Statistical Estimation for Dynamical Systems

Spring 2020

Material is preliminary and subject to change

Instructor:	Tomoko Matsuo	**Email:**	Tomoko.Matsuo@colorado.edu
Lectures[a]**:**	T/TH 2:30-3:45pm	**Class Room:**	AERO 111
Office Hours:	M 3:30-4:30pm	**Office:**	AERO 467
TA:	Ofer Dagan	**Email:**	Ofer.Dagan@colorado.edu
Office Hours:	W 10:00-11:00am	**Meeting Room:**	AERO 224L (or AERO 403[b])
Recitations[c]**:**	F 10:00-11:00am	**Class Room:**	TBD
TFs:	Jack Center	**Email:**	Jack.Center@colorado.edu
	Jesse Tambornini	**Email:**	Jesse.Tambornini@colorado.edu
Web Site:	Canvas (`https://canvas.colorado.edu`)		
Q&A:	Piazza[d]		
Feedback:	Google Form[e]		

[a] All lectures and recitations will be recorded and posted online via course website
[b] TA Office Hours in AERO 403 on 2/5, 3/4, 4/22, and 4/29
[c] Recitations will be offered as needed in March and April
[d] Piazza is used for class-wide Q&A and discussion sessions, and can be accessed via course website
[e] Google Form is used to submit feedback anonymously, and can be accessed via course website

Required Textbook (for readings and assignments):

- D. Simon (2006), *Optimal State Estimation: Kalman, H∞, and Nonlinear Approaches*, John Wiley and Sons, Inc.
  Note e-book version available on publisher website: link to buy
  and errata for the text can be found online here: link

References (for your own edification, not required):

- J. Crassidis and J. Junkins (2011), *Optimal Estimation of Dynamic Systems*, 2nd edition, Chapman and Hall.
  (available through CU library as e-book)
- R. F. Stengel (1994), *Optimal Control and Estimation*, Dover.
  (classic, very good and very, very cheap).
- B. Tapley, B. Schutz, and G. Born (2004), *Statistical Orbit Determination*, Elsevier.
  (available through CU library as e-book)

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: (1) review of applied probability and statistics, (2) modeling and optimal state estimation for stochastic dynamical systems, (3) theory and design of Kalman filters for linear systems, and (4) 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; and
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 Chpts.
1	Introduction, 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	Advanced topics	8, $\cdots$

Course Grading:
Course grades will be determined on the basis of participation (5%), homework (20%), midterm 1 (25%), midterm 2 (25%), and a final project (25%).

Course Format and Logistics:

- All homework assignments are to be turned in electronically via Canvas (see requirements on submission quality).
- Homework assignments will be collected, and *partially* graded.
- Collaboration on homework assignments is allowed, but students must turn in their own homework in a timely manner (see policies below).
- You are encouraged to ask your questions on homework assignments and projects via Piazza so that Q&A interactions will benefit the entire class. Your participation in public Q&A sessions will be counted towards the course participation grade (which is % of the overall grade).
- Any student may opt to answer 'Advanced Questions' for extra credit, but extra credit will only be considered if all regular assignment questions are also completed. Note that zero extra credit will be given otherwise.
- Students will be encouraged to work in pairs for the final project.
- All 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 each other on exams in any way.

Electronic Assignment Submission Requirements:
Students should make an effort to turn in assignments that are organized with a professional appearance. It is your responsibility to turn in legible and complete electronic submissions for homework assigments, exams, and projects. If your assignment is not legible for grading, you will receive one and only one warning to resubmit your assignment. Repeat offense, or failure to comply with turning in a legible and clearly organized assignment 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 1 week of the assignment being returned to the class**. No exceptions. E-mails must clearly articulate the specific reasons for the regrade request. The entire assignment will be regraded by the instructor, if request is granted, and thus there is no guarantee of receiving a higher grade. This includes scrutinization of time of the original assignment submission.

Due Date Extension Policy:
Students are responsible for contacting and working out an alternative plan with the instructor for submitting homework assignments, exams, projects, and any other assignments if these cannot be completed in time. Exams and projects must be rescheduled with the instructor **via e-mail at least 2 weeks prior.** Homework and other assignment extensions require **at least 48 hours e-mail notice to the instructor.** The rescheduling and extension policy will be strictly enforced, so plan ahead and manage your time well.

Unapproved Late Submissions:
Penalties will be applied for unapproved late submissions as follows.

- Late homework assignments will have a 5% deduction immediately, and an additional 2% deduction will be applied for each hour the assignment is late. No assignments will be accepted 48 hours after the original due date.
- Late exams and projects will have 10% deduction immediately, and an additional 4% deduction will be applied for each hour the assignment is late. No exams and projects will be accepted 24 hours after the original due date.
- Late submission on homework assignments, exam, project, etc. results in an immediate forfeiture of any extra credit attempted for that submission.

General Policies

Accommodations 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 or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Classroom Behavior:
Students and faculty each have responsibility for maintaining an appropriate learning environment. 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.

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. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records.

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 a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct intimate partner abuse (including dating or domestic violence), stalking, 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, 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, please see the regular due date extension policy above. See here for full details.