ASEN 6084: Optical Multi-Object Tracking
Syllabus, Spring 2026

Lecture: Mondays & Wednesdays, 8:30am–9:45am in AERO 250

Instructor

Prof. Marcus Holzinger
Office: AERO 457 / Email: marcus.holzinger@colorado.edu
Office Hours: TBD

Prerequisites

ASEN 5044 - Statistical Estimation for Dynamical Systems

Course Website

https://canvas.colorado.edu

This semester we will be using Canvas, CU Boulder's learning management system. We will be using Canvas for posting all class information (assignments, notes, slides); work will also be turned in and returned through this site. There will also be a discussion board that will be used.

To access Canvas, go to: https://canvas.colorado.edu. Log-in using your CU login name and IdentiKey password.

Once you log-in, click on ASEN6084 to go into our course.

Make the most out of Canvas by downloading the Canvas Student App to view your grades, view course materials, submit assignments, take quizzes, and more.

Subscribe to notifications to be reminded of due dates, receive announcements, and grades. Browsing the Canvas Guides or help videos for information on how to use Canvas. If you run into any problems, click the Help Icon within Canvas to report a problem or chat 24x7 with Canvas Support.

For additional assistance, contact the IT Service Center at `help@colorado.edu` or 303-735-4357.

Course Text

Required: None

Not required, will be used as reference texts:

- *Tracking and Data Fusion: A Handbook of Algorithms*, Yaakov Bar-Shalom, Peter K. Willet, Xin Tian, YBS Publishing, 2011.
- *Statistical Multisource-Multitarget Information Fusion*, Ronald Mahler, Artech House, 2007.
- *Applied Optimal Estimation*, Edited by A. Gelb, 1974.

Cheap (in Dover) and worth buying for reference:

- *Factorization Methods for Discrete Sequential Estimation*, Gerald J. Bierman, 2006.
- *Stochastic Processes and Filtering Theory*, Andrew H. Jazwinski, 2007.

1 Course Description

This course focuses on exploiting sensor information to detect, track, and characterize objects acting in a particular domain. Whether using radar, telescopes, or other phenomenologies in air-, space-, or other domains, many core principles remain the same. This course will cover phenomenological modeling, detection methods, and several multi-object tracking frameworks. Selected generic and domain-specific characterization methods will also be discussed. Assignments and projects will incorporate empirical data collection and reduction.

2 Learning Objectives

After completing this course students will

- Be conversant with sensors observing one or more phenomenologies
- Be capable of reducing raw observations to useable tracking data
- Be able to quantify the quality of obtained tracking data
- Be capable of selecting, implementing, and testing multi-target tracking using simulated and empirical observations in a domain of their choice (e.g., space, air)
- Understand the process of defining a small research project

3 Course Format

The course will consist of two weekly lectures, homework and a final project. Lecture attendance is highly recommended since many topics are not covered in any textbook. The final project will be assigned mid-semester, and will be due at the end of the semester. Project presentations will be held the last week of class or during the finals week (TBD).

Collaborative study and exploration of the course material is highly encouraged.

4 Grading

Final grades will be determined by the following elements and associated weightings:

Element	**Weight**
Homework	20 %
Project proposal	10 %
Project status update	15 %
Project report	30 %
Project presentation	20 %
Discretionary	5 %
Total:	100 %

Policies for homework and exams are described in the following subsections.

4.1 Homework

Homework is assigned to provide students with an opportunity to receive quantitative & qualitative feedback on worked problems representative of exam material.

Homework will be due at the beginning of lecture on the indicated due date. Late homework will not be accepted. In-class verbal due date announcements override projected dates in the lecture plan. Homework should be professional, legible, indicate units, and sufficiently describe all important steps in a solution. Use only one side of the page, and put your name and page number on each page. Your final answer for each problem should be boxed. When collaborating with other students on homework, you must list their names as collaborators (see the Collaboration Policy). Homework grades will be assigned as shown below:

Mark	Grade
✓+	100%
✓	80%
✓−	50%
X	0%

4.2 Exams

There will be no exams in this class.

4.3 Project

The project is a detailed, rigorous, professional quality technical paper on a student-proposed topic of interest relevant to this course, and comprises 75% of the course grade. The technical paper format shall follow AIAA formatting requirements (see AIAA Author Resources) and shall be written using LaTeX. As part of this term project requirement, several intermediate deliverables are required and described below.

All deliverables below shall be uploaded to Canvas before class starts on indicated due dates (the system time-stamps submissions).

AIAA Author Resources:
`https://www.aiaa.org/publications/journals/author-resources`

4.3.1 Project Proposal Students will submit a project proposal, detailing the technical work they will do over the term. It will identify the problem to be addressed, clearly explain why the problem is important and relevant, enumerate the specific tasks to be done, and discuss the expected results. The instructor will review these proposals and suggest modifications in scope and content as necessary.

4.3.2 Project Status Update The project status update will document the revised scope and content (if necessary) and present preliminary results. This will provide an additional structured opportunity for the instructor to suggest modifications in scope and content, if necessary.

4.3.3 Project Report The final project report will be a 'conference quality' paper, including typical conference paper sections such as an abstract, introduction, theory (or methodology), results, conclusion, and references.

4.3.4 Project Presentation During the final exam period (and a portion the preceding week), students will present their project in a conference-format presentation. Presentations will be scored by student peers, the instructor, and guest reviewers.

4.4 Discretionary

The instructor reserves 5% of the total grade to allocate as deemed appropriate based on participation in Canvas or other relevant factors. In general, the instructor uses this category to over-emphasize graded elements that students performed well on.

5 Distance Learning

While this course contains a distance learning section, classrooms in the AERO building are not fully equipped for live concurrent discussions with distance students during lecture. Instead, lecture capture is used, providing recorded lectures.

6 University Policies

This class will be conducted in accordance with university policies:

6.1 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 (`www.colorado.edu/disabilityservices/students`). 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.

6.2 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 let the instructors know of any such conflicts within the first two weeks of the semester so that we can work with you to make reasonable arrangements. See the campus policy regarding religious observances for full details.

6.3 Classroom and On-Campus 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 Conduct & Conflict Resolution.

6.4 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 (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and 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.

6.5 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 academic integrity policy can be found at the Honor Code Office website.

7 Tentative Course Schedule

The following is a tentative schedule of topics. Adjustments may be made based on class progress and student interests.

Important Dates (Spring 2026)

First Day of Classes (University)	Thursday, January 8, 2026
First Day of ASEN 6084	Monday, January 12, 2026
Martin Luther King Jr. Day	Monday, January 19, 2026 (No Class)
Last Day to Add/Drop (no penalty)	∼January 22, 2026 (verify with Registrar)
Midsemester Reading Day	Thursday, February 26, 2026
Spring Break	March 16–20, 2026 (No Class)
Last Day to Withdraw (with W)	∼Late March (verify with Registrar)
Last Day of Classes	Friday, April 24, 2026
Reading Days	April 25–26, 2026 (Sat–Sun)
Final Exams	April 27 – May 1, 2026 (Mon–Fri)
Final Exam (ASEN 6084)	TBD (check BuffPortal in March)
Commencement	Saturday, May 2, 2026

Note: Verify exact add/drop and withdrawal deadlines at https://www.colorado.edu/registrar/students/calendar

Lecture Schedule

Lecture	Title
1	Course Introduction
2	Image Processing and Optical Sensor Fundamentals
3	Point Spread Function and Centroid Estimation
4	Centroid Error Analysis and Photometry Fundamentals
5	Background Estimation and Subtraction
6	Detection and Measurement Extraction
7	Matched Filter SNR Optimization and Statistics
8	Binary Hypothesis Testing and Neyman-Pearson Theory
9	Measurement Association Methods and Metric Spaces
10	Mahalanobis Distance and KL Divergence for Tracking
11	Kalman Filter with Process Noise and Clutter
12	MHT Architecture: Hypothesis-Oriented vs Track-Oriented
13	Clustering Operations and Properties
14	Cluster Splitting and Track-Oriented MHT
15	Hypothesis Probability Computation Using Bayes Rule
16	Hypothesis Probability Updates and Likelihood Ratios
17	TOMHT Track Scoring and Pruning Methods
18	Introduction to Finite Set Statistics (FISST)
19	Measurement Likelihood Functions and Random Finite Sets
20	Particle Filter Resampling and Finite Set Statistics
21	RFS Properties, Probability Functions, and Functionals
22	Multi-Object Density Functions and PHDs
23	FISST PDFs and Multi-Object Stochastic Filtering
24	PHD Filter and Birth Model Extension
25	PHD Particle Filter and Bernoulli/Multi-Bernoulli Filters
Final weeks: Student project presentations	