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BOOK REVIEW

Nonlinear and Adaptive Control of Complex Systems

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During the last decades, nonlinear control became a field of growing interest. The reason is twofold. Firstly, new achievements of nonlinear control theory combining Lyapunov and geometric methods strengthened its power. Secondly, new demands for high performance control arose in science and engineering. Nonlinearity plays especially strong role in control of mechanical systems such as cars, robots, vibrational units, helicopters, ships, etc. Many of those systems are characterized by high level of complexity: high dimension of the state space, multiple inputs and outputs, parametric uncertainty, unmodeled dynamics.

The book provides an exposition of nonlinear control methodology taking into account all the above factors of complexity. It consists of nine chapters.

In the introductory chapter (Chapter 1) some peculiarities of control problems for complex systems are discussed, and motivating examples from different fields of science and technology are presented.

Chapter 2 presents some results of nonlinear control theory facilitating reading subsequent chapters. The main concepts of stability theory are introduced, and issues of nonlinear coordinate changes, canonical forms and controllability are addressed. Different design techniques are considered based on linearization, stabilization, and passification of nonlinear dynamical systems.

Chapter 3 gives an exposition of the so-called speed-gradient method and its applications to nonlinear and adaptive control. This method proposed in the 70s is studied in the Russian literature. Convergence and robustness properties are examined. Problems of regulation, tracking, partial stabilization and control of Hamiltonian systems are considered.

In Chapter 4, the notions of invariant set and nontrivial attractor are introduced and studied for regular hypersurfaces. Then, the methodology of system analysis in the state space and design tools for equilibrium and set stabilization, as well as tracking control for nonlinear multivariable systems with several controlling inputs, are presented.

In Chapter 5, multi-dimesional problems of output regulation, coordinating control and curve/surface following are examined. Unlike the previous parts, the emphasis here is placed on the output space where the majority of the real problems are initially stated.

In Chapter 6, basic design methods of adaptive, robust adaptive and robust nonlinear control of uncertain plants are presented in the form of unified design tools. Various methodologies are discussed, including recursive design, augmented error based design, high-order tuner based design, and reduced order reference model design. The methods described in the chapter help system designer to overcome structural obstacles caused by violation of matching conditions or by high relative degree of the controlled plant. Applicability of the introduced design tools is illustrated by example of output-feedback control problem for uncertain single-input/single-output linear systems.

Decomposition methods in adaptive control based on separation of slow and fast motions in the system are studied in Chapter 7. Convergence conditions and accuracy estimates of decomposition for singularly perturbed and discretized systems are presented. An approach to decentralized adaptive control of nonlinear systems based on speed-gradient method is described and justified.

Chapter 8 is devoted to applications related to stabilization of the desired spatial motion of complex mechanical systems. Different systems described by the Newton, Euler and Lagrange equations are considered starting from the rigid body, which is the basis for further consideration of multi-body mechanical systems such as multi-link manipulation robots and multi-drive wheeled mechanisms. Also, energy control algorithms for oscillatory mechanical systems (controlling pendulum with moving pivot and wheeling a car out of a ditch) based on the material of Chapter 3 are presented.

In Chapter 9, the relations between control and physics are discussed. New concepts ‘feedback resonance’, ‘excitability index’ are introduced serving to better understanding of nonlinear nearly conservative systems under feedback action. The speed-gradient method of Chapter 3 is applied both to organize resonant system behavior and to reformulate the laws of dynamics for a wide class of physical systems. Applications to escape from a potential well, stabilization of unstable modes, feedback spectroscopy, and derivation of the Onzagger principle are given. This chapter outlines an interesting field of research which the authors call ‘cybernetical physics’.

Summing up, the authors present a number of original concepts and methods: set (submanifold) stabilization and coordinating control, speed-gradient control and adaptation algorithms, systems with implicit reference models, simplified robust modifications of high-order tuners and others. The volume includes a variety of motivating and numerical examples, as well as a detailed study of control problems in complex mechanisms (manipulators and wheeled robots) and physical systems.

A characteristic feature of the Authors’ approach is the combination of rigorous concepts and methods of nonlinear control (coordinate changes, invariant submanifolds and attractors, Lyapunov functions, exact linearization, passification) with flexible tools of partial linearization and approximate decomposition.

Some results published previously in the Russian literature and not well known in the West are brought to the light. Particularly, these are some results in adaptive control as well as recent results on partial stabilization – the fields where the Russian school traditionally have strong positions.

The reader should be familiar with standard university courses of calculus, linear algebra and ordinary differential equations. More advanced notions are explained in the text.

The book will be useful for researchers, engineers, university lecturers, and postgraduate students specializing in the fields of automatic control, mechanics, and applied mathematics. Its style is sometimes verbose and may seem difficult for practical engineers because of mathematical details. However, it introduces new ideas and efficient design methods that may be useful for important applications, particularly for control of mechanical systems. It makes a valuable addition to the existing literature on nonlinear, multivariable, adaptive and robust control.

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