University of Colorado Boulder
ASEN 5044
Statistical Estimation for Dynamical Systems
Fall 2024 Course Syllabus

General Information

Instructor Prof. Nisar Ahmed

Instructor Office Hours: In Person + Zoom, details to be posted to Canvas

Course Teaching Facilitators:
Aidan Bagley
Collin Hudson
Jiho Lee

TF Office Hours: In Person + Zoom, details to be posted to Canvas

Lecture Time and Location: Tues & Thur 10:00 am -11:15 am, AERO 111. All lectures will be recorded and posted online via course website. Remote/distance learning students may participate live through the Zoom meeting interface (see course website for instructions). For distance students who wish to attend 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.

Course Website: `canvas.colorado.edu`. Will be used for posting all recorded lectures, homework assignments, quizzes, 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): Dan Simon, 'Optimal State Estimation: Kalman, H_∞, and Nonlinear Approaches,' John Wiley and Sons, Inc., 2006, ISBN 9780471708582. Note: errata for the text can be found here on Canvas: link

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 very cheap).

Course Details

Description This course will introduce 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 eventually encounter in later courses and in their own 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).

Anticipated Course Schedule
Special topic extra lectures: for weeks 5-11, Prof. Ahmed will post additional pre-recorded lectures on Bayesian estimation theory (and possibly other topics, time permitting). These extra lectures can be considered as a

Week(s)	Topic	Text Chaps.
1	Intro & overview	–
1-3	Basic linear dynamical systems theory, discrete time systems	1.1-1.7
3-6	Basic probability and stochastic process theory	2.1-2.7
6-8	Least squares estimation, stochastic linear systems	3.1-3.4, 4.1-4.2
8-11	The Kalman filter (KF): basics, tuning, testing, generalizations	5.1-5.5, 6, 7
11-14	Nonlinear filters: Linearized KF and EKF	13.1,13.2
14-15	Unscented KF; advanced topics (if time)	8, $\cdots$

'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 Ph.D. students**, and is highly encouraged for others wishing to dive deeper into estimation theory and related topics.

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 be expected to work in groups of 3 for the final project. Exceptions on group sizes must be explicitly approved by the instructor.
- 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 Tuesday at 10 am (off-nominal posting/due dates will come with special notification, if needed). **It is the student's responsibility to ensure that quizzes are completed on time - 'make-up quizzes' will not be granted.**

- 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 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 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 within 2 weeks of the assignment being returned to the class** (no exceptions). E-mails must clearly articulate the specific reasons for the regrade request, although *entire* assignment will be regraded by instructor 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 for unpermitted late submissions and are non-negotiable after the fact:

- 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, and will receive a grade of 0 pts thereafter if submitted after due dates.
- 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).

These policies will be enforced for all individual and group assignments (including final project).

Rescheduling exams and homework 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 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, marital 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.

ACCOMMODATION FOR DISABILITIES, TEMPORARY MEDICAL CONDITIONS, AND MEDICAL ISOLATION 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.

If you have a temporary illness, injury or required medical isolation for which you require adjustment, please email the instructor to inform them and discuss your class related needs. Per FERPA student privacy laws, students are NOT required to state the nature of their illness when alerting the instructor. "Doctor's notes" are NOT required for classes missed due to illness; campus health services no longer provide "doctor's notes" or appointment verifications.

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 CU 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. Understanding the course's syllabus is a vital part in adhering to the Honor Code. All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: StudentConduct colorado.edu. 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 the Honor Code website 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 abuse (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. 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 cureportcolorado.edu. Information about university policies, reporting options, and support resources can be found on the OIEC website.

Please know that faculty and graduate instructors must 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 outreach from OIEC about resolution options and support resources. To learn more about reporting and support for a variety of concerns, visit the Don't Ignore It page.

RELIGIOUS ACCOMMODATIONS Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. Please communicate the need for a religious accommodation in a timely manner. 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.