ENME 621 (Fall 95)

Robust and Adaptive Linear Control

Instructor: PROF. MIROSLAV KRSTIC
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Course Objective: The course will introduce the students to state-of-the-art methods for control of LINEAR dynamical systems with uncertain models. The course is a "two-for-one" package. It covers both the *robust* approach where a priori knowledge of bounds on uncertainties is used to design a single linear controller, and the *adaptive* approach which uses a 'learning' nonlinear loop and can handle larger (parametric) uncertainties. Two excellent and comprehensive textbooks on robust and adaptive control have just come out this year. We will follow them closely. By learning both robust and adaptive control in a single course, the students will reach a thorough understanding of trade-offs between these two apparently unrelated paradigms for control of uncertain systems. This course will also ease the students into a future course on control of NONLINEAR uncertain systems, one of the most promising research areas in the 1990's.

Texts:

- Green and Limebeer, *Linear Robust Control*, Prentice Hall, 1995
- Ioannou and Sun, *Robust Adaptive Control*, Prentice Hall, 1995

Prerequisite: ENME 605 or equivalent (e.g., ENEE 663) or permission of instructor

Time and Place: TuTh 3:30–4:45, EGR 1102

Office Hours: TuTh 4:45–6:00 or by appointment

Grading: 50% Homework
50% Exam(s) and/or Project

The course will contain an (optional) project in which the students will select an application problem (from ME, EE, AE, ChE) and apply their favorite control technique learned in class.

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OUTLINE

1. Robust Control

   (a) **Introduction—Control Objectives:** model matching, disturbance attenuation, robust stability.

   (b) **Multivariable Frequency Response Design.** Singular values. Robust stability. Performance.

   (c) **Signals and Systems.** Linear spaces, norms, inner products, operators, induced norms. Small gain theorem. Passivity. Bounded real lemma.

   (d) **Linear Fractional Transformations.**

   (e) **LQG Control.** Full information + Kalman filter = Measurement feedback.

   (f) **Full Information $\mathcal{H}_\infty$ Controller.** Differential games. Riccati equation. Necessity and sufficiency.

   (g) $\mathcal{H}_\infty$ **Filter.**

   (h) $\mathcal{H}_\infty$ **Generalized Regulator.**

   (i) **Model Reduction** (time permitting)**.** Balanced realization. Truncation. Hankel norm approximations. Nehari's theorem.

2. Adaptive Control

   (a) **Parametric Models.**

   (b) **Stability Preliminaries.** Barbalat's lemma. Small in the mean. $\mathcal{L}_{2\delta}$-norm and I/O stability. Gronwall lemma. Lyapunov stability. LTV systems, exponential stability. Positive real systems, Popov-Kalman-Yakubovich lemma.

   (c) **Parameter Identifiers.** SPR-Lyapunov algorithm. Gradient algorithm. Least-squares algorithm. Parameter projection. Persistence of excitation. Sufficient richness. Identifiers. Adaptive observers.

   (d) **Model Reference Adaptive Control.** MRC. Certainty equivalence principle. Direct MRAC for relative degrees one and two. General relative degree with unnormalized update law. Stability proof. Indirect MRAC.

   (e) **Pole Placement.** Plynomial approach (Bezout equations). State space approach (observer). Linear quadratic control (Riccati equation). Indirect schemes. Stability proof.

   (f) **Robust Update Laws.** Nonparametric uncertainties. Parameter drift. σ-modification. Projection. Dead-zone. Dynamic normalization. Robust algorithms.

   (g) **Robust Adaptive Control Schemes.** Model reference. Pole placement. Robustness proofs.