAB. The built-in documentation for MATLAB is excellent. Information on installing and using MATLAB will be posted to Canvas.

Attendance Policies

- You may consider class canceled if the professor or a guest lecturer does not arrive within 15 minutes of the scheduled start of class. Before leaving class, please check email in case technical difficulties have caused the delay.
- Please note, lecture attendance is expected. Students are responsible for all material presented in class, regardless of absence.

Course Notes

- Lectures are organized around packets of typeset notes. I will provide an overview of the notes in class using slides and writing. You are expected to bring the typeset notes to class in a format that you can mark up (paper, or electronic if you have a tablet).

Topical Outline

- Unit I - Linear Algebra Overview
    - Vector spaces
    - Linear transformations and properties
    - Norms, induced norms
    - Inner products, projection theorem, and applications
    - Adjoints, decomposition theorem, and applications
    - Singular Value Decomposition
- Unit II – Introduction to Linear State Space Systems
    - Solutions to linear systems of equations
        - Least squares, minimum norm solutions
    - Solutions of linear state space systems
    - Solutions of linear, time-invariant state space systems
        - Eigenvalues, eigenvectors, Jordan form
    - Equivalent dynamical systems
    - Laplace-domain analysis of state space systems
    - Stability
- Unit III – Control Theory Concepts for Linear State Space Systems
    - Controllability, observability, and duality
    - Canonical forms and realizations
    - State-feedback controllers, observers, feedback using state estimates
    - (*time permitting*) Linear quadratic regulator, Kalman filtering, Applications

Grading:

Homework/Quiz	11%
Other	2%
Midterm Exam 1	29%
Midterm Exam 2	29%
Final Exam	29%

Letter grades are based on a curve using the course numeric grade calculated using the weights above. The numeric grade to letter grade conversion is 93-100 A, 90-93 A-, 87-90 B+, 83-87 B, 80-83 B-, 77-80 C+, 73-77 C, 70-73 C-, 0-70 F. Note that a graduate student is placed on academic probation if the grade point average for all graduate courses falls below 3.0 (B letter grade).

Other

The Other category covers preliminary activities and attendance checks.

- Several Preliminary Activities will be assigned in the first few days of class, such as the welcome post, reading class documents, etc. These activities are included in the "Other" category.
- Attendance checks – attendance may occasionally be verified using one of several methods

Note: There is no makeup for Attendance Checks.

Homework Policies

- Homework will be assigned once or twice per week.
- Recommended approach to homework: Read over the entire homework assignment shortly after it is posted. Identify problems for which the material has already been presented vs. problems for which the material has not yet been covered. Completing homework in several short sessions will generally be more effective than completing the homework in one marathon session. This is especially true for proofs and theoretical work.
- Problems or subproblems will be indicated as *Exercise*, *Required*, or *Advanced*.

- *Exercise* – Exercises are not submitted, so do not need to be formally written up. Many important concepts are developed and/or illustrated in the exercises. You are expected to know the material covered in the exercises.
- *Required* – Required problems must be submitted. Required problems will mostly be graded based on completion. More detailed grading and feedback will be provided on some selected problems.
- *Advanced* – material that goes beyond the scope of the course. You are not responsible for material covered in advanced problems.

- Homework will be collected electronically on Canvas. Guidelines for submitting homework will be posted on Canvas.
- Homework submitted more than 48 hours after the deadline is not accepted (unless you have received an extension). Homework submitted more than 12 hours after the deadline will receive a grade penalty.
- If you believe you have a valid reason to miss a deadline (e.g. conference travel, serious illness), please arrange for delayed submission at least one day before the homework is due.
- Group discussion of homework is allowed and encouraged, but each student is individually responsible for independently performing all calculations, writing any required code, and writing up the solution.
- You should be able to complete homework using only the provided course material. For most of the homework, the objective is to construct arguments built on fundamental concepts or to apply or interpret fundamental concepts. If you are "searching online for similar problem" you are not working on the skill set the homework is intended to develop.
- Please review the posted solutions to be sure you have fully grasped the concepts and ask questions as necessary. In general, we will not have time to review homework in class.
- Canvas will be used to post clarifications, corrections, and hints for homework problems. If you run into difficulty, check Canvas first.

Exam Policies

- There will be two midterm exams and a final exam.
- Each exam will consist of an in-class part and a take-home part
  - The in-class part generally consists of several True/False questions (provide a proof if true, provide a counterexample if false). The in-class part is closed book. For each exam you are permitted a hand-written note sheet consisting of a single sheet of 8.5"x11" paper. For the second midterm and final you may also bring the formula sheets from the previous exams. The formula sheet may include definitions and formulas, but may *not* include worked problems or proofs. *No computational devices* (calculators, computers, cell phones, etc.) may be used during the in-class part.
  - While working the take-home part, you are permitted to use your class notes, textbook, calculator and MATLAB/Simulink. You are not permitted to use other resources without explicit permission. The take-home part will include numerical problems requiring a computer. The take-home part is generally intended to take 4-6 hours to complete.
- **Collaboration on any part of the exam is strictly prohibited and is a violation of academic integrity.**
- **You are *not* permitted to discuss the in-class or take-home exams in any way until all students have submitted both parts of the exam.**
- You will be required to sign an honor pledge stating that you will adhere to the exam requirements.
- For the midterm exams, the in-class part will be completed during a regularly scheduled class period. The take-home part will be distributed at the end of the in-class part and is due several days later (typically 2-3). Exam dates will be posted on Canvas.

- The Final Exam will be held at the university-specified time during Final Exams week, Friday 3:00pm-5:30pm. Due to the scheduled time, the take-home component of the final will be issued several days prior and will be due at the beginning of the in-class part. The Final Exam will be *comprehensive*, but with an emphasis on material presented after the second midterm.

Accessibility: Clemson University values the diversity of our student body as a strength and a critical component of our dynamic community. Students with disabilities or temporary injuries/conditions may require accommodations due to barriers in the structure of facilities, course design, technology used for curricular purposes, or other campus resources. Students who experience a barrier to full access to a class should let the instructor know and make an appointment to meet with a staff member in Student Accessibility Services as soon as possible. You can make an appointment by calling 864-656-6848 or by emailing studentaccess@lists.clemson.edu. Students who receive Academic Access Letters are strongly encouraged to request, obtain, and present these to their instructors as early in the semester as possible so that accommodations can be made in a timely manner. It is the student's responsibility to follow this process each semester. You can access further information here: http://www.clemson.edu/campus-life/campus-services/sds/.

Title IX Statement: Clemson University is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, religion, sex, sexual orientation, gender, pregnancy, national origin, age, disability, veteran's status, genetic information or protected activity in employment, educational programs and activities, admissions and financial aid. This includes a prohibition against sexual harassment and sexual violence as mandated by Title IX of the Education Amendments of 1972.

Safe Campus: Clemson University is committed to providing a safe campus environment for students, faculty, staff, and visitors. As members of the community, we encourage you to take the following actions to be better prepared in case of an emergency:

a. Ensure you are signed up for emergency alerts (https://www.getrave.com/login/clemson)
b. Download the Rave Guardian app to your phone (https://www.clemson.edu/cusafety/cupd/rave-guardian/)
c. learn what you can do to prepare yourself in the event of an active threat (http://www.clemson.edu/cusafety/EmergencyManagement/)

Academic Integrity: As members of the Clemson University community, we have inherited Thomas Green Clemson's vision of this institution as a 'high seminary of learning.' Fundamental to this vision is a mutual commitment to truthfulness, honor, and responsibility, without which we cannot earn the trust and respect of others. Furthermore, we recognize that academic dishonesty detracts from the value of a Clemson degree. Therefore, we shall not tolerate lying, cheating, or stealing in any form. In instances where academic standards may have been compromised, Clemson University has a responsibility to respond appropriately to charges of violations of academic integrity. Further information on Academic Integrity can be found in the *Undergraduate Announcements* and in the *Graduate School Policy Handbook*.

AI Statement: The goal of this course is to learn to construct logical mathematical arguments about linear systems. Connecting and chaining together different concepts based is an important part of forming good arguments. Making connections generally requires spending time reflecting on the concepts and considering different ways of connecting ideas. AI tools may connect ideas for you without giving sufficient time to absorb the concepts. The use of AI tools on homework assignments is discouraged, but allowed. Any use of AI tools, even for idea

generation, must be cited in the submitted assignment. The use of AI tools on quizzes and exams is strictly forbidden.

Copyright Statement: Materials in this course are copyrighted. They are intended for use only by students registered and enrolled in this course and only for instructional activities associated with the course. They may not be disseminated further without permission. They are provided in compliance with the provisions of the Teach Act. Please refer to the Use of Copyrighted Materials and "Fair Use Guidelines" policy on the Clemson University website for additional information: https://clemson.libguides.com/copyright.

Modification Statement: The instructor reserves the right to modify any aspect of the syllabus at any time during the semester for reasons including but not limited to COVID-related situations.