McMaster University
Department of Electrical & Computer Engineering
EE4CL4: Control Systems Design

Winter 2009

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Catalog Description: Design of linear control systems using classical and state-space techniques; performance limitations; sampled-data control; nonlinear systems; multi-input multi-output control systems.

Lectures: Mo Th 09:30-10:20 ABB/271
Tu 10:30-11:20 ABB/271

Laboratories: Mo Tu 14:30-17:20 ITB/AB111

Tutorials: T01 Th 11:30-12:20 ABB/270 (location is subject to change)
T02 Th 11:30-12:20 ABB/162 (location is subject to change)

Prerequisite: ELEC ENG 3TP4 or ELEC ENG 3CK4

Objectives:
This course is concerned with the analysis and design of continuous-time linear feedback control systems. It will begin by introducing the concept of feedback and its fundamental properties. Control algorithms often use mathematical models of dynamical systems. Examples of such models will be provided. The concepts of stability and performance of control systems will be studied. Tools for stability and performance analysis in the time and frequency domains will be introduced. Finally, the students will be exposed to some classical linear control design techniques.

Textbook: Course notes are available at McMaster Bookstore.

Recommended Reading:
- R. C. Dorf and R. H. Bishop, *Modern Control Systems*, 11th edition, Pearson Prentice Hall, 2008. (available at McMaster Bookstore)
- G. F. Franklin, J. D. Powell and A. Emami-Naeini, *Feedback Control of Dynamic*

Systems, 4th edition, Prentice Hall Inc., 2002.
- K. Ogata, *Modern Control Engineering*, 4th edition, Prentice-Hall Inc., 2002.
- R.T. Stefani et.al., *Design of Feedback Control Systems*, 4th edition, Oxford University Press Inc., 2002.
- A.V. Oppenheim and A.S. Willsky, Signals and Systems, 2nd edition. Englewood Cliffs: Prentice-Hall Inc., 1996.

Evaluation:

Laboratories:	30%
Matlab Assignment:	10%
Mid-term Exam:	20%
Final Exam:	40%

Course Webpage: This course has a webCT-based page accessible through http://webct.mcmaster.ca/

Remarks:

Laboratories: There will be four laboratory experiments conducted by groups of three students every other week. The students must attend the lab sessions, demonstrate the results of their experiments to the TAS, and provide a report per group for each experiment. There may be quizzes in the beginning of some of the lab sessions. The students should form their groups within the first two weeks of the course. More information about the experiments including the lab manuals will become available as the term progresses.

Assignments: One comprehensive Matlab assignment will be given in mid-March which will constitute 10% of the final grade. There will also be problem sets handed out in the class for the purpose of exercise. These problems are intended to clarify the material covered in the lectures and possibly to introduce new concepts. Some of the problems will be discussed in the tutorial sessions.

Deferred Exams: THE INSTRUCTOR RESERVES THE RIGHT TO CHOOSE THE FORMAT OF ANY DEFERRED MIDTERMS OR DEFERRED FINAL EXAMS (I.E. FORMAT MAY BE WRITTEN OR ORAL)

Detailed Course Content:

- **Introduction**

  Examples of control systems
  Terminology in control

- **Mathematical Modeling of Systems**
  Linear systems and differential equations
  Laplace transform and transfer functions
  Block and signal flow diagrams
  Mason's gain formula
  Modeling approaches
    system identification
    analytical modeling based upon the laws of physics
  Modeling examples from electrical and mechanical systems
  Linearization of nonlinear dynamics

- **Analysis of Feedback Control Systems**
  Classical linear controllers
  Special inputs and responses (impulse, step, ramp, sinusoidal)
  First-order systems (time constant, final value)
  Second-order systems (under-damped, critically-damped and over-damped responses)
  Higher order systems and order reduction
  Steady-state errors and system type
  Wonham's Internal Model Principle
  Frequency response of linear systems
    Bode Diagram
    Nyquist diagram
    Nichols chart

  Performance specifications in frequency domain
    Open-loop versus closed-loop
    Input tracking and disturbance rejection

- **Stability of Linear Control Systems**

  Bounded Input-Bounded Output (BIBO) stability
  Routh-Hurwitz stability criterion
  Stability analysis in frequency domain
    The principle of argument
    Nyquist theorem
      gain and phase margins

- **Root Locus Technique**

  The concept of root locus
  Rules for sketching root locus plots
  Performance and stability analysis using root locus

- **Design of Controllers for Linear Systems**

Design specifications:
Tracking performance, disturbance rejection, noise reduction, reduced sensitivity to parameter variations
Robust stability
Controller design in frequency domain
Lead, Lag and Lead-Lag compensators
Root locus design
Lead, Lag and Lead-Lag compensators
PID controllers

- **State-space Models and Design Techniques**

State variable representation of dynamic systems
Block diagram representation of the state space models
Time response and state transition matrix
Concepts of controllability and observability
Linear quadratic regulator (LQR) design
Pole placement

Policy Reminders:

"The Faculty of Engineering is concerned with ensuring an environment that is free of all adverse discrimination. If there is a problem, that cannot be resolved by discussion among the persons concerned, individuals are reminded that they should contact the Department Chair, the Sexual Harassment Officer or the Human Rights Consultant, as soon as possible."

"Students are reminded that they should read and comply with the Statement on Academic Ethics and the Senate Resolutions on Academic Dishonesty as found in the Senate Policy Statements distributed at registration and available in the Senate Office."

"Academic dishonesty consists of misrepresentation by deception or by other fraudulent means and can result in serious consequences, e.g. the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: "Grade of F assigned for academic dishonesty"), and/or suspension or expulsion from the university. It is your responsibility to understand what constitutes academic dishonesty. For information on the various kinds of academic dishonesty please refer to the Academic Integrity Policy, specifically Appendix 3, located at
http://www.mcmaster.ca/senate/academic/ac_integrity.htm

The following illustrates only three forms of academic dishonesty:

1. **Plagiarism, e.g. the submission of work that is not one's own or for which other credit has been obtained.**
2. **Improper collaboration in group work.**
3. **Copying or using unauthorized aids in tests and examinations."**