Preface

There has been a great deal of excitement in the last ten years over the emergence of new mathematical techniques for the analysis and control of nonlinear systems: Witness the emergence of a set of simplified tools for the analysis of bifurcations, chaos, and other complicated dynamical behavior and the development of a comprehensive theory of geometric nonlinear control. Coupled with this set of analytic advances has been the vast increase in computational power available for both the simulation and visualization of nonlinear systems as well as for the implementation in real time of sophisticated, real-time nonlinear control laws. Thus, technological advances have bolstered the impact of analytic advances and produced a tremendous variety of new problems and applications that are nonlinear in an essential way. Nonlinear control laws have been implemented for sophisticated flight control systems on board helicopters, and vertical take off and landing aircraft; adaptive, nonlinear control laws have been implemented for robot manipulators operating either singly, or in cooperation on a multi-fingered robot hand; adaptive control laws have been implemented for jet engines and automotive fuel injection systems, as well as for automated highway systems and air traffic management systems, to mention a few examples. Bifurcation theory has been used to explain and understand the onset of flutter in the dynamics of aircraft wing structures, the onset of oscillations in nonlinear circuits, surge and stall in aircraft engines, voltage collapse in a power transmission network. Chaos theory has been used to predict the onset of noise in Josephson junction circuits and thresholding phenomena in phase-locked loops. More recently, analog computation on nonlinear circuits reminiscent of some simple models of neural networks hold out the possibility of rethinking parallel computation, adaptation, and learning.

It should be clear from the preceding discussion that there is a tremendous breadth of applications. It is my feeling, however, that it is possible at the current time to lay out in a concise, mathematical framework the tools and methods of analysis that underly this diversity of applications. This, then, is the aim of this book: I present the most recent results in the analysis, stability, and control of nonlinear systems. The treatment is of necessity both mathematically rigorous and abstract, so as to cover several applications simultaneously; but applications are sketched in some detail in the exercises.

The material that is presented in this book is culled from different versions of a one-semester course of the same title as the book that I have taught once at MIT and several times at Berkeley from 1980 to 1997. The prerequisites for the first year graduate course are:

- An introduction to mathematical analysis at the undergraduate level.
- An introduction to the theory of linear systems at the graduate level.

I will assume these prerequisites for the book as well. The analysis prerequisite is easily met by Chapters 1–7 of Marsden's *Elementary Classical Analysis*, (W. H. Freeman, 1974) or similar books. The linear systems prerequisite is met by Callier and Desoer's *Linear Systems Theory*, (Springer Verlag, 1991) or Rugh's *Linear System Theory*, (Prentice Hall, 1993), Chen's *Linear System Theory and Design*, (Holt Reinhart and Winston, 1984); or Kailath's *Linear Systems*, (Prentice Hall, 1980) or the recent *Linear Systems* by Antsaklis and Michel, (McGraw Hill, 1998).

I have never succeeded in covering all of the material in this book in one semester (45 classroom hours), but here are some packages that I have covered, along with a description of the style of the course

- *Analysis, Stability and some Nonlinear Control*
  Chapters 1–7 and part of Chapter 9.
- *Analysis, Some Stability and Nonlinear Control*
  Chapters 1–3, 5–6 followed by Chapters 9, 10 with supplementary material from Chapter 8.
- *Mathematically Sophisticated Nonlinear Control Course*
  Chapters 1, 2, 4, 5–7, with supplementary material from Chapter 3, and Chapters 9–11 with supplementary material from Chapter 8.

Alternatively, it is possible to use all the material in this book for a two-semester course (90 classroom hours) on nonlinear systems as follows:

- (45 hours Semester 1) Chapters 1–7.
- (45 hours Semester 2) Chapters 8–12.

For schools on the quarter system, 80 classroom hours spread over two quarters can be used to cover roughly the same material, with selective omission of some topics from Chapters 3, 6, and 7 in the first quarter and the omission of some topics from Chapters 8, 11, and 12 in the second quarter. A shorter 60 classroom hour long two quarter sequence can also be devised to cover

1. (30 hours) Introductory course on Nonlinear Systems. Chapters 1, 2, 3 (Sections 3.1—3.5), Chapter 4 (Sections 4.1—4.6), and Chapter 5.

2. (30 hours) Intermediate course on Nonlinear Control. Chapter 3 (Section 3.9), Chapter 8, Chapter 9, 10, and parts of Chapter 11.

The structuring of courses at Berkeley favors the two semester structure, with the first course for second-semester graduate students (taught in the spring semester), and the second course called “Advanced Topics in Nonlinear Control” for second-year graduate students (taught in the fall). However, I wish to emphasize that we frequently see undergraduate students taking this course and enjoying it.

Access to a simulation package for simulating the dynamics of the nonlinear systems adds a great deal to the course, and at Berkeley I have made available Matlab, Simnon and Matrix-X at various times to the students as simulation toolkits to use to help stimulate the imagination and help in the process of “numerical experimentation.” While I have usually had take home final examinations for the students, I think that it is useful to have “project-based” final examinations with numerical examples drawn from a set of particularly topical applications. A word about the problem sets in this book; they are often not procedural, and frequently need thought and sometimes further reference to the literature. I have found that this is a nice way to draw oneself into what is a very exciting, dynamic and rapidly evolving area of research. I have included these also because over the years, it has been a pleasant surprise to me to see students solve problem sets based on the archival literature with ease, when they are given adequate background. I have chosen applications from a wide variety of domains: mechatronic systems, classical mechanical systems, power systems, nonlinear circuits, neural networks, adaptive and learning systems, flight control of aircraft, robotics, and mathematical biology, to name some of the areas covered. I invite the reader to enjoy and relate to these applications and feel the same sense of scientific excitement that I have felt for the last twenty odd years at the marvels and mysteries of nonlinearity.

The author would be grateful for reports of typographic and other errors electronically through the WWW page for the book:
`robotics.eecs.berkeley.edu/~sastry/nl.book`
where an up to date errata list will be maintained along with possible additional exercises.

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