Lynch, Stephen

Dynamical systems with applications using MATLAB. (English) Zbl 1066.37001

Boston, MA: Birkhäuser (ISBN 0-8176-4321-4/pbk). xv, 459 p. (2004).

This book is an introduction to the theory of discrete and continuous dynamical systems with the aid of the numerical software MATLAB (and Simulink) including its Symbolic Math Toolbox. The intention of the author was to cover a broad field of topics, "rather than fine detail", and therefore, "theorems with proofs have been kept to a minimum" (from the introduction). The text has a definite applied flavor and is driven by a variety of examples from many disciplines like biology (population dynamics, epidemiology), chemistry (reaction kinetics), economics or physics (electric circuits, nonlinear optics).

As a basic principle, these examples are investigated with MATLAB and over 60 programs are listed throughout the book. The source code of these programs can be downloaded from the web as well. No advanced techniques or prerequisites from, e.g., functional analysis are needed to understand the book and beyond mathematicians, the text is also readable for applied scientists and engineers.

Concerning a formal description, the book consists of 18 chapters, supplemented by a quick tutorial introduction to MATLAB by example (Chapter 0), as well as solutions to the exercises. Very systematically, each chapter begins with a description of its aims and objectives, and is closed by a listing of MATLAB programs and a set of exercises. The first 6 chapters deal with discrete dynamical systems, followed by 10 chapters on continuous dynamical systems, and a finale about neural networks.

Chapter 1 deals with linear difference equations including applications to the Leslie model from population dynamics, and Chapter 2 uses some features connected with the iteration of maps (period doubling, a heuristic notion of chaos, Feigenbaum universality) to introduce nonlinear dynamical systems. These ideas are extended to complex iterative maps in Chapter 3, in order to understand fractals like Julia sets or the Mandelbrot set. An application of the methods introduced so far (e.g., a linear stability analysis) to electromagnetic waves and optical resonances can be found in Chapter 4. Fractals generated by iterated function systems are discussed in Chapter 6, as well as concepts like fractal dimensions or a multifractal formalism. The part of the book concerned with discrete dynamical systems is closed by Chapter 6 on different methods to "control", that is to avoid chaotic behavior of a given system.

The second part of the book begins with an elementary introduction into ordinary differential equations (Chapter 7). Results on autonomous planar systems can be found in Chapter 8, starting with the linear theory (canonical forms), over the Hartman-Grobman linearization theorem, to methods to obtain phase portraits of nonlinear systems using isoclines, direction fields and linearization. These techniques are applied to biological models in Chapter 9 (predator-prey, competing species). Chapter 10 deals with limit cycles and contains the Poincaré-Bendixson theorem and Bendixson's criterion. Basic concepts from Hamiltonian systems and stability theory (including Lyapunov functions) can be found in Chapter 11, and local bifurcation phenomena (saddle-node, transcritical, pitchfork, Hopf) are featured in the following Chapter 12. While the continuous theory so far dealt with autonomous systems of dimension less than 2, Chapter 13 provides linear theory and a statement of the center manifold theorem in three dimensions, as well as a discussion of chaos in, e.g., the Lorenz and Rössler system. Chapter 14 introduces the Poincaré map to investigate periodic nonautonomous systems in the plane, as well as a brief discussion of Hamiltonian systems with two degrees of freedom and Smale's horseshoe map. Local and global bifurcations are considered in Chapter 15, including Melnikov functions to determine the number and location of limit cycles for small parameters. Finally, Chapter 16 gives a really nice and instructive approach to (the second part of) Hilbert's 16th problem on the number of limit cycles of a planar polynomial system, where the Liénard equation is used as example.

The book closes with an introduction to neural networks and neurodynamics in Chapter 17, and to the simulation tool Simulink in Chapter 18.

As audience for the book, the reviewer sees graduate students of natural sciences and engineering. For people with a primarily mathematical interest, one can recommend the book as supplement to introductory texts on the mathematical theory of dynamical systems by, e.g., [D.K. Arrowsmith and C.M. Place, Dynamical systems. Differential equations, maps and chaotic behavior. London: Chapman & Hall (1992, Zbl 0754.34001)], [J. Guckenheimer and P. Holmes, Nonlinear oscillations, dynamical systems, and bifurcations of vector fields. Applied Mathematical Sciences, 42, New York etc. Springer Verlag: (1983; Zbl 0515.34001)], [J.K. Hale and H. Koçak, Dynamics and bifurcations. Texts in Applied Mathematics, 3, New York etc.: Springer Verlag, XIV (1991, Zbl 0745.58002)] or [S. Wiggins, Introduction to applied nonlinear dynamical systems and chaos. 2nd ed., Texts in Applied Mathematics, 2, New York NY: Springer, IXI (2003; Zbl 1027.37002)], which feature a more extensive bibliography and perspectives to modern questions of nonautonomous or infinite-dimensional nature.

Reviewer: Christian Poetzsche (Minneapolis)

MSC:

37-01 Introductory exposition (textbooks, tutorial papers, etc.) pertaining to dynamical systems and ergodic theory
34-01 Introductory exposition (textbooks, tutorial papers, etc.) pertaining to ordinary differential equations
37-04 Software, source code, etc. for problems pertaining to dynamical systems and ergodic theory
34-04 Software, source code, etc. for problems pertaining to ordinary differential equations

Keywords:

dynamical systems; differential equations; MATLAB; limit cycles; Poincaré map; bifurcation; stability; fractals; chaos control; neural networks; examples from many disciplines

Software:

Matlab