# University of Colorado Boulder
# ASEN 5044
# Statistical Estimation for Dynamical Systems
# Fall 2018 Course Syllabus

## General Information

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

**Teaching Assistant:** Young-Young Shen (`Youngyoung.Shen@colorado.edu`)

**Lecture Time and Location:** Tues & Thur 11-12:15, ECCS 1B12. All lectures will be recorded and posted online via course website. 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, which is currently not accessible to users using assistive technology. 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, assignments, exams, and announcements/corrections)

**Instructor Office Hours:** ECAE 175, Tues 3 pm - 4:30 pm

**TA Office Hours:** Mon 3-4 pm, Seebass Conference Room (ECAE 153)

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

**Recommended supplements (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
R. Stengel, 'Optimal Control and Estimation,' Dover, 1994, 9780486682006 (classic: very good and very, 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 | Advanced topics / Guest lectures | 8, $\cdots$ |

**Special topic extra lectures:** for weeks 5-11, Prof. Ahmed will record/post extra 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). **Attendance at and 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 (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.
- Weekly 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).
- 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.
- Homeworks and exams will feature 'Advanced Questions' that must be answered by Ph.D-level students enrolled in the course (regardless of year/department), in addition to regular homework and exam questions (Ph.D. students will thus be scored on a slightly higher grading scale).
- Non-Ph.D. students (i.e. B.S. or Master's) 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 designated course website dropboxes (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 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 (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 (please read carefully)** If you qualify for accommodations because of a disability, please submit to your professor a letter from Disability Services in a timely manner (for exam accommodations provide your letter at least one week prior to the exam) so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities. Contact Disability Services at 303-492-8671 or by e-mail at dsinfo@colorado.edu. If you have a temporary medical condition or injury, see Temporary Injuries guidelines under the Quick Links at the Disability Services website and discuss your needs with your professor.

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, students must contact the professor at least 2 weeks prior to anticipated absences for exams. See the campus policy regarding religious observances for full details.

The University of Colorado Boulder (CU Boulder) is committed to maintaining a positive learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct, discrimination, harassment or related retaliation against or by any employee or student. CU's Sexual Misconduct Policy prohibits sexual assault, sexual exploitation, sexual harassment, intimate partner abuse (dating or domestic violence), stalking or related retaliation. CU Boulder's Discrimination and Harassment Policy prohibits discrimination, harassment or related retaliation based on race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Individuals who believe they have been subject to misconduct under either policy should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127. Information about the OIEC, the above referenced policies, and the campus resources available to assist individuals regarding sexual misconduct, discrimination, harassment or related retaliation can be found at the OIEC website.

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 differences of race, color, culture, religion, creed, politics, veteran's status, sexual orientation, gender, gender identity and gender expression, age, disability, and nationalities. 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.

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the academic integrity policy of the institution. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access, clicker fraud, resubmission, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code Council as well as academic sanctions from the faculty member. Additional information regarding the academic integrity policy can be found at honorcode.colorado.edu.