ASEN 6519: Advanced State Estimation
Spring 2021 Course Syllabus

General Information

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

Time and Location: Tues & Thurs 8:30 am - 9:45 am, AERO 114.

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

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 new course will introduce students to 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. Special emphasis will be placed on the development of practical discrete-time Bayesian state space filtering algorithms for systems that are 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 and maximum likelihood estimation, Cramer-Rao bounds;
- Principles of Bayesian estimation theory and recursive Bayesian filtering;
- Statistical linearization and Unscented / Sigma Point filtering;
- 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 tracking in clutter;
- Bayesian decentralized state estimation and data fusion with multiple networked filters;
- Highlights of other topics of as time/interest permits (e.g. intro to finite set statistics (FISST) and machine learning techniques).

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

Prerequisites: (FIRM REQUIREMENTS) (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.).

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 are expected to consist of short theoretical and programming problems for toy 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 some level of individual contributions will be expected on group projects.

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.

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 PAUSE (no lectures)
12	Data association (cont'd)
13-14	Decentralized data fusion and state estimation
15-16	Other selected topics (time/interest permitting)

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 "Accommodation for Disabilities" 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.