School of Mech & Aero Eng
Seoul National University

Fall '07

Advanced Flight Dynamics and Control: Multivariable Control Systems

Time. MW 2:30-3:45 pm
Room. Room 301, Bldg 301
Instructor. H. Jin Kim (`hjinkim@snu.ac.kr`)
Office Hours. M 4-6 pm (or email for appointments)
Office. Room 1305, Bldg 301
Course Web Site. `http://plaza.snu.ac.kr/~hjinkim/multivar_fall07`
Prerequisite. classical feedback control for single-input single output (SISO) systems, linear systems course

Overview

This course covers tools and methods for the analysis and synthesis of linear multivariable feedback systems. The emphasis is on contemporary control system design, connection between frequency domain and state space methods, systematic consideration of model uncertainty and closed loop performance, and convex analysis and design methods.

- **Analysis:** Given a controller, determine if desired properties are satisfied in the presence of noise, disturbance, and model uncertainties.
- **Synthesis:** Design a controller so that the desired properties are satisfied.
- Other considerations: mechanical design and sensor/actuator selection/placement to make a control problem easier.

Topics to be covered in the class include:
1. MIMO (multi-input multi-output) Systems
2. Linear Algebra Review
3. Standard Feedback Optimization Setup for LTI (linear time-invariant) Systems
4. H2 Optimization Problem and Design Examples
5. Robustness Analysis
6. H-Infinity Optimization Problem and Design Examples
7. Building Uncertain Models and Analysis of Uncertain Systems
8. Structured Singular Value and Design Examples
9. Convex Optimization
10. Linear Matrix Inequality

Reference. Lecture notes will be available on the course web site. Some contents are from various course materials offered at MIT, Stanford, Berkeley, Delft, KAIST, and some examples from Matlab toolboxes will be used. There is *no required textbook*, although the following reference will be helpful if you want to understand technical details:

Essentials of Robust Control by Kemin Zhou and John C. Doyle, Prentice Hall

Grading. Homework 30 %, In-class Exam 30 %, Project and In-class Activities 40 %

Notice.

1. We will extensively use MATLAB (the control systems and mu-synthesis toolboxes, and LMI control toolbox) for designing controllers, and analyzing/simulating systems. These were combined into Robust Control Toolbox, and you can find more information including a manual here:
`http://www.mathworks.com/products/robust/`

2. Please email me to get on the course mailing list, with the subject "[Multivar] email list". Include your name and a bit of your background such as Master or Ph.D., year, department, research area, and preparation so far.

3. Please refrain from using "`@hanmail.net`" accounts in email correspondents with me. I would appreciate if you put "[Multivar] ..." in the subject of all course-related email.

Introduction

0.1 What You Might Have Learned So Far

0.1.1 Classical Control:

- Stabilization: PID, lead/lag, additional compensation
- Performance: closed loop poles (loop gain bandwidth)
- Command Following: zero steady state error (high DC loop gain)
- Disturbance Rejection: large loop gain in spectrum of d
- Robustness: gain/phase margins

0.1.2 Modern Control

- Stabilization: Observer based control (observer + full state feedback with either pole placement or LQR)
- Performance: quadratic optimization index
- Command Following: Integral control
- Disturbance Rejection: ??
- Robustness: ??

0.2 A Bit of History

- Classical PID techniques - Optimality?
- 50's–70's : State-space techniques
  - optimal control
  - stochastic disturbance rejection (LQG)

  $\longrightarrow$ requires accurate signal/system description
- 70's–80's : Process Control
  - large plant-model mismatch
  - unclear nature of disturbances

  $\longrightarrow$ worst-case design
- 1981: Formulation of H_∞ problems (Zames)
- 1982: Robustness analysis (Safonov, Doyle)
- 1984: Operator theoretic solution of H_∞ problems (Francis, Doyle)
- 1989: Riccati solution of H_∞ problems
- 1990 –: Linear Matrix Inequalities

0.3 Multivariable Control

Multivariable control considers feedback control systems with multiple input and output variables (multi-input/multi-output, or MIMO, systems). More broadly, multivariable control means systematically addressing modelling, uncertainty, performance in control system design.

- Classical Control (frequency domain techniques): Feedback amplifier (Black), Nyquist criterion (Nyquist), Bode integral formula, gain/phase margin (Bode), Servomechanism (Hazen, James, Nichols, Phillips)
- Modern Control (state space methods): Stochastic control (Wiener), Nonlinear control (Popov), Optimal control (Bellman, Pontryagin, Kalman), Stability theory (Kalman), Geometric approach (Wonham)
- Robust Control (combination of frequency domain and state space): H_∞ Optimization (Zames), Robustness of MIMO systems, Robust performance, μ Synthesis (Doyle), Convex programming approach with linear matrix inequality (LMI) (Boyd)