University of Colorado Boulder
ASEN 5014
Linear Control Systems
Fall 2021 Course Syllabus

General Information

Instructor: Nisar Ahmed, Associate Professor,
Smead Aerospace Engineering Sciences (`Nisar.Ahmed@colorado.edu`)

Teaching Assistants:
Manoj Settipalli, PhD student,
Smead Aerospace Engineering Sciences (`Manoj.Settipalli@colorado.edu`)

Instructor and TA Office Hours: TBD, in person and via Zoom, details to be posted to Canvas

Lecture Time and Location: Mon, Wed, & Fri 09:40 am - 10:30 am, AERO 114. All lectures will be recorded and posted online via CU's Lecture Capture System and the course Canvas website. Remote/distance learning students may participate live through the Zoom meeting interface (see course website for instructions). For distance students who wish to participate live lectures, this course requires the use of the Zoom conferencing tool. If you use assistive technology to access the course material, please contact the instructor immediately to discuss.

Note: all students attending in person and on campus must adhere to CU Boulder's COVID-19 campus policies, including mask requirements. See General Policies below.

Course Website: canvas.colorado.edu (will be used for posting all recorded lecture captures, assignments, exams, and announcements/corrections; links to Zoom lecture and office hours, Piazza, and Gradescope are also provided).

Required Textbook (for readings and assignments, e-book version available): *Modern Control Theory*, W. L. Brogan, 3rd ed. Prentice-Hall, 1991. ISBN 0-13-589763-7.

Optional text supplements (not required):

Linear Systems, P. Antsaklis and A. Michel, Birkhauser, 2006. e-ISBN 0-8176-4435-0. Available through CU library as an e-book.

A Linear Systems Primer, P. Antsaklis and A. Michel, Birkhauser, 2007. e-ISBN-13: 978-0-8176-4661-5. Available through CU library as an e-book.

Optimal Control and Estimation, R. Stengel, Dover, 1994. ISBN: 9780486682006 (classic: very good and cheap).

Course Details

Description   Modeling, analysis, and design of continuous-time control systems using the state space approach. Vector spaces, linear operators, and linear equation solution theory are used to describe system solutions and their stability, controllability, and observability properties. State observers and state feedback control are developed, along with an introduction to linear-quadratic optimal control and other advanced topics.

Learning Objectives   Linear systems are models for dynamical physical processes. Although physical systems are usually non-linear, linear models are simpler and often provide reasonable approximations: their dynamic behavior is very well understood theoretically. This means they can be easily manipulated to introduce desirable (or remove undesirable) behaviors, which is the whole point of control systems engineering.

   This course will provide an understanding of the state space perspective of linear systems theory, with specific application toward feedback control system design. Although mathematics (especially linear algebra) is the language by which the theory is described, *this is not a math course.* The theorem-proof format is avoided in favor of an exposition of the main ideas and use of these ideas to demonstrate key theoretical results. The geometry and insight behind matrix algebra, in particular, is stressed. *However, expect to learn a little math in the process. Careful use of terminology is necessary to grasp ideas and do well on exams.*

This course is a foundation for further graduate work in various fields, particularly nonlinear dynamical systems, estimation, and autonomous unmanned vehicle design. It introduces standard viewpoints, methods, and terminology used in applications and research literature. It also provides the basis for understanding how many computational analysis and design tools work (e.g. MATLAB's Control System Toolbox). In short, by the end of this course, you will think, work, and communicate in the language of modern linear systems and control theory.

Specific learning objectives:

1. Develop expertise with state space models for mathematically analyzing and manipulating multivariable dynamical systems described by continuous-time differential equations or discrete-time finite difference equations.

2. Discover simple yet valuable geometric insights about linear operators using key concepts from linear algebra; understand how they lead to powerful state space analysis/synthesis techniques for multivariable control systems.

3. Explain and apply ideas behind advanced methods for stability analysis and optimal control system design, which will also be glimpsed; recognize practical limitations of the theory, e.g. due to inaccuracies in system models.

Anticipated Course Schedule

Week(s)	Topic
1	Intro & overview
1-2	State space models for linear & nonlinear dynamical systems
3-7	Formal linear algebra review: vectors spaces, mappings, solution analysis, eigenspaces, etc.
7	**MIDTERM EXAM 1** (expected: out Oct 6, due Oct 13)
8-10	Linear systems theory: matrix-vector ODEs, controllability, observability, modal analysis
10-12	State space control design and analysis: full state feedback, observers, etc.
12	**MIDTERM EXAM 2** (expected: out Nov 10, due Nov 17); Start final project
12-13	Intro to optimal control and linear quadratic regulator (LQR)
14-16	State space stability and Lyapunov analysis; advanced topics (if time)
16	**FINALS WEEK: FINAL PROJECT REPORT DUE**

Grading, Assignments and Exams Course grades will be determined on the basis of homework (15%), online Canvas quizzes (15%), midterm 1 (20%), midterm 2 (20%), and a final project (30%).

Important things to note:

- Students will work in pairs for the final project (there may be a team of 3 students, depending on enrollment parity).

- Weekly homework will be assigned, collected, and *partially graded.* Quizzes will be fully graded automatically on Canvas. Solutions for full problem and quiz sets will be posted to Canvas.

- Collaboration on homework is encouraged, but students must turn in their own homework in a timely manner (see policies below). Students may use Piazza for online discussion (this will be loosely monitored by instructor and TAs).

- A series of weekly quizzes will be assigned and administered through Canvas. These will be posted on Friday morning and be due the following Sunday at 11:59 pm (off-nominal posting/due dates will come with special advance notification, as needed).

- All exams will be take home and open-book/open-note. Students will have exactly one week to complete exams and may not collaborate with each other on exams in any way (CU honor code applies).

- Students will **not** require an exam proctor, but will submit all assignments and exams electronically for grading via Gradescope (see requirements on submission quality).

- Students may opt to answer optional 'Challenge Questions' for extra credit, but extra credit will only be considered if all regular homework assignment questions are also completed (zero extra credit received otherwise). Students must submit their own work for challenge questions (no group submissions). Help from instructor/TAs will be more limited on these questions, and solutions may or may not be posted for challenge questions.

Electronic assignment submission requirements: It is your responsibility to turn in legible and complete electronic submissions for homeworks, exams, and projects. *If your assignment is not legible for grading, you will receive one and only one warning to resubmit your assignment.* Repeated failure to comply with legibility requirements after the first warning will result in zero credit for that assignment.

Regrade policy: Requests for regrades on any assignment must be submitted **to the instructor in writing via e-mail and Gradescope within 2 weeks of the assignment being returned to the class** (no exceptions). Requests must clearly articulate the specific reasons for the regrade request, although *entire* assignment will be regraded by instructor/TA if request is granted, and thus there is no guarantee of receiving a higher grade (this includes scrutinization of time/date of original assignment submission).

Late submissions: Students are responsible for contacting and working out an alternative plan with the instructor for submitting homeworks, exams, projects, and any other assignments if these cannot be completed in time. **Penalties will be applied and strictly enforced for unpermitted late submissions and are non-negotiable after the fact for all individual and group assignments (including final project):**

- Homeworks lose 10% of total assignment grade if turned in past time deadline on due date , 10% per day late thereafter , and receive a grade of 0 points for if submitted late by 7 days or more. Penalties will be enforced for lateness, unless exceptions are explicitly granted by instructor (see above).

- Exams and projects are automatically penalized 10 points if submitted past time deadlines on due dates without permission from instructor, and will receive a grade of 0 pts thereafter if submitted after due dates without permission from the instructor.

- Late time or late date submission on any assignment (homework, exam, project, etc.) results in immediate forfeiture of any extra credit attempted for that assignment (i.e. extra credit only counts if assignment turned in on time on due dates).

Rescheduling assignment submissions: Exams must be rescheduled with the instructor **via e-mail at least 2 weeks prior**. Homework, project and other assignment extensions require **at least 48 hours e-mail notice to the TA and instructor.** The rescheduling and extension policy will be strictly enforced, so plan ahead and manage your time well – **do not wait until the last minute to start assignments or ask for extensions!** **All students must adhere to the CU Honor Code.** See below under 'General Policies' for more information regarding expectations for academic integrity, and repercussions for violations thereof.

General Policies (please read carefully)

Classroom Behavior Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on classroom behavior and the Student Conduct & Conflict Resolution policies.

Requirements for COVID-19 As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct & Conflict Resolution policies. For more information, see the policy on classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

As of Aug. 13, 2021, CU Boulder has returned to requiring masks in classrooms and laboratories regardless of vaccination status. This requirement is a temporary precaution during the delta surge to supplement CU Boulder's COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home. In this class, if you are sick or quarantined, please alert the instructor about absence due to illness or quarantine. Because of FERPA student privacy laws, you are NOT required to state the nature of your illness as part of this notification. A "doctor's note" or quarantine verifications for classes missed due to illness or quarantine is NOT required; campus health services do not provide "doctor's notes," appointment verifications or quarantine verifications.

Accommodation for Disabilities If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see Temporary Medical Conditions on the Disability Services website.

Preferred Student Names and Pronouns CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors'

class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code academic integrity policy. Violations of the Honor Code may include, but are not limited to: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found on the Honor Code website.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by or against members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or email cureport@colorado.edu. Information about OIEC, university policies, reporting options, and the campus resources can be found on the OIEC website.

Please know that faculty and graduate instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about their rights, support resources, and reporting options.

Religious Holidays Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all

students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, you must notify the instructor at least 2 weeks in advance to schedule make up for completing and turning in exams and other assignments (see Course Details above). See the campus policy regarding religious observances for full details.