ASEN 5128 Small Uncrewed Aircraft System Guidance, Navigation, and Control

Spring 2023 Syllabus

Lecture: AERO 111 Tuesday and Thursday, 11:30 am – 12:45 pm

Instructor

Prof. Eric Frew
Hours: TBD

Text

Required: *Small Unmanned Aircraft: Theory and Practice*
by Randal W. Beard and Timothy W. McLain
https://github.com/randybeard/uavbook

Prerequisites

This class is open to advanced graduates from all departments with a background in dynamics and control equivalent to ASEN 5014 and/or a background in sensor fusion and estimation equivalent to ASEN 5044.

Overview

Uncrewed aircraft systems (UAS) are being heralded as the next revolution in the aerospace industry. The purpose of this course is to introduce students to advanced techniques for guidance, navigation, and control of the emerging class of small uncrewed aircraft systems (SUAS), which are informally defined as aircraft too small to carry a person as payload.

The first third of the course will focus on aircraft dynamics and control with emphasis on linearization techniques applicable to the computing and sensing resources available on SUAS. Automatic guidance and control are the foundations of unpiloted flight. Therefore the class will develop the full, nonlinear aircraft equations of motion, linearize these equations into simpler form, and learn how to use classical (e.g. successive loop closure) control techniques to stabilize the aircraft.

The middle third of the course will focus on estimation algorithms and sensor fusion architectures to derive aircraft state information from inexpensive sensors. Common sensors will be described in order to develop models of their drift and error performance. Particular emphasis will be placed on a navigation architecture that combines inertial sensors, air data sensors, and GPS position and velocity measurements.

The final third of the course will investigate the impact of wind on aircraft guidance and control. Aircraft dynamics will be revisited to derive where spatial- and time-varying winds enter into the aircraft equations of motion. Gust sensitivity will be discussed as well as static and dynamic soaring concepts whereby the aircraft can gain energy under certain flight conditions.

Students will develop an aircraft simulation capability in order to demonstrate the topics covered during the course. By the completion of the course students will have a complete nonlinear simulation of an aircraft under closed-loop guidance and control in wind.

Topics covered in this course include:

1. Introduction
2. Coordinate Frames
3. Kinematics and Dynamics
4. Forces and Moments
5. Linear Design Models
6. Autopilot Design
7. Nonlinear Design Models
8. Waypoint and Orbit Following
9. Sensors
10. State Estimation
11. Wind Models
12. Equations of Motion in Wind
13. Soaring Concepts and Wind Energy Extraction

Course Grading

20% Homework
30% Exam 1
30% Exam 2
20% Final Project

Grades for the overall course are set based on the following criteria. **Grades do not correspond to pre-specified ranges of scores.**

A, A-	Demonstrates mastery of the course material in both conceptual and quantitative aspects.
B+, B	Demonstrates comprehensive understanding of the material, with a solid conceptual grasp of key concepts and strong quantitative work.
B-, C+	Demonstrates good understanding of most key concepts, with few major quantitative errors.
C	Demonstrates satisfactory understanding of the material, with sufficient quantitative work
C-	Demonstrates adequate understanding of the material to proceed to the next level; quantitative work with some persistent errors.
D	Little understanding is evident, consistently poor quantitative work.
F	Unsatisfactory performance.

Homework Policy

Homework will be assigned each Thursday and will be due the following Thursday in class. Students are allowed to collaborate with one another on the homework; however, each student must submit his own work.

Exams

Exams will be open note, open book take home exams. Exam 1 will cover the first half of the course (Topics 1 – 6). Exam 2 will focus on material from the second half of the course.

Final Project

This course will have a final project in place of a final exam. The project will require students to implement concepts or topics based on material presented in the course, and then submit a final paper describing the results. The main mechanism for disseminating research into the broader scientific community is through conference and journal publications. As researchers, technical writing is one of the most critical, yet overlooked, skills you can obtain. Details of this assignment will be provided during the second week of the course.

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, marital status, political affiliation, or political philosophy.

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

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 illness, injury or required medical isolation for which you require adjustment, notify the instructor. 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 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 in 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 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 abuse (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. 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 including confidential services 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.

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.

Course Outline

Numbers in parenthesis indicate book chapters. '+' indicates material not covered in the textbook.

Week	Dates		Tuesaday		Thursday	
1	8/26-8/30	Equations of Motion; Aircraft Dynamics; Guidance and Control.	Introduction (1)		Coordinate Frames (2)	
2	9/2-9/6		Kinematics and Dynamics (3)		Forces and Moments 1 (4)	HW 1 due
3	9/9-9/13		Forces and Moments 2 (4)		Linear Design Models 1 (5)	HW 2 due
4	9/16-9/20		Linear Design Models 2 (5)		Linear Modes and Reduced-Order Models (5)	HW 3 due
5	9/23-9/27		Autopilot Design - Lateral (6)		Autopilot Design - Longitudinal (6)	HW 4 due
6	9/30-10/4		Advanced Control Methods (+)		Nonlinear Design Models (9)	HW 5 due
7	10/7-10/11		Waypoint Guidance and Straight Line Following (10)		Guidance Vector Fields for Closed Curves (10+)	HW 6 due
8	10/14-10/18	Sensors; Estimation; Navigation and Sensor Fusion.	Sensors - Proprioceptive (7)		Sensors - Exteroceptive/Navigation (7)	**EXAM 1 due**
9	10/20-10/25		Air Data Systems (7+)		Kalman Filter Estimation Review (8)	HW 7 due
10	10/27-11/1		State Estimation 1 (8)		State Estimation 2 (8)	HW 8 due
11	11/4-11/8		Multi-Sensor Fusion 1 (+)		Multi-Sensor Fusion 2 (+)	HW 9 due
12	11/11-11/15		Attitude-Heading Reference System (+)		Advanced Sensor Fusion Methods (+)	HW 10 due
13	11/18-11/22	Wind;	Wind Models (+)		Equations of Motion in Wind (+)	**EXAM 2 due**
14	11/25 - 11/29	FALL BREAK			FALL BREAK	
15	12/2-12/6	Autonomous Soaring.	Autonomous Soaring (+)		Optimal Strategies for Static Soaring (+)	Final Project
16	12/9-12/13		Optimal Trajectories for Dynamic Soaring (+)		Dynamic Path (Re)Planning for Guidance in Wind (+)	Final Project
Finals	12/14-12/18				Final Project due	