University of Colorado Boulder
ASEN 5044
Statistical Estimation for Dynamical Systems
Fall 2020 Course Syllabus

General Information

Instructor: Prof. Nisar Ahmed (`Nisar.Ahmed@colorado.edu`)

Instructor Office Hours: via Zoom, TBA

Teaching Assistants:
Ofer Dagan (`Ofer.Dagan@colorado.edu`),
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Young-Young Shen (`Youngyoung.Shen@colorado.edu`)

TA Office Hours: via Zoom, TBA

Lecture Time and Location: Tues & Thur 11:40 am -12:55 pm, 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.

Note: due to limited COVID-19 room capacity, in person attendance is limited to students from the hybrid/in-person section of the course who have been assigned to either the Tuesday or Thursday lecture cohorts. Students may only attend for their designated cohort day and must conform to safety practices on campus (see COVID guidelines below). Per CU campus plan, fully remote/online instruction will take place after Fall Break through recorded/posted Zoom lectures (further details to follow in due course).

Course Website: `canvas.colorado.edu` (will be used for posting all recorded lectures, 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): 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 online here: 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: link
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

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	3.1-3.7, 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, $\cdots$

Special topic extra lectures: for weeks 5-11, Prof. Ahmed will post additional pre-recorded lectures on Bayesian estimation theory. 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 Ph.D. students**, and is highly encouraged for others wishing to dive deeper into estimation theory.

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 one 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 notification, if 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 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 1 point if turned in past time deadline on due date, 1 additional point per day late thereafter, and receive a grade of 0 points for if submitted late by 7 days or more.

- 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 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 Code of Conduct.

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 public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,

- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,

- clean local work area,

- practice hand hygiene,

- follow public health orders,

- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert CU Boulder Medical Services.

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 and Conflict Resolution. For more information, see the policies on COVID-19 Health and Safety and classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the âĂIJAccommodation for DisabilitiesâĂİ statement on this syllabus. Before returning to campus, all students must complete the COVID-19 Student Health and Expectations Course. **Before coming on to campus each day, all students are required to complete a Daily Health Form.**
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 and complete the

[Health Questionnaire and Illness Reporting Form](#) remotely. In this class, if you are sick or quarantined, Faculty: insert your procedure here for students to alert you about absence due to illness or quarantine. Because of FERPA student privacy laws, do not require students to state the nature of their illness when alerting you.

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 policy may include: 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 at the [Honor Code Office 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 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 cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and 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 options for reporting and support resources.

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.