University of Colorado Boulder
ASEN 5044
Statistical Estimation for Dynamical Systems
Fall 2023 Course Syllabus

General Information

Instructor: Prof. Penny Axelrad (Penina.Axelrad@colorado.edu)

Course Teaching Assistants:
Neil Bruhn (Neil.Bruhn@colorado.edu),
Gavin Brown (Gavin.M.Brown@colorado.edu)

Office Hours: In Person + Zoom, see Canvas for details

Lecture Time and Location: Tues & Thur 10:00 am -11:15 pm, AERO111. All lectures will be recorded and posted online via course website. If you use assistive technology to access the course material, please contact the instructor to discuss.

Course Website: canvas.colorado.edu will be used for posting all recorded lectures, homework assignments, quizzes, exams, solutions, and announcements/corrections; links to Zoom office hours and Gradescope are also provided there.

Required Textbook (for readings and assignments, e-book version available): Dan Simon, "Optimal State Estimation: Kalman, H_∞, and Nonlinear Approaches," John Wiley and Sons, Inc., 2006, ISBN 9780471708582. Note: Matlab examples + errata for the text can be found here: link (also on Canvas)

Optional text supplements (not required):
J. Crassidis and J. Junkins, "Optimal Estimation of Dynamic Systems," 2nd edition, Chapman and Hall, 2011 – available through CU library as an e-book.
R. Stengel, "Optimal Control and Estimation," Dover, 1994, 9780486682006 (classic: very good and inexpensive).

Course Details

Description This course introduces students to the theory and methods of state estimation for general linear and nonlinear dynamical systems, with a particular emphasis on aerospace and other engineering applications. Major topics include: review of applied probability and statistics; modeling and optimal state estimation for stochastic dynamical systems; theory and design of Kalman filters for linear systems; linearized and extended Kalman filters for non-linear systems.

Learning Objectives Students will gain both a fundamental and practical understanding of estimation algorithms from a general dynamical systems standpoint. This will prepare them to tackle challenging estimation problems that they will encounter in later courses and future professional/research pursuits. By the end of this course, students will:

1. be well-acquainted with basic theory and engineering usage of probability and statistics;

2. explore, explain, and apply core concepts of estimation theory, especially to problems defined by discrete-time, stochastic, linear and nonlinear, state space dynamic process and measurement models;

3. formulate and solve dynamic state estimation problems using Kalman filters, least-squares estimators, and other related estimation algorithms;

4. design, simulate, evaluate, visualize and tune estimator performance for real applications in software (e.g. Matlab, Python).

Course Schedule

Week(s)	Topic	Text Chaps.
1	Intro & overview	–
1-4	Basic linear dynamical systems theory, discrete time systems	Ch. 1
4-8	Basic probability and stochastic process theory	Ch. 2
9-10	Least squares estimation, stochastic linear systems	Ch. 3, 4.1-4.2
10-12	Kalman filter (KF) basics, tuning, testing, generalizations	Ch. 5, 6, 7
14-16	Nonlinear and linearized filters (CKF, EKF, UKF)	Ch. 13.1-2, 14

Special topic extra lectures: Previously recorded optional lectures by Prof. Nisar Ahmed on Bayesian estimation theory will also be posted to Canvas. These extra lectures can be considered as a 'mini-course' to complement the main course material outlined above, and no pre-requisites will be needed to follow them (although they will build on previous course material and on each other). **Viewing of these extra lectures is optional, but strongly recommended for students intending to pursue follow-on 6000-level courses or estimation-related research.**

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

- Students will be expected to work in groups of 2-3 for the final project.
- Weekly homework will be assigned, collected, and *partially graded*. Quizzes will be fully graded automatically. Full solutions for homework and quizzes will be posted to Canvas.
- Collaboration on homework is encouraged, but each student must turn in their own worked solutions for the homework. No credit may be assigned for identical solutions submitted by two or more students. Discussion pages on Canvas are available for questions regarding assignments.
- A series of approximately weekly online quizzes will be assigned and administered through Gradescope. These will be posted on Thursday and are due the following Monday at 11:59 pm as shown on the course schedule. Collaboration of any kind on quizzes is not permitted.
- Two midterm exams will be take-home and open-book/open-note. Students will have exactly one week to complete exams and may not collaborate with anyone on exams in any way (CU honor code applies). Collaboration/cheating on an exam will be considered a serious violation of the honor code, subject to the assignment of a grade of F in the course.

- 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 choose to answer optional 'Challenge Questions' for possible 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 not always be posted for challenge questions.

Electronic assignment submission requirements: It is each student's responsibility to submit legible, complete, and on-time electronic submissions for homeworks, exams, and projects. If we find a submission is not legible for grading, we will provide the student one warning to resubmit the assignment; however, subsequent assignment submissions that are not legible will get zero credit.

Regrade policy: Requests for correction of grading errors on any assignment must be submitted to the instructor in Gradescope within 1 week of the assignment being returned to the class.

Late submissions: All assignments are due by 11:59pm (MT) on the date specified on the course schedule and in Gradescope. Nominally quizzes are due on Monday nights, homework and midterm exams are due on Thursday nights. Final project deadlines are as shown on the course schedule and in Gradescope.

- Students will each be allowed two 1-week homework extensions, and two 1-day quiz extensions. Details on how to submit late materials will be provided on Canvas shortly.
- Midterm exams and final project deadlines are as specified on the schedule and in Gradescope. If you cannot make an exam or project deadline due to an extenuating planned or unplanned circumstance, contact the instructor as soon as possible.
- Extra credit is only available for assignments turned in on time.

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: Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure 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 INFECTIOUS DISEASES: Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all public health orders to reduce the risk of spreading infectious diseases.

The CU Boulder campus is currently mask optional. However, if masks are again required in classrooms, students who fail to adhere to masking requirements will be asked to leave class. 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. Students who require accommodation because a disability prevents them from fulfilling safety measures related to infectious disease will be asked to follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

For those who feel ill and think you might have COVID-19, or if you have tested positive for COVID-19, please stay home and follow the further guidance of the Public Health Office. For those who have been in close contact with someone who has COVID-19, but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home.

ACCOMMODATION FOR DISABILITIES: Disability Services determines accommodations based on documented disabilities in the academic environment. If you qualify for accommodations because of a disability, submit your accommodation letter from Disability Services to your faculty member in a timely manner so your needs can be addressed. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance.

If you have a temporary medical condition, or require medical isolation *for which you require accommodation*, please notify the instructor. Note that you are not expected to provide details on your condition or documentation from a medical provider. Also 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 (including use of paper writing services or technology [such as essay bots]), 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. Visit Honor Code for more information on the academic integrity policy.

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 protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, 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 concerns, 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 incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive an outreach from OIEC about their options for addressing a concern and the support resources available. To learn more about reporting and support resources for a variety of issues, 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, you must notify the instructor at least 2 weeks in advance of an assignment or exam deadline for which you have conflict due to religious observance. See the campus policy regarding religious observances for full details.

MENTAL HEALTH AND WELLNESS: The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, you are encouraged to contact Counseling and Psychiatric Services (CAPS) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through Academic Live Care. The Academic Live Care site also provides information about additional wellness services on campus that are available to students.