Robust and Adaptive Control for Aerodynamic Systems
A Remote-Learning EDGE Course
Website https://ufl.instructure.com/courses/488181
EAS 6939
Class Periods: Recording schedule Friday 0900-1200 (Pre-recorded lectures become available online)
Location: UF REEF Building; 1350 N Poquito Rd; Shalimar, FL 32579
Academic Term: Fall 2023

Instructor:
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Office Hour: Wednesday, 1900-2000, Weekly

Course Description
In this EDGE course, students strengthen and extend their understanding of modern robust, optimal, and adaptive control theories to address flight control challenges for aerospace systems. Topics include robust servomechanism design, linear quadratic methods, optimal observer-based feedback, loop transfer recovery, multivariable frequency domain analysis, and guidance fundamentals. In addition, students will learn how to augment robust baseline controllers with model reference adaptive control, which restores baseline control performance in the presence of uncertainties. Topics are introduced from fundamental principles with progressive complexity. To reinforce understanding, applied examples in MATLAB follow each subject. Upon successfully completing this course, students gain a theoretical understanding of relevant control for aerospace systems, develop a set of tools to apply these methods through homework assignments, and learn how to systematically apply the tools to tune flight controllers to successfully address real-world aerospace problems.

Course Pre-Requisites / Co-Requisites
Students should be familiar with linear algebra, ordinary differential equations, classical control for SISO systems, and state space control theory. Basic programming skills in MATLAB are essential.

Course Objectives
1. Become proficient in a selected set of highly relevant modern control and estimation methods for aircraft flight control.

2. Develop a useful code-based toolset through homework and project exercises that enables application of modern control and estimation methods within and beyond this course.

3. Learn how to systematically tune flight control systems comprised of modern control and estimation methods.

Materials and Supply Fees
MATLAB is required to run codes provided in class, and complete homework and projects.

Required Textbooks and Software
- Robust and Adaptive Control with Aerospace Applications
  Eugene Lavretsky and Kevin Wise
  Springer, first edition, 2013
  ISBN-10: 1447143957
  Note: A second edition will be available in late October.

Recommended Materials
- Optimal Control Linear Quadratic Methods
  Anderson, B. and Moore, J.
  Dover, 2007

ISBN-10: 9780486457666

Comments: This text is a good supplement to many of the topics in the required textbook. It is also inexpensive; copies can be found for under 10 dollars.

- Aircraft Control and Simulation
Stevens, B. and Lewis F.
Wiley, third edition, 2015
ISBN-10: 1118870980
Comments: This is recommended for students with particular interest in subject matter of this course and its application to full nonlinear aircraft simulation. A second edition can be found for significantly less than the third edition. To compare vendor prices on new and used textbooks, www.addall.com is suggested. In general, this text is not necessary to succeed in this course.

Course Schedule

Week 1:   (Recording August 25th) Course Introduction, Aircraft equations of motion review, Trim and linearization, Rigid body dynamics, development of directionally decoupled LTI control design models / Chapter 1

Week 2:   (Recording September 1st) Control design overview, Introduction to optimal control, Hamilton-Jacobi-Bellman equation / Chapter 2 / Quiz 1

Week 3:   (Recording September 8th) Finite horizon regulator, Infinite time regulator, Linear quadratic regulation (LQR) Matrix Hamiltonian equations, Stability of LTI LQR, Kalman's identity, Coded examples with aircraft application / Chapter 2

Week 4:   (Recording September 15th) Robustness properties of LTI LQR, Asymptotic properties of LQR, Command tracking motivation, Coded examples with aircraft application/ Chapter 2,3 / Quiz 2

Week 5:   (Recording September 22nd) Derivation of the robust servomechanism (command tracking control), Combining robust servomechanism design and LQ methods, Coded examples with aircraft application / Chapter 3

Week 6:   (Recording September 29th) Review of classical frequency domain methods, Bode's theorems and "Respect the Unstable," Performance-robustness tradeoffs, Systematic tuning in coded examples with aircraft application / Chapter 5

Week 7:   (Recording October 5th) Review of vector and matrix norms, The singular value decomposition, Coded examples, Multivariable Nyquist and stability margins, Additive and multiplicative disturbances / Chapter 5 / Quiz 4

Week 8:   (Recording October 13th) Frequency domain analysis of a MIMO aircraft control system, Rejection of external disturbances, Small gain theorem, Robust stability / Chapter 5

Week 9:   (Recording October 20th) Observer overview, Leuenberger observer, duality of LQ observer to LQ control, Systematic tuning, Example application to a rocket, Guidance / Chapter 6 / Quiz 5

Week 10:   (Recording October 27th) Model reference control, Scalar direct model reference adaptive control (MRAC), Application to roll dynamics of an aircraft, Mathematical preliminaries: Lyapunov stability, stability definitions, Lipschitz continuity, Barbalat's lemma, Coded examples / Chapter 7,8

Week 11:   (Recording November 3rd) MRAC for MIMO systems, MRAC with integral control, Coded examples / Chapter 9 / Quiz 6

Week 12:   (Recording November 9th) MRAC augmentation of an optimal baseline controller, Coded examples, MRAC modifications for robustness / Chapter 10,11

Week 13:   (Recording November 17th) MRAC modifications for robustness, The projection operator, Projection based MRAC design, Coded examples / Chapter 11 / Quiz 7

Week 14:   Holiday Week

Week 15: (Recording November 27th) Projection based MRAC design, Coded examples, Approximation-based MRAC, Course review / Chapter 11

Attendance Policy, Class Expectations, and Make-Up Policy
This course is designed for remote learning and as such, in-person attendance not required. If you are local or happen to be in the area, you are welcome to attend in person during recording sessions. However, due to potential changes in my recording schedule, please verify with me when you plan to attend.

You are expected to watch each lecture set (3 50-minute lectures) within 7 days after they are uploaded. In general, there is a no late homework policy unless it is associated with an excused absence that is consistent with university policies. Extended absences may require make-up work. When such absences are known, you must work with the instructor to develop a plan to make-up the work missed.

Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://gradcatalog.ufl.edu/graduate/regulations/

Evaluation of Grades

Assignment	Total Points	Percentage of Final Grade
Homework Sets (5)	100 each	40%
Quizzes (7)	50 each	20%
Project	100	20%
Final Exam	100	20%
Total		100%

Grading Policy
Your final grade will be assigned based on your total percent score according to the table below. The instructor may reduce the percent thresholds for each grade based on overall class performance. Note, if the class does well and the average is high, grade thresholds will not increase and the table below will still apply.

Percent	Grade	Grade Points
93.4 - 100	A	4.00
90.0 - 93.3	A-	3.67
86.7 - 89.9	B+	3.33
83.4 - 86.6	B	3.00
80.0 - 83.3	B-	2.67
76.7 - 79.9	C+	2.33
73.4 - 76.6	C	2.00
70.0 - 73.3	C-	1.67
66.7 - 69.9	D+	1.33
63.4 - 66.6	D	1.00
60.0 - 63.3	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:
UF Graduate Catalog
Grades and Grading Policies

Students Requiring Accommodations
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is

important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

In-Class Recording
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy
UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment
The Herbert Wertheim College of Engineering values varied perspectives and lived experiences within our community and is committed to supporting the University's core values, including the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of race, creed, color, religion, age, disability, sex, sexual orientation, gender identity and expression, marital status, national origin, political opinions or affiliations, genetic information, and veteran status.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- HWCOE Human Resources, 352-392-0904, student-support-hr@eng.ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use
All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy
There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:
<u>Health and Wellness</u>

> **U Matter, We Care:**
> Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.
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> **Counseling and Wellness Center:** https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.
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> **Sexual Discrimination, Harassment, Assault, or Violence**
> If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu
>
> **Sexual Assault Recovery Services (SARS)**
> Student Health Care Center, 392-1161.
>
> **University Police Department** at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

<u>Academic Resources</u>

> **E-learning technical suppor***t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.
>
> **Career Connections Center**, Reitz Union, 392-1601. Career assistance and counseling; https://career.ufl.edu.
>
> **Library Support**, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.
>
> **Teaching Center**, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus: https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

On-Line Students Complaints: *https://distance.ufl.edu/getting-help/; https://distance.ufl.edu/state-authorization-status/#student-complaint*.