Nonlinear Control 2: Adaptive Control

EML 6351 Sections 24516, 24518, 24519
Class Periods: Online
Location: Online
Academic Term: Spring 2024

Instructor:
Max L. Greene, PhD.
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Office Hours: Tuesday & Friday, 4:00-5:00, Zoom
As needed by appointment

Course Description
Control methods for uncertain nonlinear systems. Lyapunov-based robust, adaptive, learning, and estimation-based methods.

Course Pre-Requisites / Co-Requisites
Pre-Requisite: EML 6350 or Instructor Approval

Course Objectives
This course is intended to introduce students to control methods that can be applied to uncertain nonlinear systems. A Lyapunov-based framework is used as the baseline approach for the synthesis and analysis of the developed controllers. To compensate for uncertainty in the system, students will be introduced to topics including repetitive learning control, model reference adaptive control, Lyapunov-based adaptive control, neural network function approximation methods, composite and modular adaptive control, concurrent learning, and adaptive actor/critic-based reinforcement learning control. The content will be mathematical with illustrative examples taken from general engineering systems. Introduction to Nonlinear Control (or a baseline understanding of Lyapunov-based design and analysis methods) is a prerequisite. The student will also be expected to be able to use some simulation software (e.g., MATLAB) to complete class projects.

Required Textbooks and Software
Required Software: None.
Required Textbook: None.

Supplemental Software: MATLAB (available to students through UFApps).
Supplemental Textbooks:

1. **Nonlinear Systems, 3rd Edition** by H. Khalil, 2002
2. **Nonlinear and Adaptive Control Design** by M. Kristic, I. Kanellakopoulos, P. Kokotovic, 1995.
3. **Stable Adaptive Systems** by K. Narendra and A. Annaswamy, Dover, 1989.
4. **Reinforcement Learning for Optimal Feedback Control: A Lyapunov-Based Approach** by R. Kamalapurkar, P. Walters, J. Rosenfeld, and W. Dixon, 2018.
5. **Deep Learning** by I. Goodfellow, Y. Bengio, and A. Courville, 2016.
6. **Robust and Adaptive Control with Aerospace Applications** by E. Lavretsky and K. Wise, 2012.

Course Schedule
Week 1: Introduction, Model Reference Adaptive Control,
Week 2: Torque Filtering, Gradient Adaptive Control, Composite Adaptive Control
Week 3: Composite Adaptive Control, Torque Filtering, Persistence of Excitation
Week 4: Robust Adaptive Control, DCAL Control Method with Adaptation, **Project 1 Due**
Week 5: RISE Control with Adaptation, Concurrent Learning, Integral Concurrent Learning
Week 6: Integral Concurrent Learning, **Project 2 Due**
Week 7: Modular Adaptive Control
Week 8: Modular Adaptive Control with RISE, Projection and Modification Algorithms, **Project 3 Due**

Week 9: Modification Algorithms, Repetitive Learning Control, **Exam 1**
Week 10: Neural Networks, **Project 4 Due**
Week 11: Neural Network Adaptive Control
Week 12: Modern Adaptive Control, **Project 5 Due**
Week 15: Adaptive Optimal Control
Week 14: Modern Adaptive Control, **Exam 2 Released**, **Project 6 Due**
Week 15: Modern Adaptive Control and Course Conclusion
Finals Week: **Final Exam Due on May 2nd, 2024 at 12:00 PM**

Attendance: Not required but highly encouraged. All students are responsible for all material presented in class. Office hours will not be used to compensate for class absence.

***Late/Makeup Policy*:** Make-up exams will be given only for special circumstances that are pre-approved by the instructor. 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/

***Academic Honesty*:** All students admitted to the University of Florida have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action. This statement is a reminder to uphold your obligation as a student at the University of Florida and to be honest in all work submitted and exams taken in this class and all others. All students should review the University's honor code policy you will be held to it.

Simulations can be done in collaboration with other students. However, no simulation code for the projects should be transmitted between students. You should develop the code yourself, and tune the controller yourself, with just verbal discussion/collaboration between classmates.

Grade Evaluation
Homework may be assigned (in class problems and take-home problems) and not graded. Solutions will be posted. Simulations of each new adaptive control method will be assigned and graded. If you do not attempt the homework and simulations on your own, then a lack of understanding will be reflected in the exams.

Assignment	Total Points	Percentage of Final Grade
Simulation Projects (6)	100 each	40% Total
Exams (2)	100 each	60% (30% Each)
		100%

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 broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

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
• Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@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:
Health and Wellness

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.

Counseling and Wellness Center: https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

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/.

Academic Resources

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/state-authorization-status/#student-complaint.*