# ASEN 5014 LINEAR CONTROL DESIGN

**Course 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. Robustness to model uncertainty is addressed.

**Instructor:**
Dale Lawrence. AERO 271, 303-492-3025.
dale.lawrence@colorado.edu (e-mail is preferred)

**Prerequisite:**
Undergraduate course in signals, systems, or control (e.g. ASEN 2003, ASEN 3200, ASEN 3128, or equivalent)

**Textbook:**
*Modern Control Theory*, W. L. Brogan, 3rd ed. Prentice-Hall, 1991.
ISBN 0-13-589763-7

**Class Web Page:**
https://cuboulder.instructure.com/courses/86764

**Teaching Assistant:**
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## Syllabus Outline

| Topics | Weeks |
|---|---|
| Introduction: Fundamental Questions | 1 |
| State Space Model Construction | 1 |
| Linear Spaces | 2 |
| **Midterm Exam 1** | |
| Linear Mappings | 3 |
| **Midterm Exam 2** | |
| State Space System Solutions | 3 |
| Lyapunov Stability | 1 |
| **Project 1** | |
| Controllability and Observability | 2 |
| State Observation and Feedback Control | 2 |
| Optimization and Robustness | 1 |
| **Project 2 (in lieu of final exam)** | |

## Course Policies and Grading

**Lectures:** In person. Lectures will be recorded and slides from class will be posted. Attendance in lecture will not be taken, but attendance is strongly encouraged.

**Grading:** Two exams and two projects---20% each., homework---20%.
**Homework:** Group work is encouraged, although individual understanding will be necessary to do well on exams and on the projects. Homework will be partially graded, solutions posted, and questions about homework are encouraged in remote office hours.
**Exams:** Take home, involving both analysis and computation. Questions are designed to measure grasp of concepts, rather than memorization or repetition of homework problems. Honor system applies.
**Office hours:** To be arranged outside scheduled class meeting time, held on Zoom.
**Missed Assignments:** No make ups will be given for missed assignments (exams, projects, homework). Instead, course credit will be shifted to completed assignments in that category. Extended absences should be discussed with the instructor.
**Late Assignments:** Maximum credit decreases by 10% of nominal per day.

## Course Purpose and Learning Objectives

Linear systems are models for physical processes having dynamics. Although physical systems are usually non-linear, linear models are simpler, and can often provide reasonable approximations. They have the added benefit of a very complete theoretical understanding of their behavior and of how control can change behavior, leading to great insight into the complexities of these dynamics and useful design tools to achieve desired behavior objectives.

The purpose of this course is to provide an understanding of the theory of linear systems from the state space perspective, with specific application toward feedback control design. Although mathematics (particularly linear algebra) is the language by which the theory is described, this is not a mathematics course. A formal 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, including mathematical reasoning for demonstrating results. Careful use of terminology is necessary to understand the ideas, and to do well on exams and projects. Students will select an example application for the two individual projects to apply the ideas developed in class.

The understanding sought in this course is a foundation for further graduate work in various fields, particularly nonlinear dynamical systems, estimation and data analysis, and advanced control systems. It introduces standard viewpoints, methods, and terminology used in the applied and research literature. It also provides the basis for understanding how many computational analysis and design tools work.

The main learning objectives of Linear Control Design are

- Develop some expertise with the state space modeling/analysis/design approach, learning to see dynamical systems in a new way with new concepts, vocabulary, tools, and insights.

- See linear algebra in a new light, where matrices are representations of linear operators, and these operators have simple geometry and corresponding insights. This understanding is used widely (both within control and many other applications).
- Glimpse how optimization can be used to design control systems ``automatically".
- Understand how applications of this theory can be limited by inaccuracy in system models.

## General Policies

### 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 classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

### Requirements for COVID-19

As a matter of public health and safety, 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. CU Boulder currently requires COVID-19 vaccination and boosters for all faculty, staff and students. Students, faculty and staff must upload proof of vaccination and boosters or file for an exemption based on medical, ethical or moral grounds through the MyCUHealth portal.

The CU Boulder campus is currently mask-optional. However, if public health conditions change and masks are again required in classrooms, students who fail to adhere to masking 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 and Conflict Resolution. 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.

If you feel ill and think you might have COVID-19, if you have tested positive for COVID-19, or if you are unvaccinated or partially vaccinated and have been in close contact with someone who has COVID-19, you should stay home and follow the further guidance of the Public Health Office (contacttracing@colorado.edu). If you are fully vaccinated and have been in close contact with someone who has COVID-19, you do not need to stay home; rather, you should self-monitor for symptoms and follow the further guidance of the Public Health Office (contacttracing@colorado.edu).

Students who miss class due to illness can view the missed lectures on-line. Missed assignments will be dropped, using other assignments in that category to determine grades.

## 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. 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 Student Conduct & Conflict Resolution (honor@colorado.edu); 303-492-5550). Students found responsible for violating the Honor Code will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to 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

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, protected-class discrimination and harassment, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these policies, and individuals who believe they have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.edu. Information about university policies, reporting options, and support resources can be found on the OIEC website. Please know that faculty and graduate instructors have a responsibility to inform OIEC when they are made aware of any issues related to these policies regardless of when or where they occurred to ensure that individuals impacted receive information about their rights, support resources, and resolution options. To learn more about reporting and support options for a variety of concerns, visit Don't Ignore It.

## 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, students who miss class can view the missed lectures on-line. Exams and homework assignments are 1-week take home format; students are expected to plan their work around religious holidays accordingly.

See the campus policy regarding religious observances for full details.