UNIVERSITY OF COLORADO BOULDER
ASEN 5044
STATISTICAL ESTIMATION FOR DYNAMICAL SYSTEMS
FALL 2019 SYLLABUS

Instructor: Jay McMahon, Office: AERO 461, email: jay.mcmahon@colorado.edu

Teaching Assistant: Ofer Dagan email: ofer.dagan@colorado.edu

Lectures: T-Th 11:30 - 12:45, AERO 111. All lectures will be recorded and posted online via course website.

Course Web Site: Canvas (https://canvas.colorado.edu)

Instructor Office Hours: Mondays, 1:00 - 2:00 PM, AERO 461 (my office)

TA Office Hours: Wednesdays, 2:30 - 3:30 PM, AERO 302

Required Textbook (for readings and assignments, e-book version available on publisher website):
Dan Simon, 'Optimal State Estimation: Kalman, H∞, and Nonlinear Approaches,' John Wiley and Sons, Inc., 2006, ISBN 9780471708582. (link to buy)
Note: errata for the text can be found online here: link

References (for your own edification, 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
- Stengel, R. F., *Optimal Control and Estimation*, Dover, 1994, 9780486682006 (classic: very good and very, very cheap).
- Tapley, B., Schutz, B, and Born, G.. 'Statistical orbit determination,' Elsevier, 2004.

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 Chpts.
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	Advanced topics / Guest lectures	8, $\cdots$

Grading, Assignments and Exams: Course grades will be determined on the basis of homework (20%), midterm 1 (25%), midterm 2 (25%), and a final project (30%). Important things to note:

- Students will be encouraged to work in pairs for the final project.
- Regular homework will be assigned, collected, and *partially graded*.
- Collaboration on homework is encouraged, but students must turn in their own homework in a timely manner (see policies below). I highly recommend using the Discussion Boards on Canvas to collaborate with other students on homeworks. A new topic will be opened for each assignment.
- 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.
- Any student may opt to answer 'Advanced Questions' for extra credit on the same assignments, but extra credit will only be considered if all regular assignment questions are also completed (zero extra credit received otherwise).
- Distance learning students will **not** require an exam proctor, but will submit all assignments and exams via dropboxes on the course website.
- All assignments are to be turned in electronically via Canvas (see requirements on submission quality).

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. Repeat offense, or failure to comply with turning in a legible 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 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 points 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 (i.e. do not wait until the last minute to start assignments).

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

Online Campus Syllabus Statements

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 who are 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.

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. Class rosters are provided to the instructor with 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. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Religious Observances: 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 rescheduling policy above.
See here for full details.

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.