

Multivariable Control  
CHFEN 7203: Robust Multivariable Control  
Spring 2002  
Department of Chemical & Fuels Engineering  
University of Utah

**DESCRIPTION:** The focus of this course is on *linear robust multivariable control*. We will emphasize the ability to solve control problems rather than mathematical theory. Nevertheless, this course will require a solid background in classical and state-space control methods and may be quite challenging to some students.

**CLASS OBJECTIVE:** At the end of the class, you should be able to independently formulate a robust control problem for MLTI systems and solve it using the **Robust Control** toolbox in **Matlab**.

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**HOURS:** MWF 9:40–10:30

**ROOM:** JTB 110 (James Talmage Building on Presidents Circle).

**OFFICE HOURS :** None scheduled. You are welcomed to stop by my office at any time. Send e-mail to schedule the meeting, if you want to make sure that I am available.

**PREREQUISITES:** There are no *formal* prerequisites. However, you are expected to have a good grasp of “classical” SISO control and have working knowledge of matrices, linear algebra and linear differential equations. You must be computer literate to take this class.

**COVERAGE:** The emphasis of this class is on the analysis and synthesis of multivariable control systems. Only linear systems will be covered. Both state-space and frequency domain methods will be used.

1. We will quickly review/introduce fundamentals of robust multivariable design - definitions, analysis and performance of multivariable linear time invariant systems, interactions, directionality and robustness of MLTI systems. This part of the course will take roughly one-third of the semester. We will then consider the shaping of sensitivity and complementary sensitivity of MLTI systems, specification of model and/or disturbance uncertainty and desired performance in terms of the generalized plant (linear fractional transformation framework).

2. We will use the second half of the semester to study controller design methods for MIMO systems. This includes LQR/LQG methods, frequency-weighted LQR/LQG design, minimax design as it relates to  $H_\infty$  and  $H_2$  design methods and, finally,  $H_2$  and  $H_\infty$  synthesis. Time permitting, we will also consider  $\mu$ -synthesis methods.

**TEXTBOOKS:** We will use both of the following books:

1. Sigurd Skogestad and Ian Postlethwaite, *Multivariable Feedback Control*. Wiley, 1996.
2. Kemin Zhou with John C. Doyle, *Essentials of Robust Control*. Prentice Hall, 1998.

**OTHER CONTROL TEXTS:**

J. M. MACIEJOWSKI *Multivariable Feedback Design*. Addison-Wesley.

A very good graduate text. It is probably the best reference for the Nyquist-like techniques, which we do not cover in this class

B. FRIEDLAND *Control System Design: An Introduction to State-Space Method*. McGraw-Hill.

This book gives a clear and complete coverage of state-space methods. Some of you probably used this book in your first graduate control class on state space methods.

W. F. RAMIREZ *Process Control and Identification*. Academic Press.

This is an alternative to the Friedland's book, which chemical engineering students may find very useful (lots of chemical engineering examples!).

DALE E. SEBORG, THOMAS F. EDGAR AND DUNCAN A. MELLICHAMP *Process Dynamics and Control*. Wiley.

This is the text I use in teaching undergraduate control to chemical engineering undergrads. However, as undergraduate control reference and refresher, the following book is better.

B. A. OGUNNAIKE AND W. H. RAY *Process Dynamics, Modeling and Control*. Oxford University Press.

**LINEAR SYSTEMS TEXTS:**

THOMAS KAILATH *Linear Systems*. Prentice-Hall.

A very good book.

B. P. LATHI *Linear Systems and Signals*. Berkeley-Cambridge Press.

Good comprehensive coverage of the subject.

**TEXTS ON MATRICES AND LINEAR ALGEBRA**

GENE H. GOLUB AND CHARLES F. VAN LOAN *Matrix Computations* 2 ed. John Hopkins University Press.

An excellent book.

ROGER A HORN AND CHARLES R. JOHNSON *Matrix Analysis*. Cambridge University Press.

An excellent book.

**SOFTWARE:** Matlab with Robust Control toolbox. Most homework assignments will require computer simulation.

**HOMEWORK ASSIGNMENTS :** I view this class as an opportunity to teach and discuss latest issues in multivariable control (as should be expected from the 7 thousand level class). I will try to adhere to the seminar-like style of teaching: I will give the theoretical background, simple examples and would like to see a lot of questions and discussion. I will use the homework assignments to make sure that we are on the same page, and to give you a change to apply the theory to the realistic (and thus open-ended) examples. Be innovative and courageous: I fully expect that your solutions will differ from mine. In fact, in some instances, you may only get a sketch of my own solution, or no solution at all!

**HOMEWORK GUIDELINES:** You are encourage to use a computer word processor to typeset your reports (not a requirement, though). If a homework requires computer simulation, you should include:

1. Statement of the problem.
2. Description of the solution strategy.
3. Commented program listing.
4. Presentation of results.

**GRADING GUIDE:** This is the guide that I usually use to grade undergraduate homework reports and it is included for your reference only. I will carefully read and comment on your reports. I will emphasize your understanding, clarity, completeness and creativity in solving the problems.

Even for undergraduate class, the following is only a guide and not a rigid formula for grading problems.

- 10 – Problem completely correct as intended or completely correct based on an interpretation which could be correctly inferred from the problem statement.
- 9 – Substantially correct and complete but a few minor errors such as arithmetic.
- 8 – Substantially correct and complete but several minor errors or a major error such as a bad assumption.
- 7 – Minimum passing grade. Demonstrates acceptable understanding of problem and knowledge of proper methods of solution, but solution not correct or not complete.
- 6 – Below passing. Appears to understand problem and have general idea of correct methods of solution.
- 5 – Understanding of problem and partially correct method of solution.
- 4 – Indication of understanding of problem. Wrong approach to solution.
- 3 – Understanding of problem; no solution.
- 2 – Partial understanding of problem.
- 1 – Something relevant on the paper which can not be found in problem statement.
- 0 – Nothing on paper that is not in problem statement.

**SOFTWARE:** Matlab is available on some PCs, MACs and on the Cade system. We also have the Matlab classroom license, which includes Robust Control toolbox.

**EXAMS:** We will only have the final take-home exam.

**CLASS PROJECT:** The class project for most of you will require that you pick (in consultation with the instructor) a recent article from a major internationally recognized journal focused on one of the practical or theoretical problems of control. You then should

1. thoroughly research the selected subject;
2. repeat the results reported in the article;
3. present your finding to the class;
4. turn-in your project report.

You will be graded based on your presentation, project report and your answers to the questions, which will follow your presentation.

An alternative is an experimental project, which will require to practically implement one of control algorithms learned in this class or described in the literature. We have a large number of processes controller by an industrial DCS (distributed control system). It will be fairly easy (but not trivial!) to implement selected control methods on one of the processes using DCS hardware and software. One day I hope to have a way to go from Matlab (or Simulink) directly to DCS, but we do not have that yet. Some of you have control-related research projects and work with control faculty in EE and ME departments. You may want to talk with your advisers to see if they can suggest interesting experimental projects. I know that Prof. Bodson has some cool experiments. I am sure Prof. Devasia will have good suggestions for you, too.

The key with experimental projects is to start early (after all, you will have to learn how to work with equipment, control hardware and software). See instructor for details.

**FINAL GRADE:** To determine the final grade, the following weighting will be used:

Final take-home exam:	40%
Homework:	30%
Class project:	30%

**ATTENDANCE:** No attendance will be kept.

**STUDENT FEEDBACK:** Comments and suggestions are welcomed.