AE 8803: Optimization-Based Learning Control and Games
Course Syllabus

Instructor: Dr. Kyriakos G. Vamvoudakis
Dept.: The Daniel Guggenheim School of Aerospace Engineering
Office: Knight Building 415-B
Phone: 385-3342
E-mail: kyriakos@gatech.edu
Web: http://kyriakos.ae.gatech.edu/

Time & Location: 2:00 am - 3:15 pm TR Klaus 1207
Office Hours: 11:00 am – 12:30 pm TR Montgomery Knight Building, Office 415-B
Course Web Page: http://kyriakos.ae.gatech.edu/ae8803AI.html

Textbook: There is no required text. The instructor will provide notes and research papers.

Helpful Texts:
F. L. Lewis, D. Vrabie, and V. L. Syrmos. *Optimal Control*, John Wiley & Sons, 2012 (ISBN: 978-0-470-63349-6) Preliminary version is provided by author in http://www.uta.edu/utari/acs/FL%20books/Lewis%20optimal%20control%203rd%20edition%202012.pdf

D. Liberzon, *Calculus of variations and optimal control theory: a concise introduction*, Princeton University Press, 2012 (ISBN: 978-0-691-15187-8) **(good reference on calculus of variations).** Preliminary version is provided by author in: http://liberzon.csl.illinois.edu/teaching/cvoc.pdf

D. Vrabie, K. G. Vamvoudakis, F. L. Lewis, *Optimal Adaptive Control and Differential Games by Reinforcement Learning Principles*, Control Engineering Series, IET Press, 2012 (ISBN: 978-1-84919-489-1) **(good reference on RL and optimal control)**

T. Basar, G. J. Olsder, *Dynamic noncooperative game theory*, Vol. 23. Siam, 1999 (ISBN: 978-0-89871-429-6) **(good reference on game theory)**

Required Software: Student Edition of Matlab

Course Description: This course will cover analysis and design techniques in optimal control systems and differential games.

Tentative Topics:

I. Static and Dynamic Optimization
   A. Unconstrained Optimization and Efficient Algorithms, e.g., steepest or gradient descent methods
   B. Constrained Optimization with Lagrange Multipliers (First-Order Necessary Conditions) and Second-Order Conditions

II. Calculus of Variations
   A. Motivation Examples
   B. Hamiltonian Formalism and Mechanics
   C. First and Second-Order Conditions
   D. Specification of Performance Indices

III. Optimal Control of Discrete-Time Systems
   A. Solution Concept
   B. Linear Quadratic Regulator (LQR) and Matrix Equations
   C. Steady-State Closed-Loop Control
   D. Advanced Topics

IV. Optimal Control of Continuous-Time Systems
   A. Solution Concept
   B. LQR and Matrix Equations
   C. Steady-State Closed-Loop Control
   D. Advanced Topics

V. Extensions of LQR
   A. Cross Terms in the Cost Functional
   B. Servo and Tracking Problems

VI. Final- Time-Free and Constrained Input Control
   A. Constrained Minimum-Time Problem (Bang-Bang Control)
   B. Constrained Minimum-Fuel Problem (Bang-Off-Bang Control)
   C. Constrained Minimum-Energy Problem

VII. Dynamic and Approximate Dynamic Programming
   A. Bellman's Principle of Optimality
   B. Continuous versus Discrete-Time
   C. Hamilton-Jacobi-Bellman (HJB) Equation
   D. Policy and Value Iteration
   E. Q-learning

VIII. Differential Games
   A. Pontryagin's Principle and Bellman's Equation
   B. Zero-Sum Games and Hamilton-Jacobi-Isaacs Equation (HJI)
   C. Non-Zero-Sum Games and Nash Equilibrium

IX. Reinforcement Learning
   A. Reinforcement Learning
   B. Duality of Optimal Control and Optimal Estimation
   C. Motion Planning with Randomized Trees and Optimal Control
   D. Output Feedback

Tentative Grading Policy: Homework 30%
Midterm 35% (Mid-class)
Final Project 35% (Please come talk to me to pick a project that is related to your field of interest.)

Homework Assignments:

- Due at the beginning of the class on the due date. Solutions to the homework will be posted on the web at the time that they are due. Therefore, NO LATE HOMEWORK will be accepted.
- Electronic submissions will be accepted before the class starts.
- Late homework will not be accepted without formal documentation of extenuating circumstances (e.g., a note from a Dean, a physician, etc.).

Course Policies: 1. NO CELL PHONES are allowed during lecture. 2. Be on time to class. Tardy is discouraged. 3. No make-up exams/quizzes. If you miss the exam, a zero score will be assigned to the missed exam/quiz. 4. If you miss a class due to personal emergency or medical reasons, please be sure to inform the instructor by e-mail. 5. Homework assignments are to be submitted by the due date. You may discuss homework problems with your classmates, but you are responsible for your own works. 6. After an assignment grade has been posted online, students must see the instructor within one week if they wish to discuss the assignment and their work.

Principles of Community: Students are expected to be polite and professional when interacting with one another and with the instructor. Abusive or insensitive behavior will not be tolerated.

Academic Support: The instructor will provide assistance through normal protocols, such as office hours, but cannot serve as a private tutor.
Special Accommodations: Special accommodations can be made for students with disabilities. Please bring any such issues to the instructor's attention *no later than the second week of class*.

Georgia Tech School of Aerospace Engineering Values

Discussion Points

1. **Honesty:** The School of Aerospace Engineering values honesty and integrity of all members of our community. An important element of this value is the academic honor code.

   Georgia Tech Honor Challenge Statement: I commit to uphold the ideals of honor and integrity by refusing to betray the trust bestowed upon me as a member of the Georgia Tech community.

   Honor Code: http://policylibrary.gatech.edu/student-affairs/academic-honor-code#Article_I:Honor_Agreement

2. **Well Being:** The School of Aerospace Engineering values the complete well-being of all members of its community, which includes professional, physical, spiritual, emotional, and

social dimensions. There are numerous resources to support the health and well-being of all members of our community: https://gatech.instructure.com/courses/108574

Mental Health Resources:
Emergencies: Can either Call 911 or call Campus Police at 404.894.2500 http://www.police.gatech.edu/
Center for Assessment, Referral, & Ed. (CARE): https://care.gatech.edu/ 404.894.3498 (Counselor On-Call)
Counseling Center: https://counseling.gatech.edu/ 404.894.2575
Stamps Health Services: https://health.gatech.edu/ 404.894.1420
Student Life and Dean of Students: https://studentlife.gatech.edu/content/get-help-now 404.894.6367
Victim-Survivor Support (VOICE): https://healthinitiatives.gatech.edu/well-being/voice 404-385-4464/(or 4451)
National Suicide Prevention Lifeline: 1.800.273.TALK (8255)
Georgia Crisis and Access Line: 1.800.715.4225

COVID-19 Safety
GT Safety Guidelines: https://health.gatech.edu/tech-moving-forward
Current guidance is summarized at the site above and please continue to follow the site above and other Institute communications in case changes occur:

3. **Social Justice:** The School of Aerospace Engineering values social justice for all members of the Georgia Tech community and the larger society. Social justice means that everyone's human rights are respected and protected. We stand committed in the fight against racism, discrimination, racial bias, and racial injustice. Our shared vision is one of social justice, opportunity, community, and equity. We believe that the diversity and contributions from all of our members are essential and make us who we are. We believe that our impact must reach beyond the classroom, research labs, our campus, and the technology we create, but must also improve the human condition where injustice lives. We will continue to work to understand, value, and celebrate all people and create an inclusive educational and work environment that welcomes all.

   As a matter of policy, Georgia Tech is committed to equal opportunity, a culture of inclusion, and an environment free from discrimination and harassment in its educational programs and employment. Georgia Tech prohibits discrimination, including discriminatory harassment, on the basis of race, ethnicity, ancestry, color, religion, sex (including pregnancy), sexual orientation, gender identity, national origin, age, disability, genetics, or veteran status in its programs, activities, employment, and admissions.

   http://policylibrary.gatech.edu/equal-opportunity-nondiscrimination-and-anti-harassment-policy

Tentative Roadmap			Fall 2024 (AE 8803)	
Number of Lecture	**date**	**day**	**Topic**	**Reading Assignments**
1	**20-Aug**	**tue**	Introduction, Unconstrained and Constrained Optimization	Sections 1.1-1.2 Liberzon and Chapter 1 in Lewis
2	**22-Aug**	**thurs**	Unconstrained and Constrained Optimization	Sections 1.1-1.2 Liberzon and Chapter 1 in Lewis
3	**27-Aug**	**tue**	Unconstrained and Constrained Optimization	Sections 1.1-1.3 Liberzon and Chapter 1 in Lewis
4	**29-Aug**	**thurs**	Calculus of Variations	Chapter 2 in Liberzon
5	**3-Sep**	**tue**	Calculus of Variations	Chapter 2 in Liberzon
6	**5-Sep**	**thurs**	Calculus of Variations	Chapter 2 in Liberzon
7	**10-Sep**	**tue**	Calculus of Variations	Chapter 2 in Liberzon and Section 3.1 in Lewis
8	**12-Sep**	**thurs**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
9	**17-Sep**	**tue**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
10	**19-Sep**	**thurs**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
11	**24-Sep**	**tue**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
12	**26-Sep**	**thurs**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
13	**1-Oct**	**tue**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
14	**3-Oct**	**thurs**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
15	**8-Oct**	**tue**	Applications of Optimal Control	-
16	**10-Oct**	**thurs**	Extensions of LQR	Chapter 4 in Lewis
17	**15-Oct**	**tue**	Extensions of LQR	Chapter 4 in Lewis
18	**17-Oct**	**thurs**	Dynamic Programming	Chapter 6 in Lewis
19	**22-Oct**	**tue**	Midterm Exam in Class	-
20	**24-Oct**	**thurs**	Approximate Dynamic Programming and Learning	Notes
21	**29-Oct**	**tue**	Differential Games	Chapter 10 in Lewis and Section 7.3 in Liberzon
22	**31-Oct**	**thurs**	Policy and Value Iteration	Notes
23	**5-Nov**	**tue**	Q-learning	Notes
24	**7-Nov**	**thurs**	Differential Games and Learning	Part 3 in Vrabie and Chapter 11 in Lewis
25	**12-Nov**	**tue**	Differential Games and Learning	Part 3 in Vrabie and Chapter 11 in Lewis
26	**14-Nov**	**thurs**	Advanced Topics	Research Papers
27	**19-Nov**	**tue**	Advanced Topics	Research Papers
28	**21-Nov**	**thurs**	Advanced Topics	Research Papers
29	**26-Nov**	**thurs**	Advanced Topics	Research Papers
30	**28-Nov**	**thurs**	Thanksgiving, No Class	-
31	**3-Dec**	**tue**	Project Presentations	-