Syllabus for ELEG 5403 Control Systems

MSE/MSEE online Fall 2021 8W1: Aug 23 – October 12, 2021

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Text Book: Modern Control Systems, 12th (or may use the 13th edition) by Dorf and Bishop, Prentice-Hall). ISBN 978-0136024583

Welcome to the course in control systems. This class will introduce design and analysis concepts for developing feedback control systems. Control systems design in multidisciplinary in that it combines the dynamics of mechanical, thermal, biological, and aeronautical systems with digital and analog electronics to meet a set of desired performance objectives. Most of the material is analytical/mathematical in nature; however, the objective is always towards developing a design that could be created as a physical prototype. In the design process we will account for the implementation aspects of microprocessors/microcontrollers, analog-to-digital conversion, communication protocols and fixed-point math. Applications will focus on automotive, aerospace, robotics, power electronics and motor drives.

Coursework will consist of the following:

1. There will be 6 homework assignments given throughout the course. These will generally be taken from the end-of-chapter questions in the textbook, and in other cases will be developed by the instructor related to topics of student interest. Students are encouraged to collaborate with one another in solving the homework problems. However, what you submit for grading must be your own work that indicated your understanding of the assignment.
2. There will be two exams. Practice problems similar to the tests will be provided. The exams are made available to students with a 24 hour completion deadline. Exams do not need to be proctored.
3. A simulation-based design project is required to be completed. The use of Matlab/Simulink modeling will address non-ideal effects associated with microcontroller-based computations such as sample-rate and quantization errors.
4. The last instructional day is Thursday July 16, 2020. The design project and all course materials must be turned in by Saturday July 18, 2020 11:59pm to BlackBoard.

Notify the instructor at least one week in advance to make alternative plans in the event of schedule conflicts with regard to tests and assignment due dates.

Course Grading

- 6 Homework Assignments Combined (7% each): 42% of Total
- Two Written Tests at 14% Each: 28% of Total
- Design Project and Report: 30% of Total

Grade Assignment Guidelines

Grades will be based upon an evaluation of each individual student's performance For guidance purposes, the following are ***approximate*** grade assignments for the overall course average, and may be adjusted up or down:

≥89% → A; ≥79% → B; ≥69% → C; <69% → D ; <60% or missing tests/project → F

The final course grade will account for trends throughout the semester and classroom participation.

Class Topic Schedule

Date – Class	Chapter	Video	Topic
Aug 23-25	Chap 1 and 2	#1, #2, #3,	Introduction & Modeling
Aug 26 – 28	Chap 2-3	#3, #4, #5	Modeling & State Space
Aug 29-31	Chap 3	#6, #7, #8	Feedback System Characteristics
Sep 1 – 3	Chap 4	#9, #10, #11	Feedback System Characteristics
Sep 4 – 7	Chap 4 and 5	#12, #13	Feedback System Performance
Sep 8 – 10	Chap 5	#14, #15, #16	Stability
Sep 11 – 13	Chap 6	#17, #18	Root Locus Analysis **(Test 1 after Chapter 5)**
Sep 14 - 17	Chap 7	#19, #20, #21	Root Locus Design
Sep 19 - 22	Chap 7 and 8	#22, #23, #24, #25	Frequency Domain
Sep 23 - 27	Chap 8 and 9	#26, #27	Stability Analysis (Freq Domain)
Sep 28 - 30	Chap 9	#28, #29, #30	Lead-Lag & PID Controller Design **(Test 2 after Chapter 9)**
Oct 1-5	Chap 10	#31, #32,#33	Lead-Lag & PID Controller Design
Oct 6 - 12	Chap 10		**Project: Turn in no later than 10/16/2021 11:59pm**

Personal Conduct

As a core part of its mission, the University of Arkansas provides students with the opportunity to further their educational goals through programs of study and research in an environment that promotes freedom of inquiry and academic responsibility. Accomplishing this mission is only possible when intellectual honesty and individual integrity prevail.

Each University of Arkansas student is required to be familiar with and abide by the University's 'Academic Integrity Policy' which may be found at http://provost.uark.edu/ Students with questions about how these policies apply to a particular course or assignment should immediately contact their instructor.

Students are required to conform to University standards of conduct. In particular, the University faculty, administration and staff are committed to providing an equal educational opportunity to all students. The University of Arkansas does not condone discriminatory treatment of students or staff on the basis of age, disability, ethnic origin, marital status, race, religious commitment, sex, or sexual orientation in any of the activities conducted upon this campus.

Control Systems ELEG 5403
Student Survey

Name:

Alternate email address:

(upload to BlackBoard as 'Assignment 0')

1. I have read and understand the content of the course syllabus.

2. Are you familiar with Matlab/Simulink?

3. Please list advanced mathematics courses you have taken (e.g., linear algebra, complex variables…).

4. Mark the following indicating your level of interest for examples to be given in class and for the design project. (1 – Low, 2 – Medium, 3 – High interest):

   a. ___ Automotive (electric and hybrid electric vehicles)
   b. ___ Biomedical (blood sugar and insulin regulation for diabetes, blood gas/pressure regulation, neuromuscular interfaces, balance and gait improvement).
   c. ___ Aerospace (missile and aircraft guidance)
   d. ___ Power Electronics and System (motor drives, utility interfaces, DC/AC and AC/AC converters, renewable energy, electric generators)
   e. ___ Robotics and Automation
   f. Other applications – Please describe:

Homework Assignments
(Notify instructor if time extension is needed)

HW-1 Due Aug 31, 11:59pm (Videos 1,2,3,4, 5)
E2.14
E2.23
P2.26
P2.31
CP2.10– use values of K at increments of 0.10, that is, in Matlab: K=[0.1:0.1:10];

HW-2 Due Sept 7, 11:59pm (Videos 6, 7, 8)
E3.13
E3.19 by hand (not Matlab) using formula and method given in class: G(s)=C*inv(s*I-A)*B
E3.20
AP3.7
CP3.5

HW-3 Due Sept 14, 11:59pm (Videos 9 through 13)
P4.4
DP4.2
CP4.7
CP4.10
E5.6
P5.10
AP5.1

Test 1: After completion of HW-1, HW-2, HW-3 (schedule individually with the instructor, approximately Jun 22-29)

HW-4 Due Sept 21, 11:59pm (Videos 14, 15)
E6.8
E6.19
P6.13
E7.13 using Matlab
E7.16 using Matlab
E7.23 using Matlab

HW-5 Due Sept 28, 11:59pm (Videos 20, 21, 22, 23, 24, 27)
P8.7
P8.11
E9.30 using Matlab
E9.31 using Matlab
E9.32 using Matlab
E9.33 using Matlab

Test 2: After completion of HW-4 and HW-5 (schedule individually with the instructor)

HW-6 Due Oct 5, 11:59pm (Videos 28, 29, 30)
P10.29
AP10.4
DP10.7
CP10.4
CP10.6

ELEG5403: Design Project

Due: No later than Saturday Oct 16th, 2021 at 11:59pm

General instructions:

- Select one of the three topics listed below.
- Turn in a single document pdf file that includes a narrative description of your design process. Graphical results such as output step responses should be copied from Matlab-Simulink and inserted into your document file. Each figure in your report should include a commentary on the results; that is, describe what the conditions were and the significance of the result. For example "The step response of the wind generator rotor speed with the modified PID controller given by equation (4) is shown in Figure 3. It is noted that the percent overshoot has been reduced to 5% compared to the 10% overshoot achieved by the PI controller given by equation (3)."

Design Option 1: Blood pressure control during anesthesia (Dorf and Bishop page 259).

1. Include in the system model that there is a 150 ms time-delay in the patient's MAP impulse response (figure 4.25).
2. Design a lead-lag controller using the frequency domain methods from Chapter10 to best match the performance achieved by PID-2 given in the textbook example (Table 4.2). Does the lead-lag meet the specified requirements? Indicate related stability margins of each controller design.
3. Develop an equivalent digital implementation of your lead-lag design from part (1) and also a digital equivalent for PID-2. Evaluate the performance in Simulink and comment on your choice for the sample time in terms of how slow of a sample rate can be implemented without performance degradation. Also describe the difference between your results for the continuous time (Laplace) implementation in part (1) compared to the digital implementation.
4. Evaluate the performance in the case where the digital controllers of part (2) are used when the actual patient parameter p=1.5 instead of the textbook nominal value of p=2. Comment on how the performance changes with this variation in p.

Design Option 2: Aircraft bank angle control (Dorf and Bishop page 348).

1. Include in the system model that there might be a 125 ms time-delay in the actuator response.
2. With inclusion of the actuator time-delay, design a PID controller using the frequency domain methods from Chapter10 to best match the performance requirements DS1 as 20% overshoot but with DS2 as 2.1 seconds. Also add a third requirement as DS3 for the settling time to be less than 4.75 seconds. Indicate related stability margins of each controller design. Evaluate the controller under the same conditions as given in the textbook.
3. Design a lead-lag controller using the frequency domain methods from Chapter10 to best match the performance requirements as described in part (1): DS1 as 20% overshoot; DS2 as 2.1 seconds; DS3 settling time to be less than 4.75 seconds. Indicate related stability

margins of each controller design. Evaluate the controller under the same conditions as given in the textbook. Also evaluate how the system performs without a time-delay in the actuator (without changes to the controller design).

4. Develop an equivalent digital implementation of your PID design from part (1) and also a digital equivalent for lead-lag controller in part (2). Evaluate the performance in Simulink and comment on your choice for the sample time in terms of how slow of a sample rate can be implemented without performance degradation. Comment upon the difference between your results for the continuous time (Laplace domain) implementations in parts (1) & (2) compared to the digital implementations. Also evaluate how the system performs without a time-delay in the actuator (without changes to the controller design).

Design Option 3: Wind turbine speed control (Dorf and Bishop page 497).

5. Include in the system model that there might be a 75 ms time delay in the communication network of the generator speed measurement signal.
6. With inclusion of the measurement time delay, design a PID controller using the frequency domain methods from Chapter10 to improve the performance requirements for less than 12% overshoot with rise time less than 1 second. Also meet a third requirement for the settling time to be less than 1.5 seconds. Indicate related stability margins of each controller design. Evaluate the controller under the same conditions as given in the textbook (i.e., disturbance responses). Also evaluate how the system performs without a time-delay in the measurement signal (without changes to the controller design).
7. Design a lead-lag controller using the frequency domain methods from Chapter10 to to improve the performance requirements for less than 12% overshoot with rise time less than 1 second. Also meet a third requirement for the settling time to be less than 1.5 seconds. Indicate related stability margins of each controller design. Evaluate the controller under the same conditions as given in the textbook (i.e., disturbance responses). Also evaluate how the system performs without a time-delay in the measurement signal (without changes to the controller design).
8. Develop an equivalent digital implementation of your PID design from part (1) and also a digital equivalent for lead-lag controller in part (2). Evaluate the performance in Simulink and comment on your choice for the sample time in terms of how slow of a sample rate can be implemented without performance degradation. Comment upon the difference between your results for the continuous time (Laplace domain) implementations in parts (1) & (2) compared to the digital implementations.

Design Option 4: Autonomous Vehicle Control

Reference: Y. Xia, F. Pu and S. Li, "Lateral Path Tracking Control of Autonomous Land Vehicle Based on ADRC and Differential Flatness," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 5, May 2016.

1. Given that the transfer function between the steering angle input and the lateral position

$$G(s) = \frac{y(s)}{\delta_f(s)}$$

of the autonomous vehicle is given by Xia *et al* as

$$G(s) = \frac{45.61s^2 + 12.83s + 259.8}{s^4 + 2.627s^3 + 0.9324s^2}$$

For *C(s)=K*, using root locus methods, determine the ranges of K such that the closed-loop system is stable (comment on the results in comparison to most feedback systems encountered in the course).

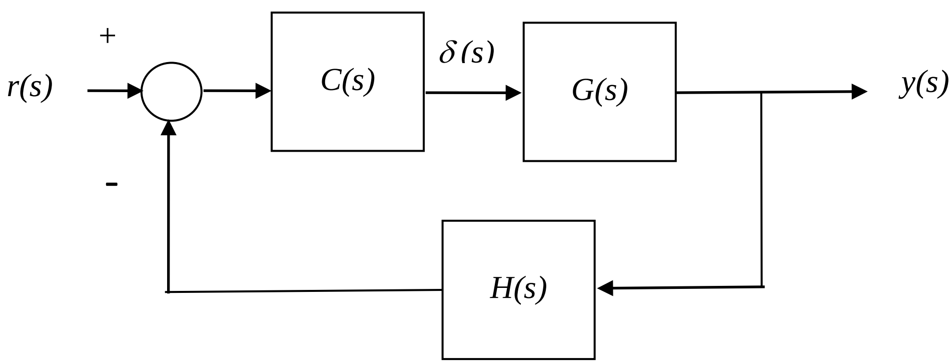
2. Using root locus and frequency domain methods, design a PD controller to meet the following requirements:
    a. 10% maximum overshoot for a unit step input for the commanded lane position r(t).
    b. No more than 2.0 second settling time for a unit step input r(t).
3. Design a lead (or lead-lead) compensator using frequency domain methods to meet the requirements given in part 2a and 2b.
4. Using the zero-order hold approximation for the measurement transfer function:

$$H(s) = \frac{2/T_s}{s + 2/T_s}$$

    Determine a sample time T_s for a digitally analog-converter measurement of the lane position y(t) that will allow for keeping the requirements in part 2a and 2b.
5. Use Simulink to evaluate how your controller design will respond to a lane-change command of 4.0 meters at a ramp rate of 1.5 meters per second.
6. Given that the transfer function if yaw angle to steering input is given by

$$G_\varphi(s) = \frac{3.171s + 7.872}{s^3 + 2.627s^2 + 0.9324s}$$

    a. Simulate the response of $G_\varphi(s)$ for the closed-loop control input $\delta_f(s)$ that was obtained in part 5. Comment upon how a passenger would perceive this response.
7. Modify your controller design to reduce the yaw oscillations observed in part 6. Comment upon the difficulty in achieving improved damping in the yaw response.



Autonomous vehicle block diagram.