EEE 480 Feedback Systems Outline

Topic	Reading Material	Contents
1. Control Problems	Ch.	Quick introduction, general concepts and terminology of feedback systems, block diagrams. Feedback versus feedforward, sensors and actuators, disturbances, uncertainty and robustness, stabilization, tracking, performance, sensitivity, optimality.
2. System Models	Ch., handouts	Modeling for control, ODE/state-space concepts, linearization, time-scaling.
3. Dynamic Response	Ch.	Quantifying properties of dynamic response. Laplace transforms and frequency domain description, block diagram algebra, transfer functions for feedback and interconnected systems. Limit theorems, internal model principle Partial fraction expansion Effect of pole-zero locations on step response Performance indicators (overshoot, damping, settling time, rise time, bandwidth, resonance frequency)
4. Simple Controllers	Ch.	The PID controller. Lead and Lag compensators.
5. System Approximations	Handouts	Understanding the notion of approximation in systems. Quantifying the dominant dynamics, modeling error. Model order reduction principles. Handout examples.
6. System properties	Ch.	Stability, Routh
7. Design Tools	Ch. Ch.	1. Pole-placement (Root-locus, dominant target matching) 2. Loop-shaping (Bode/Nyquist)
8. Design Computations	Ch. Ch.	Pole-placement (Lead-Lag Designs) Loop-shaping (Lead-Lag Designs)

NOTES

1.	Simple examples to motivate the study of feedback systems. **General problem:** Given a system G: (u,d) → y, and a set of reference signals y*, design a controller C: (y,y*) → u, such that y~y*. Model-matching version: G_c: r → y, G_m: r → y*. Find C: (y,r) → u s.t. C_c~G_m.
2.	**Modeling issues:** We are primarily interested in the model u → y. We need to know how the control input affects the output. We do not know the disturbances (certain "disturbances" can be measured leading to feedforward controllers) but we should know certain gross properties (spectrum, energy/power bounds). Similarly for modeling errors, we should know a bound on the so-called multiplicative uncertainty. **Improving the design of control systems:** More accurate models: Dynamic compensators, general design methods. Respect the uncertain: Design constraints, specifications/control objectives, feasibility
3.	**Specifications:** The difficult part is to translate linguistic specifications (well-behaved closed-loop, quick settling, reasonable overshoot, good disturbance attenuation) to quantitative ones (stability, damping ratio > 0.7, Bandwidth > 1.3, |S(jw)| < -20 dB for w in [0,.5], zero steady-state error to steps). Basic analytical tools help to define what is feasible and some of the necessary ingredients a compensator must possess.
4.	The general shape of compensators: An integral part for high gain at low frequencies, a derivative part to shape the crossover and a proportional part to adjust the level.
5.	**Distance between systems:** Peak magnitude of the frequency response of the difference $\max_w(\|G_1(jw)-G2(jw)\|)$. From this, a reduction of the model order can be achieved by eliminating small terms in the partial fraction expansion. Dominant modes = modes of the big terms. Near pole-zero cancellations, fast dynamics lead to terms with small residues. System approximation concepts are particularly useful in simplified designs.
6.	A nice analytical tool…
7.	The two basic analysis/design methods. **Root-Locus:** Determine how the roots of a polynomial move as we change the coefficients. (coefficients = affine functions of a single parameter). **Nyquist:** Complex analytic argument to determine the RHP roots of a polynomial.
8.	The controller computations. Dynamic compensators introduce poles and zeros to reshape the root-locus/Nyquist plots. -Root-locus design essentially works by shaping a dominant 2^{nd} order approximation of the closed loop. -Nyquist/Bode design adjusts the loop transfer function around the crossover frequency. The choice depends on specifications and user preference. Usually, designs involve an interplay of the two, at least at the conceptual level. **Design Evaluation:** Simulation, Experiment, Operation. Did we actually achieve the desired response? Do we need to iterate and what needs to be modified? **What is hard?** *In 480:* Root-locus, Nyquist plots, Design computations, Modeling (some) *In reality:* Modeling, Quantify modeling approximations, Estimate disturbance/uncertainty properties, Decide design specifications, Feasibility issues, Quantify performance, Optimality, Design computations (multiple objectives), Managing the global behavior (saturation handling, nonlinear effects), Maintenance Issues

Week	Instruction	Lab
1	General Intro, Systems, Applications, Robustness-Performance trade-off. Modeling and Simulations (MATLAB).	-
2	Models for control, State-Space essentials, Linearization. Laplace review, PFE, Limit Value theorems. Block diagram algebra, Loop tf computations.	#1. MATLAB/SIMULINK
3 HW1	Step and frequency responses, 1-2-3 order, effects of pole/zero location, performance indicators. Control objectives, Basic controller shapes: PID-Lead/lag: Frequency resp of closed-loop, Sensitivity and Complementary sensitivity. 2DOF controllers, prefilters.	#1 cont.
4 HW2	System approximations, dominant dynamics, unmodeled dynamics, Model-order reduction, uncertainty, robustness, Stability (Routh, 3^{rd} order example R/L crossings)	#2 System Responses
5 HW3	Root-Locus analysis: concept, computations. Real axis rule, asymptotes, breakaway points, angle of departure/arrival, RL patterns	#2 cont.
6 EX1	RL examples and design hints: design for a 2^{nd} order dominant CL system	#3 Modeling and approximations, uncertainty estimates
7 HW4	RL design	#3 cont.
8 EX2	Nyquist analysis: The basic theorem and examples	#4 Simple R/L design (car)
9 HW5	Nyquist-Bode (frequency domain) examples and Sensitivity properties, Loop shaping principles	#4 cont.
10 HW6 EX3	N/B Design	#5 Simple N-B design (car)
11 HW7	Lead-lag compensation (R/L-N/B)	#6 Torque pendulum control (instability)
12 EX4	Case studies	
13 HW8	Case Studies, Nonlinear effects (saturation), Discretization	#7 Temperature control (Saturation), Cart&Pendulum control (nasty)
14+ EX5	Case Studies, Review	#7 cont.