

ENEE 661: Nonlinear Control Systems (Tu-Th 3:30-4:45 pm, spring 2010, CSI 2117)
Course website <http://www.enee.umd.edu/courses/enee661.S2010/>

Instructor: P. S. Krishnaprasad (krishna@isr.umd.edu; 301-405-6843); office in A.V. Williams Building - room 2233. Office hours: M 5:00-7:00 and Tu 5:00 -7:00.

Course Goals: This course is intended to introduce the student to the analysis of the *qualitative* behavior of nonlinear systems, and the synthesis and design of controllers for such systems. Concepts centered on equilibria, periodic orbits, and steady-state response of input-output systems will be discussed. Techniques include Lyapunov's direct method, linearization, frequency domain stability analysis, and functional analysis methods. Additionally, techniques with a geometric flavor, including center manifold reduction, Lie-algebraic approaches to nonlinear control systems, and elementary bifurcation analysis will be introduced. We will also discuss nonlinear oscillations and averaging theory at an introductory level. Examples from physics, engineering and biology will be used throughout the course (see next page for details).

Course Prerequisite: ENEE 660 or equivalent, or permission of instructor. A prior course in advanced calculus (e.g. MATH 410 or MATH 411) is recommended. A good course in differential equations would also serve as adequate mathematics background.

Topic Prerequisite: It is desirable that the student be familiar with basic concepts and tools from linear system theory including, the Nyquist criterion, matrix exponentials and the variation of constants formula, controllability, observability and stabilizability. It would be helpful (but not essential) to be familiar with normed vector spaces, the Inverse Function Theorem, and the Implicit Function Theorem. We will cover these items.

References:

- (a) H.K. Khalil, *Nonlinear Systems*, Prentice Hall, 3rd ed., Englewood Cliffs, 2002 (**this is the textbook**).
 - (b) S. Sastry, *Nonlinear Systems: Analysis, Stability and Control*, Springer-Verlag (series in interdisciplinary applied mathematics), New York, 1999.
 - (c) M. Vidyasagar, *Nonlinear Systems Analysis*, 2nd ed., Prentice Hall, Englewood Cliffs, 1993.
- For mathematical background on advanced calculus, we recommend
- (d) A. Avez, *Differential Calculus*, Springer-Verlag, New York, 1986.
- For background material on frequency domain methods in linear systems, see
- (e) G. F. Franklin, J. D. Powell and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 2nd edition, Addison-Wesley, Reading, 1991.
- For background material on state space theory of linear systems, see
- (f) T. Kailath, *Linear Systems*, Prentice Hall, Englewood Cliffs, 1980,
 - (g) W. J. Rugh, *Linear System Theory*, Prentice Hall, Englewood Cliffs, 1993.

Core Topics:

1. Existence, uniqueness and continuous dependence on initial conditions of solutions to ordinary differential equations.
2. Lyapunov's direct method for time-invariant and time-varying systems; Stability and instability results of Lyapunov and Chetaev; Lasalle's Invariance Principle.
3. Regions of attraction and their estimation, matrix Lyapunov equation.
4. Linearization Theorem, stability and instability results.
5. Linearization Theorem for periodic systems, Floquet theory.
6. Input-output stability and the Small Gain Theorem, and passivity.
7. Absolute stability (Circle and Popov criteria), and passivity.
8. Stabilization using state feedback (via linearization).
9. Periodic orbits and orbital stability.

Additional Topics (a selection from) Volterra series representation; relative degree and zero dynamics; bifurcations; perturbation theory and averaging; singular perturbations; models of hysteresis; applications in robotics; orbital mechanics; evolutionary games.

Grading: Weekly homework sets (10%), Mid-term Examination I on Tuesday, February 23 (25%), Mid-term Examination II on Tuesday, April 6 (25%), and Final Examination (40%) to be held in two parts – in class, Wednesday May 19, 10:30 a.m. – 12:30 p.m., and **take home** the same evening for a maximum of 5 hours of work. The mid-terms and the in-class part of the final examination will be of the closed-book variety.