ASEN 6044: Advanced State Estimation
Spring 2026 Course Syllabus

General Information

Instructor: Prof. Nisar Ahmed (`nisar.ahmed@colorado.edu`), Smead AES Dept.

Time and Location: Tues & Thurs 2:30 pm - 3:45 pm, AERO 114.

Course Website: `canvas.colorado.edu` (posted course materials, announcements, assignments, recorded lectures, etc.)

Office Hours: TBD (other times by appointment only)

Course Textbook:

B. Ristic, S. Arulumpalam, N. Gordon, *Beyond the Kalman Filter: Particle Filters for Tracking Applications*, Artech House Radar Library, 2004, ISBN-13: 978-1580536318.

Description This advanced graduate course will cover principles and techniques for designing, implementing, and analyzing probabilistic state estimators for dynamical systems that require "going beyond" traditional least-squares and Kalman filtering approaches. Emphasis will be placed on the development of practical discrete-time Bayesian state space filtering algorithms for systems generally characterized by partial observability and non-Gaussian uncertainties, which arise in many applications governed by complex non-linear stochastic dynamics and measurement processes. Topic coverage will include:

- Nonlinear least-squares; Maximum likelihood estimation, Cramer-Rao bounds;

- Principles of Bayesian estimation theory and recursive Bayesian filtering;

- Statistical linearization, Unscented / Sigma Point filtering; MMSE Estimation

- Sequential Monte Carlo particle filtering techniques;

- Gaussian mixture filtering and mixture condensation techniques;

- Multiple model filtering techniques for jump-Markov hybrid dynamics;

- Data association algorithms for object tracking in clutter;

- Bayesian decentralized estimation and data fusion with networked filters;

- Other topic highlights as time/interest permits (e.g. finite set statistics (FISST), machine learning techniques).

Students will complete programming projects related to target tracking, vehicle navigation, localization, control, autonomous systems, and other applications connected to their research/professional interests.

Prerequisites: (1) ASEN 5044: Statistical Estimation for Dynamical Systems (or equivalent graduate level coursework in probability and linear estimation/Kalman filtering with permission of instructor); and (2) demonstrable competency completing projects and assignments on one's own in a technical programming language (e.g. Matlab/Octave, Python, C/C++, C#, Java, Julia, etc.). **THESE ARE FIRM NON-NEGOTIABLE REQUIREMENTS – DO *NOT* ENROLL IN THIS COURSE UNLESS YOU MEET BOTH OF THESE PRE-REQS!**

Course Details

Grading and Project Assignments Course work will involve a mix of assignments and projects. There will be no exams. Assignments will ensure that students demonstrate basic understanding of the course material. Projects will integrate and explore concepts and techniques covered throughout the course. Assignments will consist of short theoretical and programming problems motivated by different applications, as well as questions to guide development of and reporting on final project applications. The final project will be developed over the course of the semester, and will serve in place of a final exam.

Students are highly encouraged to collaborate with one another on assignments, although individual assignments must be submitted. Students have the option of working together in groups of two (max) on the final project if they so choose, though significant individual contributions will be expected on group projects.

Benefits and Learning Objectives This course will enable students to:

1. define, explain and demonstrate fundamental problems in non-linear non-Gaussian state estimation along with algorithmic tools for recursive Bayesian filtering, including: non-linear least squares and maximum likelihood techniques; Monte Carlo techniques including the particle filter and Rao-Blackwellized particle filters; Gaussian mixture filters; multiple model filters; data association filters; decentralized data fusion techniques.

2. develop and implement software to simulate and evaluate the performance of advanced state estimation algorithms for real-world/research applications.

Tentative Course Schedule (may vary somewhat)

Week(s)	Topic
1	Course intro & overview
1-3	Nonlinear least squares and maximum likelihood point estimation
3-5	Bayesian estimation principles, DT recursive Bayes filters
6-7	Particle filtering
8-9	Gaussian mixture filtering
9	Jump Markov systems, multiple model filters
10	Data association for target tracking
11	SPRING BREAK (no lectures)
12	Data association (cont'd)
13-14	Decentralized data fusion and state estimation
15-16	Other selected topics (time/interest permitting)

Grading breakdown: assignment/project exercises: 40%; final project: 40%; class participation: 20% (students are highly encouraged to ask and answer questions during class,

office hours, via e-mail, etc.). Note that group final project report submissions will result in the same grade for both group members.

All students must adhere to the CU Honor Code (see below).

Conditional Generative AI Use:
You are permitted (but not required) to conditionally use generative AI tools in this course for the following purposes only:

- partial code generation (i.e. $\leq 30\%$ as measured by total non-trivial lines of code submitted) for programming exercises on homework assignments and for the final project assignment;

- to review or study course material and topics on your own.

If you use gen AI tools for partial code generation on homeworks or the final project, you must document your usage by stating this explicitly at the top of your assignment and cite the portions (lines of code) that were generated by the specific tool you used. **Failure to properly document gen AI usage for coding assignments on homeworks and the final project will be treated as a potential CU Honor Code violation (see below).**

You **may not** use gen AI tools to produce solutions for other non-programming questions on homework or final project assignments.

Work submitted for grading must conform to these rules, in order to receive full credit reflective of *your* own individual competency, learning, and understanding of the material.

CU 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 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 of 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 Student Conduct & Conflict Resolution and will be subject to academic sanctions from the faculty member. Visit Honor Code for more information on the academic integrity policy.

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, political affiliation, or political philosophy.

For more information, see the policies on classroom behavior, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

REQUIREMENTS FOR INFECTION DISEASE Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all applicable campus policies and public health guidelines to reduce the risk of spreading infectious diseases. If public health conditions require, the university may also invoke related requirements for student conduct and disability accommodation that will apply to this class.

If you feel ill and think you might have COVID-19 or if you have tested positive for COVID-19, please stay home and follow the guidance of the Centers for Disease Control and Prevention (CDC) for isolation and testing. If you have been in close contact with someone who has COVID-19 but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home but should follow the guidance of the CDC for masking and testing.

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 required medical isolation for which you require adjustment, please contact the instructor as soon as possible to arrange for any necessary accommodations or assignment extensions.

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 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.

All incidents of academic misconduct will be reported to the Honor Code Council (303-492-5550). 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 Honor Code 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 violence (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.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 any assignment (see Course Details above).

See the campus policy regarding religious observances for full details.

MENTAL HEALTH AND WELLNESS The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact Counseling and Psychiatric Services (CAPS) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through Academic Live Care. The Academic Live Care site also provides information about additional wellness services on campus that are available to students.