ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

automatica

Automatica ▮▮▮ (▮▮▮▮) ▮▮▮–▮▮▮

www.elsevier.com/locate/automatica

Book review

Nonlinear and Adaptive Control of Complex Systems
Alexander L. Fradkov, Iliya V. Miroshnik and Vladimir O. Nikiforov, Kluwer Academic Publishers, Dordrecht, ISBN 0–7923–5892–9

The last decade has witnessed an unprecedented flourishing of textbooks and research monographs devoted to nonlinear systems and control theory (see Isidori, 1995, 1999; Khalil, 2002; Krstić, Kanellakopoulos, & Kokotović, 1995; Sepulchre, Janković, & Kokotović, 1997; Van der Schaft, 2000; Vidyasagar, 1993 to cite but a few). However, it is not until recently that part of the vast bulk of the technical literature on the topic of nonlinear systems from the former Soviet Union has been made available to the western audience. The book "Nonlinear and Adaptive Control of Complex Systems", by A.L. Fradkov, I.V. Miroshnik, and V.O. Nikiforov, presents a self-contained exposition of results that were previously available only from monographs in Russian or from various journal articles (mostly from *Automation and Remote Control*). In this book, the authors deal with the control of complex nonlinear systems, in which the term *complexity* is to be intended in the broader sense of high dimensionality of the input and output spaces, the presence of uncertainties and external disturbances, and the requirement to meet multiple objectives and performance criteria simultaneously. The methodologies employed by the authors can be distinctively split into those based on classic nonlinear geometric control, and those based on adaptive and robust control. Throughout the book, however, the underlying geometric picture of the problem, and the corresponding solution being considered at time, is always emphasized. Tools and concepts from geometric control theory (invariant distributions, zero-dynamics submanifolds, exact linearization) are employed together with classic and modern Lyapunov-like techniques for stability analysis and design. Particular emphasis is given on the concept of partial stability, that is, stability of sets and of particular trajectories in the state or output space, and on design methods to achieve partial stabilization, of which the so-called *speed gradient method* is the most prominent. As expected, passivity theory plays a major role in the robust and adaptive design techniques presented throughout the book. A distinctive feature of the approach being pursued by the authors to deal with the issue of complexity is to resort to model simplification, both in terms of the use of approximate models and of time-scale separation. In the first case, consistently with the geometric and set-stability framework adopted, linearized models of the system dynamics are obtained and analyzed in the neighborhood of invariant manifolds, rather than equilibrium points. In the latter case, methods from singular perturbation analysis are employed to analyze the behavior of systems whose structure can be simplified by means of a decomposition between slow and fast dynamics. This approach is pursued mainly when dealing with adaptive and robust control design.

The layout of the book is given in the preface, where the contribution of each author is outlined. Chapter 1 serves as a brief introduction, clarifying the scope of the book, and presenting several examples of complexity in control. The focus is on control of uncertain multi-input multi-output nonlinear systems, with particular interest in output tracking and regulation called, in this context, *output coordination*. The various types of uncertainties to be dealt with (i.e., functional, parametric, and unstructured) are introduced, in relation with the various approaches (adaptive and robust) to be employed. Chapter 2 contains a review of classic results in analysis and design tools for nonlinear systems, ranging from Lyapunov stability (including set and partial stability) to passivity theory. A version of the KYP lemma (called the *Feedback Kalman–Yakubovich Lemma*) regarding conditions for output-feedback passivation of linear system is given at the end of Chapter 2, and its proof presented in details in Appendix. The chapter is completed with basic results on exact linearization of SISO systems and stability by linearization. Being extremely succinct, the only practical purpose of this chapter is to fix the notation for the subsequent ones. Apart from the two introductory chapters, the book appears to be divided into three distinct sections, devoted respectively to speed-gradient techniques, geometric methods, and adaptive control. Chapter 3 presents a self-contained exposition of speed-gradient and partial stabilization techniques. To the reviewer's knowledge, this is the first time that an exposition of the basic ideas of speed-gradient design is available in a monograph. Although some of the proofs are deferred to the literature, the methodology is presented with sufficient depth and perspective. The role of speed-gradient techniques is analyzed in the context of adaptive and robust regulation and tracking of nonlinear systems, partial stabilization, and control of Hamiltonian systems. To see some interesting applications, however, the reader must wait until the end of Chapters 8 and 9, where examples of control of mechanical and physical systems are discussed. A better organization of the work, in the reviewer's opinion, could be achieved presenting those results directly within Chapter 3. This is especially true as far as Chapter 9 is concerned, since its short length and narrow scope barely justify its existence as a separate chapter. The geometric approach to the control of MIMO nonlinear system is the subject of Chapters 4 and 5. In the former, the basic concepts of regular hypersurfaces, and attractive and invariant submanifolds are introduced, and their properties discussed in relation to the fundamental problem of set stabilization. The focus of Chapter 4 is to establish a general framework for control based on the definition of suitable submanifolds in the state space which must be rendered invariant and attractive by state feedback. The main ingredients of the methodology are the decomposition of the systems dynamics into a *longitudinal dynamics* that is, the desired dynamics to be imposed, and a residual *transversal dynamics* to be offset. The specific structure of the submanifolds in question is dictated by the particular problem at issue, which may take the form of tracking or stabilization. The reader must be aware that the focus is mainly on local design, since the authors make use of arguments based on stability in the first approximation. In the next chapter, this methodology is applied in the context of *output coordination*, that is, the fulfillment of tasks posed directly in the output space. These include output regulation problems, in which the desired submanifold is the system zero dynamics, and curve-following problems, in which the desired submanifold is a regular hypersurface in the output space. The latter problem, by far the most interesting, is treated clearly and rigorously. Specific and significant examples to the control of rigid bodies, robotic manipulators in the task space, and mobile robots are deferred to the first part of Chapter 8. Chapter 6 departs from the contents of the previous one, and presents a nice self-contained exposition of recent results in adaptive and robust design for nonlinear systems. Here, the focus is on global design for single-input, single-output systems, and the methodology is mainly that of the recursive adaptive backstepping design of (Krstić et al., 1995), with some new developments (such as design with high-order tuning functions) due to the third author. The problem of robustness with respect to external disturbances is considered throughout the chapter, and remedies to counteract the effect of parameter drifting are discussed in detail. State-feedback and output-feedback design techniques for nonlinear systems, including model-reference adaptive control, are discussed in the first half of the chapter, while the second half is devoted to uncertain linear systems. The performance of several methods for adaptive output feedback design techniques for linear systems (including classic certainty equivalence controllers with augmented error or high-order tuners, and nonlinear adaptive backstepping controllers) are comparatively evaluated. The chapter is very well written, and constitutes a shorter and somewhat more agile alternative to (Krstić et al., 1995), useful for a short (one quarter-based) course on modern adaptive control systems. Chapter 7 presents methods for simplifying the analysis of control systems based on decomposition into fast and slow dynamics (making use of classic averaging and singular-perturbation methods), and on neglecting weak coupling between subsystems by means of techniques from decentralized control. In both cases, the focus is on adaptive and speed-gradient schemes. Although necessarily limited in its scope, this chapter provides a nice introduction to these techniques, especially with respect to the speed-gradient methodology; the interested reader, however, may want to complement the chapter with more thorough results available in the literature.

As the book is intended primarily as a research monograph, its use in a classroom may be limited. The material on speed-gradient techniques certainly fulfills this role, and it is targeted to the graduate researcher. However, certain sections may be used to complement the material for an advanced course on nonlinear design (Chapters 4, 5, and the first part of Chapter 8) or used as reference for a short course on adaptive control systems (Chapters 6 and 7, but also Chapter 3). The style of the book is clear, although the English could be improved here and there, and its technical soundness quite good. The material is presented with completeness and rigor, although some proofs are deferred to the appropriate literature. In essence, the book is a welcomed addition to the literature on nonlinear systems, and it is definitely a suggested reading for the researcher in nonlinear control.

Andrea Serrani
Department of Electrical Engineering, The Ohio State University, 205 Dreese Labs, 2015 Neil Avenue Columbus OH 43210, USA
E-mail address: serrani@ee.eng.ohio-state.edu

References

Isidori, A. (1995). *Nonlinear control systems* (3rd ed.). New York, NY: Springer.
Isidori, A. (1999). *Nonlinear control systems*, Vol. II. New York, NY: Springer.
Khalil, H. K. (2002). *Nonlinear systems* (3rd ed.). Upper Saddle River, NJ: Prentice-Hall.
Krstić, M., Kanellakopoulos, I., & Kokotović, P. V. (1995). *Nonlinear and adaptive control systems*. New York, NY: Wiley.
Sepulchre, R., Janković, M., & Kokotović, P. K. (1997). *Constructive nonlinear control*. London, UK: Springer.
Van der Schaft, A. (2000). *L_2-gain and passivity techniques in nonlinear control*. London, UK: Springer.
Vidyasagar, M. (1993). *Nonlinear systems analysis* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

About the reviewer
Andrea Serrani received the *Laurea* degree (B.Eng.) *cum laude* in Electrical Engineering from the University of Ancona, Italy, in 1993, and the *Dottorato di Ricerca* (Ph.D.) in Artificial Intelligence Systems from the same institution in 1997. From 1994 to 1999, he was a Fulbright Fellow at the Department of Systems Science and Mathematics, Washington University in St.Louis, where he obtained the Doctor of Science degree in Systems Science and Mathematics in 2000. From 2000 to 2002, he held a research associate position at the Department of Electronics and Automation at the University of Ancona, Italy. Since 2002, he has been an Assistant Professor with the Department of Electrical Engineering at The Ohio State University, Columbus, OH, USA. His research interests lie in the field of control and systems theory, with emphasis on nonlinear control, nonlinear dynamical systems, and control of autonomous vehicles.

doi:10.1016/j.automatica.2003.12.002