

AME552: Nonlinear Control Systems

Instructor: *H. Flashner*
Office: *Olin Hall 430E*
Office Hours: *Tu 2-4*
Phone: *(213) 740-0489*
e-mail: *hflashne@usc.edu*

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

Homework+Projects: 20%
Midterm Examination: 30%
Final Examination: 50%

Homework will be assigned every week and **must** be submitted the following week 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. Servomechanism 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