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Book reviews

Stable adaptive control and estimation for nonlinear systems—neural and fuzzy approximator techniques

J. T. Spooner, M. Maggiore, R. Ordóñez, K. M. Passino, John Wiley & Sons, Inc., New York, 2002, ISBN: 0-471-41546-4

1. Introduction

Approximator-based control, primarily using neural networks and/or fuzzy systems as the main tool for function approximation, had been regarded as non-rigorous, but sold under the fashionable name of intelligent control. To some extent, this view point has some elements of true in it as historically it was indeed the case where we only knew the existence of a stabilizing controller but lacked the techniques to construct it. As the approximator-based control matures, we cannot only design stable controllers constructively, but also be able to quantify closed-loop performance.

From the view point of control system design, we have been talking about building models that are complex enough to capture the dominant dynamics of the systems, yet simple enough for us to do control system design. In almost all cases, we have to simplify the model, under some assumptions, so that control system design can be carried out. Sometimes, we have to linearize the simplified model as well in order to tap the rich linear system theory for control system design. Though our ultimate objective is to control the original systems, "approximation" has been accepted in the control community except for that it was introduced at the modeling stage, and mathematical rigor was emphasized for the subsequent analysis. By assuming that the systems took certain simplified forms, such as linear-in-the-parameters, then carrying out the design rigorously with ease and elegance, it does not mean that practical systems are indeed in the simplified forms. Modeling errors do exist, and robust control is supposed to handle this very fact.

On the other hands, approximator-based control takes a different approach. Recognizing the very fact that realistic model building itself might be more difficult for complex systems in practice than controller design, many researchers have devoted to function approximator-based control design with guaranteed closed-loop stability and control performance using neural networks (Ge, Lee, & Harris, 1998; Ge, Hang, Lee, & Zhang, 2001; Lewis, Jagannathan, & Yesildirek, 1999; Narendra & Lewis, 2001; Poznyak, Sanchez, & Yu, 2001) and fuzzy systems (Wang, 1994) as the main parametrization tools, for unknown nonlinear systems without requiring the parametrization form, such as linear-in-the-parameters, as an attractive alternative though using approximators may raise the complexity of computing. Though many developed designs utilize adaptive control techniques and neural/fuzzy parametrization in the linear-in-the-parameters form, the residue approximation errors have to be dealt with explicitly in controller design. Though a small change in approach, it reduces the workload on modeling dramatically, and speeds up the development of a working control system. Approximator-based control deserves due recognition in the context of advanced control system design. Thanks to the collective efforts of many researchers, many remarkable and fundamental contributions have been made in approximator-based control with rigorous mathematical treatments, and detailed analysis of stability, robustness and convergence of the closed-loop systems (Ge et al., 1998, 2001; Lewis et al., 1999; Lewis & Parisini, 1998; Narendra & Lewis, 2001; Poznyak et al., 2001; Wang, 1994).

2. The book

The book under review is yet another remarkable contribution toward approximator-based control. This book covers the major issues of approximator-based adaptive control for state-feedback control, output feedback control, and their applications and extensions in a manner easy-to-read and easy-to-follow. After a brief introduction to stability, robustness, adaptive control, and the roles of approximators in Chapter 1, the book opened the doors to 14 chapters grouped into four distinct parts. At the end of each chapter, a list of well-selected exercises is given for the readers to dwell on.

The first part (Part I) is the foundation of the book, and ranges from Chapters 2 to 5. It presents the background materials, and establishes the notation used in this book. Chapter 2 provides the mathematical foundations including the definitions of vectors, matrices, and signals, functions, stability, boundedness, and Lyapunov analysis, which are fundamental in the synthesis and analysis of adaptive systems. In Chapter 3, the two main approximators, neural networks and fuzzy systems are described clearly and concisely. Essential concepts are introduced. For neural networks, they include neuron input mappings, activation functions, multilayer perceptron, radial basis neural networks (RBNN), and tapped delay neural networks. For fuzzy systems, they include rule-base and fuzzification, inference and defuzzification, and Takagi–Sugeno fuzzy systems. Chapter 4 introduces optimization tools for minimizing the approximation errors, which are essential for non-model-based modelling for complex nonlinear systems. After the problem formulation, several algorithms are presented in sequence, including linear least squares (batch and recursive least squares), and nonlinear least square (gradient optimization, linear search and conjugate gradient). Chapter 5 presents the approximation properties of conventional neural networks and fuzzy systems, which are essential in the subsequent development of control system design, and provide insights into the choices of approximators in practical applications.

Part II (Chapters 6–9) of the book concentrates on state-feedback control for nonlinear systems. In Chapter 6, a collection of standard control design techniques is presented for certain classes of nonlinear systems, which lays the foundation for further development later. After the briefing of the error system and Lyapunov candidate, non-adaptive control system designs are presented for canonical system representations and systems with uncertainties, which are presented in a very constructive and easy-to-follow manner. In particular, fundamental theorems and constructive design steps are clearly spelled out for approximator-based control design. Chapter 7 focuses on direct adaptive control system design for systems whose error dynamics are affine in the input. For closed-loop robustness, stable control system designs are presented based on both σ- and ε- modifications for parameter adaptation. Inherent robustness, performance analysis and extensions are also discussed. Indirect adaptive control is then detailed in Chapter 8. The chapter starts with control system design for systems with uncertainties satisfying matching conditions including static and dynamic uncertainties. The control laws are developed via certainty equivalence in the presence of additive uncertainties and multiplicative uncertainties. Next, adaptive control is investigated for systems with uncertainties dissatisfying matching conditions using backstepping. As the concluding chapter of Part II, Chapter 9 dedicates to controller design by fully exploiting the mathematical structures for the physical systems under study, and extensive comparison studies with other "conventional" techniques through analysis, experiments and/or simulation. It is found that much stronger stability results are obtainable by utilizing the structural properties of the systems. This very fact has also been exploited by many researchers in conventional control (Krstic, Kanellakopoulos, & Kokotovic, 1995; Spong & Vidyasagar, 1989) and approximated-based control (Ge et al., 1998, 2001; Lewis et al., 1999). The simulation and experimental results presented in this chapter are very useful for better understanding of the control designs given in Chapters 7 and 8.

In Part III, from Chapters 10 to 12, the authors present output-feedback control for nonlinear systems for which only inputs and outputs rather than full states are measurable as frequently encountered in practice. In Chapter 10, after the briefing of a partial information framework, control system design tools are developed. Several fundamental concepts are clearly presented, which include output feedback systems, separation principle, and observability. Efforts have also been extended to multiinput–multioutput (MIMO) systems, avoiding adding integrators, copying with uncertainties, and output tracking. By employing the separation principle, the design task is separated into two portions: state feedback control design and a nonlinear high-gain-type observer development. The projection of the observer estimate is helpful to guarantee the stability of the estimation error and avoid the destabilizing peaking phenomenon. To solve the tracking problem, the trick is to find, though difficult, a practical internal model to convert the tracking problem into a standard stabilization problem, where one observer is used to estimate the state and another observer to estimate the stable inverse of the plant. Following the same pattern of state feedback control, adaptive output-feedback control follows next in Chapter 11. Through the deployment of the separation principle, the techniques seen in Chapters 7 and 8 are extended to the output feedback framework in terms of adaptive stabilization and adaptive tracking, respectively. In Chapter 12, the output-feedback control techniques of nonlinear systems presented in Chapters 10 and 11 are applied to three practical systems. These practical applications help the reader to understand and appreciate approximator-based control better.

In the concluding part of the book, Part IV firstly extends the approximator-based control to discrete-time control in Chapter 13, and decentralized control in Chapter 14, then presents the perspectives on intelligent adaptive systems. In Chapter 13, after a brief discussion on the ways to convert from a continuous-time system to canonical discrete-time descriptions, non-adaptive, robust and adaptive controls are discussed in details. Decentralized systems are known to be robust to sensory and actuator failure, and economical in actual implementation. Chapter 14 familiarizes the reader with some of the tools used in the design and analysis of decentralized controllers, and presents results of development for both static and adaptive decentralized controllers. After the presentation of decentralized systems, both static and adaptive controls are presented using knowledge of the interconnections among the subsystems. To conclude Part IV, Chapter 15 gives a very good discussion on the roles of fuzzy systems and neural networks in intelligent adaptive systems, the perspectives of conventional and intelligent control.

3. Conclusion

This book provides an excellent structured presentation of approximator-based control, and is the results of many years' soul searching and dwelling by the researchers. After the elaboration of the general theory, actual applications to many real-world systems and possible extensions are presented. It is not only a valuable introductory book for newcomers to the fields, but also very readable and strongly recommended for the postgraduate engineering students, research scientist, and industrial engineers.

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About the reviewer

Shuzhi Sam Ge is an Associate Professor of the Department of Electrical and Computer Engineering, the National University of Singapore. He received his B.Sc. degree from Beijing University of Aeronautics & Astronautics (BUAA), Beijing, in 1986, and the Ph.D. degree and the Diploma of Imperial College (DIC) from Imperial College of Science, Technology and Medicine, University of London, in 1993. He has authored and co-authored over 60 international journal papers and over 100 conference papers, two monographs and co-invented two patents. He has been serving as an Associate Editor, *IEEE Transactions on Control Systems Technology* since 1999. He was the recipient of the 1999 National Technology Award, 2001 University Young Research Award, and 2002 Temasek Young Investigator Award, Singapore. His current research interests are adaptive control, nonlinear control, intelligent control, and sensor fusion.

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Fixed-interval smoothing for state-space models

Howard L. Weinert; Kluwer Academic Publishers, Dordrecht, MA, 2001, ISBN: 0–7923–7299-9

This book concerns the important topic of fixed-interval smoothing for linear Gaussian models. In addition to traditional applications in tracking and automatic control, the fixed-interval smoother constitutes the expectation step in the expectation-maximization (EM) algorithm for estimating parameters in these models, which has applications in fields ranging from time-series analysis (Shumway & Stoffer, 1982) to speech recognition (Digalakis, Rohlicek, & Ostendorf, 1993) to signal classification (Ainsleigh, Kehtarnavaz, & Streit, 2002). A focused textual treatment of this topic is therefore desirable since it would allow the space required for a complete historical and mathematical development of the smoothing algorithms with an adequate set of examples and comparisons. The present book falls short of these desired attributes in a number of ways, however.

The book is very brief, consisting of 118 pages, of which nearly 40 pages is devoted to bibliographic notes. The remaining pages are split into five chapters, which cover (1) the general form of the state-space model, (2) complementary models, (3) discrete-time smoothers, (4) continuous-time smoothers, and (5) smoothers for two-point boundary-value problems. Of these, the general reader will likely have little interest in the last two chapters. The book contains no examples, no problems, no figures, and-practically no interpretive discussion of the mathematical derivations. It appears that the book was a set of private mathematical notes, or perhaps a concise technical report, to which Dr. Weinert added an annotated bibliography and sent to the publisher without further modification. The book therefore has little academic value, which, to be fair, was not the advertised intent. For reasons listed below, however, the book has limited research or implementation value outside of a narrow audience. This is a more serious drawback since, as stated in the preface, the book is intended "for those doing research on smoothing, and for those who want to choose a smoothing algorithm for a particular application".

Dr. Weinert states in the preface that "For the most part I let the mathematics speak for itself". Unfortunately, the mathematics do not speak very clearly. The author develops all of the smoothing algorithms using the formalism of complementary models (Weinert & Desai, 1981; Desai, Weinert, & Yusypchuk, 1983), which is a non-standard approach to the development of fixed-interval smoothing algorithms. This approach seems (at least to this reviewer) to obfuscate what should be straightforward statistical and algebraic developments. Furthermore, Dr. Weinert introduces the complementary models with no explanatory narrative, so that for example, he does not clarify what he means by the "linear span of the generating variables: $S = \mathrm{sp}\{x_0, u, v\}$" when the variables x_0, u, and v have vastly different dimensions (p. 14). Given that the complementary models are developed from a direct-sum decomposition of the space S in terms of the span of the observations and its orthogonal complement in S, this point deserves at least some comment. While the extremely devoted reader, who is willing to refer back to the original research articles and work through some of these issues himself, would be able plow through the