AME552: Nonlinear Control Systems

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Grading: The final grade will be calculated according to the following formula:

Homework+Projects:	*20%*
Midterm Examination (March 4):	*30%*
Final Examination: (May 6 4:30-6:30)	*50%*

Homework will be assigned every week on Thursday and **must** be submitted the following Thursday with **no** exceptions !

Textbook: H. K. Khalil *Nonlinear Systems*, Third Edition, Prentice-Hall., 2002

Reference Books:

1. H. J. Marquez, *Nonlinear Control Systems: Analysis and Design,* John Wiley Interscience, 2003.
2. J. J. Slotine and W. Li *Applied Nonlinear Control*, Prentice-Hall, 1991.
3. M. Vidyasagar, *Nonlinear Systems Analysis,* SIAM, 2002
4. J. E. Gibson *Nonlinear Automatic Control*, McGraw-Hill,1963.
5. J. C. Hsu and A. V. Meyer *Modern Control Principles and Applications*, McGraw-Hill, 1968.
6. D. Graham and D. McRuer *Analysis Of Nonlinear Control Systems*, John Wiley 1961 (also Dover edition 1971).
7. G. J. Thaler and M. P. Pastel *Analysis and Design of Nonlinear Feedback Control Systems*, McGraw-Hill, 1962.
8. C. A. Desoer and M. Vidyasagar *Feedback Systems: Input- Output Properties*, Academic Press, 1975.

Course Outline

1. **Introduction**
   (a) State-space representation of nonlinear systems
   (b) Basic characteristics of nonlinear systems.
2. **Second Order Systems (Phase plane analysis)**
   (a) Classification of equilibrium points.
   (b) Systems with multiple equilibria
   (c) Analysis of piecewise linear control systems
      i. Feedback systems in standard form
      ii. Classification of nonlinearities
   (d) Applications
      i. Servomechanism with variable gain
      ii. Servomechanism with Coulomb friction
      iii. Servomechnism with deadzone and with delay
      iv. Pulse control of spacecraft
      v. Digital autopilot control of the Shuttle.
3. **Describing function analysis**
   (a) The principle of harmonic balance.
      i. Describing functions for various nonlinearities.
   (b) Stability of limit cycles by describing function method.
   (c) Limit cycle analysis of control systems.
4. **Lyapunov Stability Theory**
   (a) Mathematical preliminaries
      i. Linear vector spaces
         A. Norms and inner products
         B. Normed and inner product spaces
      ii. Nonlinear differential equations
         A. Existence and uniqueness
   (b) Lyapunov's direct method
      i. Definite functions
      ii. Stability and instability theorems
   (c) La Salle theorems
   (d) Stability of linear systems

i. Lyapunov equation for time-invariant systems.
ii. Stability conditions for time varying systems.

(e) Lyapunov's linearization (indirect) method

(f) Region of attraction

(g) Frequency Domain Analysis of Feedback Systems

i. Absolute stability (Lure) problem
ii. Kalman-Yakubovitch lemma.
iii. Circle criterion.
iv. Popov's theorem.

5. **Nonlinear Control Design Methods**

(a) Sliding Mode Control

(b) Robust Control of Nonlinear Systems

(c) Backstepping

6. **Feedback Linearization**

(a) Lie derivatives and Lie brackets

(b) Input-state linearization of SISO systems

(c) Input-output linearization of SISO systems

7. **Input-Output Stability**

(a) Function spaces

(b) Input-output stability

(c) Small-gain theorem

i. Circle criterion

(d) Passivity

i. Circle criterion
ii. Popov criterion

(e) Dissipativity

i. Storage Functions
ii. Stability of dissipative systems

(f) Control design using input-output methods