ECE 726: Advanced Feedback Control

NC State University, Fall 2024

Lecture Time: Tuesday & Thursday 11:45 am– 1:00 pm
Room: MRC 313

Instructor Information

• Instructor: Dr. Aranya Chakrabortty
• Office: Keystone Science Center, Room 100-20
• Office Hours: Monday 4:00 – 5.00 pm, or by appointment

• Email: achakra2@ncsu.edu
• Phone Number: 919-513-3529
• Web: https://achakra2.wordpress.ncsu.edu

Pre-requisite:
ECE 308: Elements of Control
ECE 516: System Control Engineering (*desired, but not a hard pre-requisite*)

Syllabus/Course Content:
1. Review of linear system theory
2. Optimal control using Calculus of Variations
3. Pontryagin's Minimum Principle
4. Linear Quadratic Regulators (LQR), Linear Quadratic Gaussian (LQG), Kalman Filters
4. Minimum-time, minimum-fuel, and bang-bang control designs
5. Data-driven optimal control using Reinforcement Learning
6. Course project on real-world applications of optimal control in practical systems such as electric power grids, robotics, process control, aircraft autopilots, machine learning and deep learning-based control, etc.

Textbook : Donald E. Kirk, *Optimal Control Theory,* Dover Publications, NY, 2004.

It is also strongly suggested that students consult the following book (held on reserve in the NCSU library) regularly during the second half of the course when LQR control design will be taught:

B. D. O. Anderson and J. B. Moore, *Linear Quadratic Methods*, Prentice-Hall, 1990.

Other reference books of interest (On reserve in library):
1. H. Kwakernaak, R. Sivan, *Linear Optimal Control Systems*, Wiley-Interscience, 1972.
2. P. Antsaklis and A. Michel, *Linear Systems Primer*, Birkhauser, 2007.
3. R. F. Stengel, *Optimal Control and Estimation*, Dover, 1994.
4. A. Bryson and Y. Ho, *Applied Optimal Control,* Hemisphere Pub, 1981.
6. F.L. Lewis and V.L. Syrmos, *Optimal Control*, 2nd Ed.,Wiley Interscience, 1995.
7. G.E. Dullerud and F. G. Paganini, *A course in robust control theory*, Springer, 2000.

Course website:
TBD (will be shared during first week of classes)

Students can access all lecture videos and notes from the course website. The website will also have a link to the Moodle site where all homeworks, solutions, reading assignments, Matlab files, past sample exams, announcements, student forum, and other resources will be uploaded.

Syllabus has been uploaded to the course website. This course overview document has been uploaded to the "Syllabus and Course Information" folder in Moodle. A Matlab primer has also been added to the Resources folder.

Grading Policy:
There will be 7 or 8 homework assignments throughout the semester, a midterm, a final exam, and a small research project. The weight for each is as follows:

Homeworks: 20%
Midterm: 30%
Final Exam: 40%
Course project: 10%

Homework assignments will be uploaded to the 'Homework' folder in Moodle. All homework will be due in a week from the day the assignment is handed out. There will be 20% penalty for each session late. Submission will not be accepted if more than two sessions late.

Distance learning students are requested to scan their completed homeworks as a single pdf file, and e-mail it to the instructor at achakra2@ncsu.edu by the submission deadlines stated on the homework.

Solutions: Solutions to homework and exams will be uploaded to the Solutions folder in Moodle.

Course Research Project:
Students (divided in groups) will select a practical/industrial application of optimal control, and design and simulate a controller of their choice taking suitable operational constraints of the chosen plant into account. A brief presentation will be given by each group during the last week of classes. More detailed information will be given on this before Thanksgiving Break.

Course outline

08/22 (Th) Review of linear system theory
08/27 (T) Introduction to linear optimal control
08/29 (Th) Calculus of variations
09/03 (T) Calculus of variations (contd.)
09/05 (Th) Euler's equations – part 1
09/10 (T) Euler's equations - part 2
09/12 (Th) Euler's equations for multi-input multi-output systems
09/17 (T) Optimal control with linear constraints
09/19 (Th) Optimal control with nonlinear constraints
09/24 (T) Application examples
09/26 (Th) Linear Quadratic Regulators (LQR) designs
10/01 (T) LQR designs for tracking
10/03 (Th) Matlab/Simulink Examples of LQR
10/08 (T) Midterm Exam
10/10 (Th) Holiday – Fall Break
10/15 (T) Linear Quadratic Gaussian (LQG) control

10/17 (Th) LQG (contd.)
10/22 (T) Matlab/Simulink examples of LQG
10/24 (Th) Frequency-domain approaches for designing LQR
10/29 (T) Further discussions on LQR and LQG control
10/31 (Th Reinforcement Learning
11/05 (T) Reinforcement Learning
11/07 (Th) Matlab examples of RL
11/12 (T) Pontryagin's Minimum principle for bounded systems
11/14 (Th) Minimum-time problems
11/19 (T) Minimum-fuel problems
11/21 (Th) Matlab examples of minimum-time problems
11/26 (T) Model Predictive Control
11/28 (Th) Holiday – Thanksgiving Break
12/03 (T) Review of course materials
12/05 (Th) Project Presentations

Final Exam: **Take-Home exam. The instructor will give more information after classes start.**

Software needed: Matlab and Simulink
Other related simulation packages will be provided by the instructor.

Academic integrity

It is the aim of the faculty of NCSU to foster a spirit of complete honesty and a high standard of integrity. The attempt of students to present as their own any work that they have not honestly performed is regarded by the faculty and administration as a serious offense and renders the offenders liable to serious consequences, possibly suspension.

Students with disabilities

Any student who, because of a disability, may require special arrangements in order to meet the course requirements should contact the instructor as soon as possible to make any necessary arrangements. Students should present appropriate verification from Student Disability Services during the instructor's office hours. Please note instructors are not allowed to provide classroom accommodations to a student until appropriate verification from Student Disability Services has been provided.

Civility in the classroom

Students are expected to assist in maintaining a classroom environment that is conducive to learning. Inappropriate behavior in the classroom that leads to the distraction of others shall not be tolerated under any circumstances.