

Syllabus for AMS 231

Introduction to Nonlinear Control Theory - Spring 2005

Jorge Cortés

May 6, 2005

This is the Syllabus for AMS 231 - Introduction to Nonlinear Control Theory, Spring 2005. This course covers the analysis and design of nonlinear control systems using Lyapunov theory and geometric methods. The contents of the course include properties of solutions of nonlinear dynamical systems (with special emphasis on planar systems), Lyapunov stability analysis techniques, effects of perturbations, input-output stability, feedback linearization, controllability, observability, and nonlinear control design tools for stabilization.

Instructor

Jorge Cortés, `jcortes` at `ucsc.edu`. Office at Baskin Engineering, # 147

Course Objectives

By the end of the course, you would/should have:

1. learned and used various tools for the analysis and control of nonlinear systems.
2. got a feeling and gained insight into the complexity of nonlinear systems.
3. known and played around with a wide variety of interesting, inherently nonlinear examples.

Prerequisites

Basic knowledge of calculus, linear algebra and ordinary differential equations is assumed. You will benefit from having familiarity with Matlab/Mathematica/Maple.

Text

Our main references will be

- H. K. Khalil. *Nonlinear Systems*. Prentice Hall, Englewood Cliffs, NJ, second edition, 1995
- S. S. Sastry. *Nonlinear Systems: Analysis, Stability and Control*. Interdisciplinary Applied Mathematics. Springer Verlag, New York, 1999

They should be available at the Bay Tree Bookstore.

Additional recommended texts and readings

You will also find great insight in

- H. Nijmeijer and A. J. van der Schaft. *Nonlinear Dynamical Control Systems*. Springer Verlag, New York, 1990
- A. Isidori. *Nonlinear Control Systems*. Springer Verlag, New York, third edition, 1995
- E. D. Sontag. *Mathematical Control Theory: Deterministic Finite Dimensional Systems*, volume 6 of *TAM*. Springer Verlag, New York, second edition, 1998
- F. Bullo and A. D. Lewis. *Geometric Control of Mechanical Systems*, volume 49 of *Texts in Applied Mathematics*. Springer Verlag, New York, 2004

Calendar (this version: May 6, 2005)

Date	Topics	Reading	Tests & Deadlines
(1st wk) Mar 29 Mar 31	Syllabus and intro Planar systems	Sastry-Ch.1, Khalil-Ch.1 Sastry-Ch.2, Khalil-Ch.2	
(2nd wk) Apr 5 Apr 7	Bifurcations Math. preliminaries	Sastry-Ch.2, Khalil-Ch.2 Sastry-Ch.3, Khalil-Ch.3	
(3rd wk) Apr 12 Apr 14	Lyapunov stability	Sastry-Ch.5, Khalil-Ch.4	<i>Hmwk #1 due on 4/12</i>
(4th wk) Apr 19 Apr 21			
(5th wk) Apr 26 Apr 28	Input-output stability	Sastry-Ch.4, Khalil-Ch.5 Sastry-Ch.4, Khalil-Ch.6	<i>Hmwk #2 due on 4/26</i>

End Part I

Midterm			<i>Tuesday, May 3</i>
---------	--	--	-----------------------

(6th wk) May 5	Passivity	Sastry-Ch.6, Khalil-Ch.12	
(7th wk) May 10 May 12	Feedback control Feedback linearization	Sastry-Ch.9, Khalil-Ch.13	
(8th wk) May 17 May 19			<i>Hmwk #3 due on 5/17</i>
(9th wk) May 24 May 26	No class Geometric control	Sastry-Ch.8	
(10th wk) May 31 Jun 2		Sastry-Ch.11	<i>Hmwk #4 due on 5/31</i>

End Part II

Final			<i>Monday, June 6 7:30pm - 10:30pm</i>
-------	--	--	--

Contents

We will cover the following topics along the course. Time permitting, we could expand on advanced stability techniques, perturbed systems and geometric control:

1. (Linear versus nonlinear systems)”

Nonlinear phenomena, multiple equilibria, limit cycles, complex dynamics, manifolds as state space, linearization methods for nonlinear systems, some classical examples.

(Sastry, Ch.1; Khalil, Ch.1)

2. (Planar dynamical systems):

Phase plane techniques, limit cycles, Poincaré-Bendixon theorem, multiple equilibria, index theory, bifurcations (fold, pitch, fork, Hopf, saddle connection).

(Sastry, Ch.2; Khalil, Ch.2)

3. (Mathematical preliminaries):

Ordinary differential equations, control systems, solutions of initial value problems, existence and uniqueness of solutions, continuous dependence on initial conditions and parameters, differential equations with discontinuities, (time-dependent) vector fields, flows, introduction to differential topology.

(Sastry, Ch.3; Khalil, Ch.3)

4. (Lyapunov stability):

Definitions of (in)stability, basic (in)stability theorems, converse Lyapunov theorems, LaSalle Invariance Principle, exponential stability theorems, linear systems, feedback stabilization.

(Sastry, Ch.5; Khalil, Ch.4)

5. (Input-output stability):

Definitions of input-output stability, small gain theorems, passivity, passivity theorems, describing functions, harmonic balance, connections with state space stability.

(Sastry, Ch.4; Khalil, Chs.5, 6)

6. (Feedback linearization):

SISO systems, input-output linearization, full state linearization, zero dynamics, applications to inversion, tracking and stabilization, MIMO systems, linearization by state feedback, full state linearization, dynamic extension, sliding mode, robust linearization.

(Sastry, Chs.6, 9; Khalil, Chs.12, 13)

7. (Geometric nonlinear control):

Basics of differential geometry, tangent spaces, distributions and codistributions, Frobenius theorem, controllability concepts, driftless control systems, Chow's theorem, observability concepts, local decompositions, controlled invariant distributions and disturbance decoupling.

(Sastry, Chs.8, 11)

Homework

There will be a set of homework problems every other week. Homework assignments will be due every other Tuesday before the beginning of class. No late homework will be accepted.

Grading policy

Homework: 40%

Midterm: 30%

Final exam: 30%

In exceptional cases, I reserve the right to give extra points for excellent performance on the midterm and final. Please do not count on it as a way to avoid doing the other assignments.

Room location and hours

Lectures take place at Porter Acad, room 250, Tuesdays and Thursdays, from 6:00pm to 7:45pm.

Office hours

Instructor: Wednesdays, from 1:00pm to 2:00pm at BE 147. Please, send me email describing the problem before coming to office hours. Be prepared to show attempts at solving the problem.

If you have any questions about the course, please send me email. I will try to respond as quickly as possible. Additionally, I will share questions that are particularly good (and their answers) with the rest of the class by broadcasting my answer to the entire class.

Course webpage

<http://www.soe.ucsc.edu/classes/ams231/Spring05/>

The webpage contains this syllabus, the list of homework due and the list of scores. Please check it periodically for updates and other announcements related to the course.

Protected material (if any) can accessed using the login `ams231` and a password that will be provided in class.