Linear Control Systems

EEL 4657 Sections: 12308, 12335, 12336, 12338
Class Periods: Tuesday Period 8-9 (3:00 PM - 4:55 PM), Thursday Period 9 (4:05 PM - 4:55 PM)
Location: PSY 0130
Academic Term: Fall 2019

Instructor:
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Office Hours: Thursday, 2 pm, NEB 463

Teaching Assistant/Peer Mentor/Supervised Teaching Student:
Please contact through the Canvas website

- Castrense Nigrelli, cnigrelli@ufl.edu, NEB 289, TBA

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

Course Pre-Requisites / Co-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.

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 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).

Materials and Supply Fees

$160.00

Required Textbooks and Software

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

b. **Title:** Analog and Digital Control Systems Design – A Laboratory Manual and Reference Guide
   Author: Haniph A. Latchman and Rami Okasha
   ISBN number: 9781119471851
   Available through the UF Bookstore

Recommended Materials

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

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

Attendance Policy, Class Expectations, and Make-Up Policy

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. Quizzes are administered daily; make-up quizzes are only allowed in exceptional circumstances such as documented medical emergency – these should be discussed with the Instructor.

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, 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 exam will be given on (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 side of one sheet of letter-sized paper, written in their own original handwriting. The date of the final exam is Tuesday, 12/10/2019 at 7:30 AM - 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/.

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.

Late lab assignments will be accepted only in exceptional circumstances which need to be discussed with your TA for approval.

Labs will be held in NEB 289

Section	Meeting Time	TA
308	T, E2-E3 (8:20 PM – 10:10 PM)	TBA
335	W, 11-E1 (6:15 PM – 8:10 PM)	TBA
336	R, 11-E1 (6:15 PM – 8:10 PM)	TBA
338	R, 5-6 (11:45 AM – 1:40 PM)	TBA

Module 1: System Modeling

1.1: Modeling of Quanser 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 Quanser 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 Quanser SRV02 System using Lead Controller
3.2: Development, Simulation, and Implementation of Lag Controller for OOTB µPAD Controls Platform
3.3: Development, Simulation, and Implementation of Lead Controller for OOTB µPAD Controls Platform

Module 4: Cascade Control Scenarios

4.1: Control of a Ball and Beam Using Quanser SRV02 System and Practical PD Controller
4.2: Gyro Stabilization using OOTB µPAD Controls Platform and PID Controller

Evaluation of Grades

Assignment	Total Points	Percentage of Final Grade
Homework Sets	100 each	20%
Quizzes	100 each	10%
Midterm Exam	100	30%
Final Exam	100	40%
		100%

Grading Policy

Percent	Grade	Grade Points
90.0 - 100.0	A	4.00
85.9 - 89.9	A-	3.67
81.8 - 85.8	B+	3.33
77.7 – 81.7	B	3.00
73.6 – 77.6	B-	2.67
68.5 – 72.5	C+	2.33
64.4 – 68.4	C	2.00
60.3 – 64.3	C-	1.67
56.2 – 60.2	D+	1.33
52.1 – 56.1	D	1.00
48.0 – 52.0	D-	0.67
0 - 47.9	F	0.00

More information on UF grading policy may be found at:
http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#grades

Students Requiring Accommodations

Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, https://www.dso.ufl.edu/drc) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

University Honesty Policy

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- Robin Bielling, Director of Human Resources, 352-392-0903, rbielling@eng.ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students 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.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:

Health and Wellness

U Matter, We Care:
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: http://www.counseling.ufl.edu/cwc, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)
Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

Academic Resources

E-learning technical suppor*t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

Career Resource Center, Reitz Union, 392-1601. Career assistance and counseling. https://www.crc.ufl.edu/.

Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall*,* 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus*:* https://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf.

On-Line Students Complaints*:* http://www.distance.ufl.edu/student-complaint-process.