ECE 446
Design of Feedback Control Systems

Overview

Course Catalog Description: Credits (3)
Modeling of continuous and sampled-data control systems. State-space representation. Sensitivity, stability, and optimization of control systems. Design of compensators in the frequency and time domains. Phase-plane and describing function design for non-linear systems, and laboratory design project.
Prerequisites: ECE 445 Introduction to Control Systems

No required Textbook

References:

1. Norman S. Nise. *Control Systems Engineering*, Wiley, 5th edition, 2008. ISBN: 978-0471-79475-2.
2. Karl J. Åström and Richard M. Murray. *Feedback Systems: An Introduction for Scientists and Engineers*, Princeton University Press, 2008. ISBN: 978-0-691-13576-2. http://www.cds.caltech.edu/~murray/amwiki/Main Page
3. Peter Dorato. *Analytic Feedback System Design: An Interpolation Approach*, Brooks/Cole, 2000.
4. Gene Franklin, J.D. Powell, and Abbas Emami-Naeini. *Feedback Control of Dynamic Systems*, Prentice Hall, 5th edition, 2006. ISBN: 0131499300.
5. *Handbook of Networked and Embedded Control Systems*, D. Hristu-Varsakelis and W. Levine (eds.), Birkhauser, 2nd printing, 2008.
6. M. Gopal. *Control Systems: Principles and Design*, McGraw-Hill, 2008.
7. Chi-Tsong Chen. *Linear System Theory and Design*, Oxford University Press, New York, 3rd edition, 1999. ISBN: 0195117778.
8. P. J. Antsaklis and A. N. Michel. *A Linear Systems Primer*, Birkhäuser, Boston, 2007. ISBN: 0817644601.

Class Goals: The main goal of this course is to gain a solid foundation in feedback control systems design. ECE 446 complements ECE 445 by giving students the opportunity to design and apply controllers to a real-world problem. More specifically, the class goals are:

1. Understanding (i) How to design feedback control systems in the frequency domain – Root-locus, Bode diagrams; (ii) analytical feedback control design.

2. Understanding how to design, tune and realize practical PID controllers.

3. Understanding of fundamental theoretical results associated with Lyapunov stability, controllability, and observability.

4. Understanding how to design feedback control systems in the time domain – Study of state feedback, output feedback (state estimators), and LQR.

5. Basic understanding of nonlinear control systems, discretization, and digital control systems.

6. Knowledge and use of software available for control design and implementation (LabVIEW, Matlab/Simulink).

7. Give an introduction to Model Predictive Control (MPC), hybrid control systems, and Cyber-Physical-Systems.

8. Laboratory Experiments. Students will perform three or four guided lab exercises and work in teams on a challenging term project involving the design and verification of a control system.

Course Coordinator: Prof. Rafael Fierro

Table I: Objectives, Implementation, and Assessment

Objectives		Implementation	Assessment	A	B	C	D	E	F	G	H	I	J	K
O_1	Understanding (i) How to design feedback control systems in the frequency domain – Root-locus, Bode diagrams; (ii) analytical feedback control design.	6.5 hrs. lecture in weeks 1,2, 5	HW 1, 2, Exam I	X		X		X						X
O_2	Understanding how to design, tune and realize practical PID controllers.	2.5 hrs. lecture in week 3	HW 3, Exam I	X		X		X						X
O_3	Understanding of fundamental theoretical results associated with Lyapunov stability, controllability, and observability.	4 hrs. lecture in weeks 4, 6	HW 4 Exam I	X				X						X
O_4	Understanding how to design feedback control systems in the time domain – Study of state feedback, output feedback (state estimators), and LQR.	4 hrs. lecture in weeks 7-8	HW 5, Exam I	X		X		X						X
O_5	Basic understanding of nonlinear control systems.	4 hrs. lecture in weeks 9-10	HW 6 Exam II	X				X						X
O_6	Basic understanding of discretization, and digital control systems.	4 hrs. lecture in weeks 11-12	HW7 Exam II	X				X						X
O_7	Give and introduction to Model Predictive Control (MPC), hybrid control systems, and Cyber-Physical-Systems	4 hrs. lecture in weeks 13-14	HW 8 Exam II	X		X		X			X	X	X	X
O_8	Laboratory Experiments. Students will perform three or four guided lab exercises and work in teams on a challenging term project involving the design and verification of a control system.	12.5. lab experiments and project in weeks 4-16.	Lab and project reports	X	X	X	X	X		X	X	X		X

Table II: Expectation and Assessment Outcome
Spring 2009, Dr. R. Fierro

General expectations: Homework: Homework problems are assigned on a weekly basis. Most assignments have a simulation/Matlab component. It is expected that students will be able to answer at least 75% of the problems assigned.
Lab Experiments: Students will perform three or four guided lab exercises and work in teams on a challenging term project involving the design and verification of a control system.

Exams: Expect 75% of the students to score 70% or better on all exams.

Objectives		Outcome Assessment	Evaluation
O_1	Understanding (i) How to design feedback control systems in the frequency domain – Root-locus, Bode diagrams; (ii) analytical feedback control design.		
O_2	Understanding how to design, tune and realize practical PID controllers.		
O_3	Understanding of fundamental theoretical results associated with Lyapunov stability, controllability, and observability.		
O_4	Understanding how to design feedback control systems in the time domain – Study of state feedback, output feedback (state estimators), and LQR.		
O_5	Basic understanding of nonlinear control systems.		
O_6	Basic understanding of discretization, and digital control systems.		
O_7	Give and introduction to Model Predictive Control (MPC), hybrid control systems, and Cyber-Physical-Systems.		
O_8	Laboratory Experiments. Students will perform three or four guided lab exercises and work in teams on a challenging term project involving the design and verification of a control system.		

Course Schedule

Week	Date	Lect.	Topic	Assignment
1	19 Jan	–		
	21 Jan	1	Introduction, Motivation & Course Administration	
2	26 Jan	2	Root-locus Design Method – Lag, PI Controllers	Ref. 1
	28 Jan	3	Root-locus Design Method – Lead, PD Controllers	Ref. 1
3	02 Feb	4	Feedback (minor loop) Compensation	Ref. 1
	04 Feb	5	Lag-lead, PID Controller Design	Ref. 1, 2
4	09 Feb	6	Frequency-response Design Method – Lag Compensators	Ref. 1
	11 Feb	7	Frequency-response Design Method – Lead Compensators	Ref. 1
5	16 Feb	8	Digital Control Systems – Z Transform	Ref. 1
	18 Feb	9	Discretization	Ref. 1
6	23 Feb	10	Digital Control Design	Ref. 1
	25 Feb	11	State-space representation	Ref. 7, 8
7	02 Mar	12	Stability	Ref. 7, 8
	04 Mar	13	Controllability and Observability	Ref. 7, 8
8	09 Mar	14	Review	
	11 Mar	–	**Exam I**	
9	16 Mar	–	*Spring Break*	
	18 Mar	–	*Spring Break*	
10	23 Mar	15	Introduction to analytical design	Ref. 3
	25 Mar	16	Analytical design – Part 2	Ref. 3
11	30 Mar	17	Introduction to Nonlinear Control Systems	Ref. 4
	01 Apr	18	Linearization	Ref. 4
12	06 Apr	19	Describing functions	Ref. 4
	08 Apr	20	Introduction to Nonlinear Control Design	Ref. 4
13	13 Apr	21	State feedback and pole placement	Ref. 8
	15 Apr	22	Output feedback and estimators	Ref. 8
14	20 Apr	23	LQR design and optimization	Ref. 8
	22 Apr	24	Model Predictive Control	
15	27 Apr	25	Review	
	29 Apr	–	**Exam II**	
16	04 May	26	Hybrid Control Systems and CPS	
	06 May	–	Final Project Review	