AOE 5244: Optimization Techniques
Course Syllabus

Instructor: Dr. Kyriakos G. Vamvoudakis
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Time & Location: TR 3:30 PM to 4:45 PM
NCB Room 270

Office Hours: 11:00 AM - 12:30 PM Tuesdays & Thursdays or by appointment

Course Web Page: http://www.dept.aoe.vt.edu/~kyriakos/ and https://canvas.vt.edu/

Required 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

Additional Texts: 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.

Course 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 Programming
A. Bellman's Principle of Optimality
B. Continuous versus Discrete-Time
C. Hamilton-Jacobi-Bellman (HJB) Equation
D. Brief Remarks on Viscosity Solutions

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. Advanced Topics
A. Reinforcement Learning
B. Duality of Optimal Control and Optimal Estimation
C. Motion Planning with Randomized Trees and Optimal Control
D. Output Feedback
E. Limited Bandwidth Optimal Control

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. Student conduct is governed by Virginia Tech's Principles of Community: http://www.diversity.vt.edu/principles-of-community/principles.html

Honor System: Graduates of Virginia Tech's engineering program have very high standards of personal and professional integrity. It is the responsibility of Virginia Tech's students and faculty to ensure that this legacy continues. The Undergraduate Honor Code pledge that each member of the university community agrees to abide by states:

> "As a Hokie, I will conduct myself with honor and integrity at all times. I will not lie, cheat, or steal, nor will I accept the actions of those who do."

Students enrolled in this course are responsible for abiding by the Honor Code. A student who has doubts about how the Honor Code applies to any assignment is responsible for obtaining specific guidance from the course instructor before submitting the assignment for evaluation. Ignorance of the rules does not exclude any member of the University community from the requirements and expectations of the Honor Code. For additional information visit: https://www.honorsystem.vt.edu/

Academic Support: The instructor will provide assistance through normal protocols, such as office hours, but cannot serve as a private tutor. Virginia Tech has numerous resources to support student achievement. For information about academic support services, please see: http://www.undergraduate.vt.edu/Subpages/aca-supp_index_SCMS.html

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*. For information on the types of accommodations that are available see http://www.ssd.vt.edu/

Emergency Preparedness: The Office of Emergency Preparedness has developed the following flyer outlining simple steps to follow when preparing for or responding to an emergency: http://www.emergency.vt.edu/help/resources-help/studentPreparedness.pdf

Tentative Roadmap			Fall 2017 (AOE 5244)	
Number of Lecture	**date**	**day**	**Topic**	**Reading Assignments**
1	**29-Aug**	**tue**	Introduction, Unconstrained and Constrained Optimization	Sections 1.1-1.2 Liberzon and Chapter 1 in Lewis
2	**31-Aug**	**thurs**	Unconstrained and Constrained Optimization	Sections 1.1-1.2 Liberzon and Chapter 1 in Lewis
3	**5-Sep**	**tue**	Unconstrained and Constrained Optimization	Sections 1.1-1.3 Liberzon and Chapter 1 in Lewis
4	**7-Sep**	**thurs**	Calculus of Variations	Chapter 2 in Liberzon
5	**12-Sep**	**tue**	Calculus of Variations	Chapter 2 in Liberzon
6	**14-Sep**	**thurs**	Calculus of Variations	Chapter 2 in Liberzon
7	**19-Sep**	**tue**	Calculus of Variations	Chapter 2 in Liberzon and Section 3.1 in Lewis
8	**21-Sep**	**thurs**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
9	**26-Sep**	**tue**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
10	**28-Sep**	**thurs**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
11	**3-Oct**	**tue**	Optimal Control of Discrete-Time Systems	Chapter 2 in Lewis
12	**5-Oct**	**thurs**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
13	**10-Oct**	**tue**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
14	**12-Oct**	**thurs**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
15	**17-Oct**	**tue**	Optimal Control of Continuous-Time Systems	Chapter 3 in Lewis
16	**19-Oct**	**thurs**	Extensions of LQR	Chapter 4 in Lewis
17	**24-Oct**	**tue**	Dynamic Programming	Chapter 6 in Lewis
18	**26-Oct**	**thurs**	Dynamic Programming	Chapter 6 in Lewis
19	**31-Oct**	**tue**	Midterm Exam in Class	-
20	**2-Nov**	**thurs**	Dynamic Programming	Chapter 6 in Lewis
21	**7-Nov**	**tue**	Viscosity Solutions for HJB	Chapter 5 in Liberzon
22	**9-Nov**	**thurs**	Differential Games	Chapter 10 in Lewis and Section 7.3 in Liberzon
23	**14-Nov**	**tue**	Differential Games	Chapter 10 in Lewis and Section 7.3 in Liberzon
24	**16-Nov**	**thurs**	Differential Games and Learning	Part 3 in Vrabie and Chapter 11 in Lewis
25	**21-Nov**	**tue**	No Lecture/Thanksgiving	-
26	**23-Nov**	**thurs**	No Lecture/Thanksgiving	-
27	**28-Nov**	**tue**	Advanced Topics	Research Papers
28	**30-Nov**	**thurs**	Advanced Topics	Research Papers
29	**5-Dec**	**tue**	Advanced Topics	Research Papers
30	**7-Dec**	**thurs**	Advanced Topics (Projects are Due)	Research Papers
31	**12-Dec**	**tue**	Project Presentations	

These descriptions and timelines are subject to change at the discretion of the Instructor.