ENEE 661: Nonlinear Control Systems (Tue-Thu 2:00-3:15, spring 2008, EGR 1110)
Course website http://www.ece.umd.edu/courses/enee661.S2008/
Instructor: P. S. Krishnaprasad (krishna@isr.umd.edu; 301-405-6843). Office is in A.V. Williams Building - room 2233. Office hours: M 5:00-7:00 and Tue 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, 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. In spring 2008, we will also discuss nonlinear oscillations and averaging theory at an introductory level.* Plenty of examples from physics, engineering and biology will be used throughout the course. (See next page for details)

Course Prerequisite: ENEE 460 or equivalent. Co-requisite ENEE 663 (now ENEE 660) or permission of instructor. A prior course in advanced calculus (e.g. MATH 410) 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.

The mathematical background can be found in any standard textbook on advanced calculus. We also strongly 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: Feedback linearization and Lie brackets. Volterra series representations. Relative degree and zero dynamics. Bifurcations. Perturbation theory and averaging. Singular perturbations. Models of hysteresis. Applications in robotics, orbital mechanics and space mission design, chaotic circuits, evolutionary games.

Grading: Weekly homework sets (30%), Mid-term Examination on Thursday March 13 (30%), and Final Examination (40%) to be held in two parts – in class, Monday 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-term and the in-class part of the final examination will be of the closed-book variety.