ELEG 5423 Optimal Control

Spring 2021 8W1

Instructor: Roy McCann, Ph.D., P.E.

Textbooks:

Linear Optimal Control, Burl (Pearson)
https://www.pearson.com/us/higher-education/program/Burl-Linear-Optimal-Control/PGM94667.html

The following will also be referenced: The content that we will use in the course from these books will be posted on Blackboard (not required to purchase these books).

1. Optimal Control Systems by Naidu (CRC Press) ISBN 978-0849308925
2. Optimal & Robust Estimation & Stochastic Control Theory (CRC Press) By Frank Lewis ISBN 978-0849390081
3. (ELEG 4423/5423) Modern Control Systems, Dorf and Bishop, 12th or 13th Edition (Pearson)
4. (ELEG 5423) Optimal and Robust Control: Advanced Topics with MATLAB by Luigi Fortuna and Mattia Frasca (CRC, 2012).

This course covers the theory of advanced linear systems design and optimization. The scope includes classical and modern methods that are used or referenced in recent engineering research and practical applications. There is a large body of knowledge for optimizing the solutions to many types of problems in the quantitative sciences.

This course emphasizes:

(1) Real-time systems where the variables of interest are functions of time and the optimal solution is often computed during system operation.

(2) Design optimization of dynamic systems to achieve inherently robust operation with respect to component variation and uncertainties.

Early applications were for aircraft, missile and space systems with constraints on mass, time and fuel usage. However, optimal control and estimation theory has been applied to many diverse applications such as robotics, power generation-transmission, biomedical and automotive systems.

This course covers deterministic systems with an introduction to stochastic quadratic optimization and Kalman filters. A familiarity with linear systems theory is assumed. This course will provide detailed use of Matlab-Simulink in formulating design solutions to engineering problems.

Students are required to be aware of and comply with the University of Arkansas policies for academic integrity as described at http://www.uark.edu/campus-resources/rlee/honesty.html.

Outline

- Introduction and Mathematical Preliminaries (4 class meetings)
    - Review Matrices, Linear Algebra and Similarity Transformations
    - State Space Models of Dynamic Systems
    - Formulating Performance Indices
- Linear Systems Analysis (6 class meetings)
    - Stability
    - Controllability
    - Observability
- State-Space Design Methods (6 class meetings)
    - Pole Placement
    - Observer Design
- Calculus of Variations
    - Lagrange multipliers
    - Pontryagin Principle
- ELEG 5423: Canonical Forms (4 class meetings)
    - Kalman Decomposition
    - Singular Value Decomposition
- Linear Quadratic Optimal Control (8 class meetings)
    - Linear Quadratic Regulator (LQR) design
    - Tracking systems
- State Estimation (4 class meetings)
    - Review of random processes and stochastic signals and systems
    - Kalman Filter as the Quadratic Optimal Estimator
    - Linear Quadratic Gaussian (LQG)
- H_2 H_∞ Design Methods (8 class meetings)
    - Modern Control Paradigm
    - Norm-based robust control
    - H_2 Optimal Control
    - H_∞ Design Methods

Weekly Meetings: There will be class meetings held on Tuesdays at 6:30-7:00pm and scheduled on an ad hoc basis (Blackboard announcement at least 2 days in advance). As needed, there will be extra sessions to cover homework solutions or other items as needed on Thursdays at 6:30pm. All meetings are recorded for later viewing. Attendance is highly recommended but not required.

Design Project

A Matlab-Simulink based class project is required for the course. The topic can be selected by the student or a problem provided by the instructor can be used. The purpose is to more deeply explore the implementation details than what can be accomplished in the homework assignments. Design project is due **March 7th 11:59pm**.

Research Paper

A research paper on a student selected topic that describes an application of optimal and robust feedback control technologies will be written. The paper will be written in IEEE format (2-3 pages) with at least 5 equations, 2 figures and 10 references cited. A 5 minute oral presentation to the class will be given that summarizes the findings **(March 2, 6:30-8:00pm).** The paper will be developed in three separately graded parts: (1) initial abstract and references (3) full 2-page draft (3) oral presentation.

Grading:

Short research paper and presentation	18%
Homework (6 assignments)	42% (combined)
1 In-Class Exams	15% (combined)
Class Project (Matlab-Simulink and Report)	25% (with written report)

All graded materials must be turned in no later than 11:59pm March 7th, 2021.

Overall course grades will be assigned based on an assessment of the student's mastery of the subject matter and participation in classroom discussions and presentations. As a general guideline, the approximate course grade breakdown:

>90% → A >80% →B >70% → C >60% → D <60% → F

	Spring 2021 8W1 Date	Video Lecture (2018)	Topics	Due Dates
1	Jan 13	Jan 24	Introduction	
2	Jan 13	Jan 29	Simulink	
3	Jan 14	Jan 31	Linear Systems, notch filter	
4	Jan 15	Feb 2	Stability, positive definite	
5	Jan 15	Feb 5	Controllability, Similarity	
6	Jan 16	Feb 9	Controllability, pole placement	
7	Jan 18	Feb 12	Pole placement, observability	
8	Jan 19	Feb 14	Observer design	HW-1 Due
9	Jan 20	Feb 16	Separation principle	
10	Jan 21	Feb 19	Quadratic cost functions	
11	Jan 21	Feb 21	HW Review, RLC example	
12	Jan 22	Feb 26	RLC example, Linear Quadratic Control	
13	Jan 25	Feb 28	Calculus of Variations	
14	Jan 26	Mar 2	Lagrange Multipliers	HW-2 Due
15	Jan 27	Mar 5	Pontryagin Principle	Test 1 Available
16		Mar 9	(HW Solutions)	
17	Jan28	Mar 12	Discrete time state space	
18	Jan 28	Mar 16	Infinite time horizon LQR	
19	Jan 29	Mar 26	Kalman filter, uncertainty	
20		Mar 28	(HW Solutions)	
21	Feb 1	Mar 30	Random processes	
22	Feb 2	Apr 2	Kalman filter	HW-3 Due
23	Feb 3	Apr 4	Cuk converter	Test 1 Close
24	Feb 4	Apr 6	Discrete time Kalman filter	
25	Feb 5	Apr 9	Digital sampling	
26	Feb 8	Apr 11	Singular value decomposition	
27	Feb 9	Apr 13	Cuk convert	HW-4 Due
28	Feb 10	Apr 16	Linear Quadratic Gaussian control	

29	Feb 12	Apr 20	Design Project (PSS)	
30	Feb 15	Apr 23	Design Project (LFC)	
31		Apr 25	(Design Project)	
32		Apr 27	(Design Project)	
33	Feb 16	Recording 33	Modern Control Paradigm	HW-5 Due
34	Feb 18	Recording 34	Norm Based Robust Control	
35	Feb 19	23Recording 35	H2 Control	
36	Feb 22	Recording 36	H2 Control	
37	Feb23	Recording 37	Hinf Control	HW-6 Due
38	Feb 24	Recording 38	Hinf Control	
	Mar 2		**Research Paper Presentations**	March 2
	Mar 7		**Design Project Due**	March 7 11:59pm