EEL 4657C: Linear Control Systems - Fall 2017

1. Course Objectives

EEL 4657 is an introductory course on the analysis and design of Linear Control Systems. The material presented emphasizes the classical analysis and design control systems to achieve overall system stability and acceptable performance. The class of Linear Time Invariant (LTI) Single-input Single Output (SISO) systems is of primary focus, although a more general introductory treatment is also given in terms of state space and transfer matrix representations of Multi-input Multi-output (MIMO) systems. This course is built on material covered in pre-requisite or co-requisite courses such as EEL 3112 (Electrical Circuits II) and EEL 3135 (Signals and Systems), as well as mathematical preliminaries with particular emphasis on the solution of ordinary differential equations using Laplace transform techniques. The course also exhibits control systems as a multidisciplinary subject finding applications in electrical, chemical, mechanical, biomedical, and other branches of engineering.

The goal of the course is to provide access to the basic design and analysis tools used in practical control systems as well as to give an exposure of the student to the general area of linear systems theory which appears so very often in all branches of engineering. We consider such topics as the philosophy, benefits and costs of negative feedback, stability, robustness and performance specifications as well as system analysis and design for Single-input Single-output systems. The major tools of classical analysis, The Root Locus, the Nyquist Diagram and the associated Nyquist Stability Criterion and Bode Plots are developed and illustrated. While the main results are developed for continuous time systems using the mathematical formalism of the Laplace transform, we also provide an introductory coverage of discrete-time systems using the Z-transform. Throughout our discussion of the classical theory, we interweave hints of the more rigorous design methods of both the state-space as well as the optimal frequency domain approaches. For example, in dealing with differential equations and Laplace transforms, MIMO systems are presented as quite simple extensions of SISO systems within the state-space setting, leading naturally to the generalization of SISO transfer functions to MIMO transfer matrices. We also introduce the notion of an optimization over the set of all stabilizing controllers to attain the best possible performance or robustness measures. The treatment of these latter aspects at this point is very general and non-rigorous; the intent is purely motivational for an appreciation of more advanced material the student is may encounter later.

Lab schedules and details for the laboratory section of the class will be provide in class and online. Labs will typically begin during the second week of the semester. Matlab/Simulink will be used to integrate with laboratory velocity and position motor systems and with a ball and beam rig. Students will be required to implement Lead/Lag and PID controllers using a microprocessor students are familiar with from EEL3744 (Microprocessor Applications).

2. **Catalog Description**

EEL 4657- Linear Control Systems - Pre-requisites: Circuits II and Signals and Systems. Theory and Design of Linear Control Systems

Pre-requisites

EEL 3112, EEL 3135, and EEL3744

An undergraduate course in electrical circuits and signals and systems provides a desirable background for some of the material to be covered in the course. Specifically, it would be helpful for students to have a sound grasp of the concepts of transfer functions, time and frequency response, and Laplace Transform analysis.

A basic knowledge of z-transforms and solving difference equations would also be helpful in the discrete-time material. In addition matrices and linear algebra concepts will be used in the introduction of the state variables approach that is covered in this class. Knowledge of Microprocessors will also be useful in implementing controlling analog controllers in digital form.

3. **Instructor**
    a. Haniph A. Latchman
    b. Office location: NEB 463
    c. Telephone: (352) 392-4950
    d. E-mail address: Latchman@list.ufl.edu
    e. Web site: www.list.ufl.edu

4. **Teaching Assistants**
    a. Ding-Shin Kuo dkuo@ufl.edu
        - Office Hours: M 8, T 4-5, W 9, R 4-5 NEB222
    b. Ana Covic anaswim@ufl.edu
        - Office Hours: M 5, T 5-6, F 5 NEB222
    c. Derya Tansel derya.tansel@ufl.edu
        - Office Hours: T 4, W 5, R 6 NEB222

5. **Meeting Times**
    T 2-3, R 3

6. **Class schedule**
    3 classes per week, 50 minutes each

7. **Meeting Location**
    LAR 310

8. **Material and Supply Fees**
    None

9. **Textbooks and Software Required**

a. Title: Linear Control Systems – A Neo-classical Approach (in preparation)
   Author: Haniph A. Latchman
   Publication Date:
   ISBN number:
   Available Online as pdf for all students
   Please do not place on any Internet site.

   Recommended

b. Title: Modern Control Systems
   Author: R.C. Dorf and R.H. Bishop
   Publisher: Prentice Hall
   Publication Date: 2010
   Edition: 12

9. **Relationship to ABET Outcomes**

- **Specific Outcomes of Instruction:** To understand the essentials of mathematical system modeling; to be able to assess stability and performance properties of linear systems, and be able to design lead and lag controllers for linear systems using s-domain and frequency domain techniques.

- Outcomes Addressed by This Course: EE2, EE3, a, c, e, k (To view how the outcomes of this course fit in with the curriculum)

10. **Course Outline**

1.0 Introduction and Background
    1.1 .Open-loop Vs Closed-loop Control Systems
    1.2 Control Objectives
    1.3 Mathematical Representation of Systems
    1.4 System Classification
    1.5 Control Strategies
    1.6 History of Control Theory and Control Systems
2.0 Linear Systems Theory and Classical Control
    2.1 Introduction
    2.2 A Motivational Example - Automotive Cruise Control
    2.3 The Laplace transform
    2.4 A State-space Approach
    2.5 A Direct Transfer Function Approach
    2.6 Transfer Function Model Standardization and Simplification
    2.7 Block Diagram Reduction
    2.8 Signal Flow Diagram and Mason's Rule
    2.9 Relationship Between Transfer Function and State-space Models
3.0 s-Domain Analysis and Performance Criteria
    3.1 Stability Definitions and Conditions

- 3.2 Negative Feedback Analysis and Stability Testing
- 3.3 Transient Time Response: The Effect of Pole Locations
- 3.4 Second Order Time Response Characteristics
- 3.5 Steady State Response and System Type

4.0 Classical s-domain Design Methods
- 4.1 Constant Gain Controllers
- 4.2 The Root Locus
- 4.3 An Example
- 4.4 1st Order Lag Controllers
- 4.5 1st Order Lead Controllers
- 4.6 PID Controllers

5.0 Frequency Domain Analysis and Performance Criteria
- 5.1 The Nyquist Stability
- 5.2 Gain and Phase Margins
- 5.3 Performance Specifications in the Frequency Domain
- 5.4 Robustness and Robustness Margins
- 5.5 The Critical Direction

6.0 Frequency Domain Design Methods
- 6.1 1st Order Lag Design
- 6.2 1st Order Lead Design
- 6.3 PID Controller Design in the Frequency Domain
- 6.4 Introduction to H-infinity Design

7.0 State Variable Analysis and Design Methods
- 7.1 Observability Controllability and Minimality
- 7.2 Stability Criteria
- 7.3 State Feedback and Output Feedback
- 7.4 State Observers
- 7.5 Optimal L2 Control

11. **Attendance and Expectations**

Class Attendance

Class attendance is not required but all students are responsible for all material and information disseminated during class sessions as such information may not be posted on websites or otherwise.

Assignments

Homework and other assignments will be given periodically and will be due within the first 5 minutes of class on the designated due-date. Use regular-size paper, staple the sheets together, fold and put your name and homework number at the top. Late homework will be accepted only in exceptional circumstances which need to be discussed with the Instructor for approval. Homework assignments will not be given over the phone. Graded homework will be returned in class or during office hours.

Exams

The midterm test will be given on Tuesday, October 17 (time and location TBA). The midterm will be closed-book and closed-notes. The final examination will be comprehensive, but with emphasis on material covered since the midterm exam. For the final exam, students will be allowed one sheet of letter-sized paper, written in their own original handwriting, on **one side**. The date of the final exam is Tuesday, December 12^{th} from 7:30 am to 9:30 am in the usual classroom. Final exams are decided by the registrar's office and can be confirmed online at http://www.registrar.ufl.edu/soc/ or specifically here.

Labs

Labs will be completed on a weekly basis. Your lab grade will be out of 100 and will be used to calculate your final course grade as shown under Grading. The following is a list of the lab topics. The Module Fundamentals is due for each module on the last week of that module. A quiz will be given at the beginning of each lab. The µPAD Controls Platform labs will be done at home by all students. Students will demonstrate their results during their designated lab section, and will be evaluated by their TA. At-home labs should be completed **before** coming to your lab section. Reporting to lab without being able to demonstrate will result in a 50% penalty for that lab, assuming completion by the end of the lab section.

At the end of each module, a module report putting together the contents of all the sections of the module will be due the following week. For example, the Module Fundamentals for Module 1: Modeling is due on the third week of labs, while the Module Report for Module 1 is due on the fourth week of labs. Students will submit these assignments via Canvas.

Module 1: System Modeling
- 1.1: Modeling of Quanzer SRV02 System
- 1.2: Modeling of OOTB µPAD Controls Platform
- 1.3: Model Validation Techniques using OOTB µPAD Controls Platform

Module 2: Position Control
- 2.1: Step and Ramp Response of SRV02 System using PD Controller
- 2.2: Step Response of OOTB µPAD Controls Platform using PD Controller
- 2.3: Step and Ramp Response of OOTB µPAD Controls Platform using PID Controller

Module 3: Speed Control
- 3.1: Step Response of Quanzer SRV02 System using Lead Controller
- 3.2: Development and Simulation of Lead Controller for OOTB µPAD Controls Platform
- 3.3: Implementation of Lead Controller for OOTB µPAD Controls Platform

Module 4: Cascade Control Scenarios

4.1: Control of a Ball and Beam Using Quanzer SRV02 System and Practical PD Controller

4.2: Gyro Stabilization using OOTB μPAD Controls Platform and PID Controller

Section	Meeting Time	TA
1E15	T E1-E3	Ding-Shin Kuo
1E16	W E1-E3	Ana Covic
1E17	R E1-E3	Ana Covic
1E18	W 6-8	Ding-Shin Kuo
1E19	M 6-8	Derya Tansel
1E20	F 6-8	Derya Tansel

12. **Grading**

Coursework:

Quizzes: 10%
Discussion: 5%
Midterm Test: 30%
Final Exam: 35%
Assignments: 20%

Lab:

Weekly Evaluation: 10%
Module Fundamentals: 20%
Quizzes: 30%
Module Reports: 40%

Total EEL 4657C grade = 0.75*(coursework grade) + 0.25* (lab grade)

13. **Grading Scale (Subject to a possible curve based on relative class performance)**

Grades will be assigned dependent on absolute and relative class performance generally according to the following scheme.

90-100	A
85.9-89.9	A-
81.8-85.8	B+
77.7-81.7	B
73.6-77.6	B-
68.5-72.5	C+
64.4-68.4	C
60.3-64.3	C-
56.2-60.2	D+
52.1-56.1	D
48.0-52.0	D-
0-47.9	F

Please note that “Undergraduate students, in order to graduate, must have an overall GPA and an upper-division GPA of 2.0 or better (C or better). Note: a C- average is equivalent to a GPA of 1.67, and therefore, it does not satisfy this graduation requirement. Graduate students, in order to graduate, must have an overall GPA of 3.0 or better (B or better). Note: a B- average is equivalent to a GPA of 2.67, and therefore, it does not satisfy this graduation requirement. For more information on grades and grading policies, please visit:

https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx

14. **Make-up Exam Policy**

Make-up exams are allowed in exceptional cases such as documented medical emergency – these should be discussed with the Instructor.

15. **Honesty Policy**

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 UF student and to be honest in all work submitted and exams taken in this course and all others.

16. **Accommodation for Students with Disabilities**

Students requesting classroom accommodation must first register with the Dean of Students Office. That office will provide the student with documentation that he/she must provide to the course instructor when requesting accommodation.

17. **UF Counseling Services**

Resources are available on-campus for students having personal problems or lacking clear career and academic goals. The resources include:

- UF Counseling & Wellness Center, 3190 Radio Rd, 392-1575, psychological and psychiatric services.
- Career Resource Center, Reitz Union, 392-1601, career and job search services.

18. **Software Use**

All faculty, staff and student 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.