Book Reviews

Editor's Note—The Transactions on Automatic Control will eliminate the Book Review section after publishing all reviews that are currently either awaiting publication or are in process. The Control Systems Magazine will henceforth become the venue for all reviews of books we believe are of interest to the readership of the Transactions and the Control Systems community at large. Authors interested in having their books reviewed should contact one of the current Associate Editors for Book Reviews for the Magazine, Michael P. Polis (polis@oakland.edu) or Zongli Lin (zl5y@virginia.edu).

Nonlinear H_2/H_∞ Constrained Feedback Control: A Practical Design Approach Using Neural Networks—Murad Abu-Khalaf, Jie Huang, and Frank L. Lewis (Springer-Verlag: London, 2008). *Reviewed by Sanqing Hu and Derong Liu*

Since all physical systems are actually nonlinear, it is inevitable to encounter nonlinear control systems in real applications. While there may be an extensive understanding of the behavior of nonlinear processes, it is difficult sometimes to find satisfactory methods for their control. The widely used approach to date is linearization of nonlinear systems about a steady-state operating point to design a linear controller such as the classical PID controller. However, in many situations, the linearized model is inadequate or inaccurate because of the intrinsic nonlinearities involved. Thus, nonlinear control is one of the biggest challenges in modern control theory and has received wide attention [1]–[4]. Generally speaking, controller design of nonlinear systems is equivalent to solving the well-known Hamilton–Jacobi (HJ) equations whose exact solutions are difficult to obtain. Much work has recently been devoted to obtaining the solutions and many techniques have been developed; in particular, neural networks have become a popular approach. With enough neurons and hidden layers in their structure, neural networks have proved to be able to approximate any nonlinear function to any degree of accuracy. This makes neural networks a good feasible tool for solving the HJ equations and accounts for their popularity.

The book by Abu-Khalaf, Huang, and Lewis applies neural networks to obtain nearly-optimal convergent solutions for HJ equations with some guaranteed performance properties of the controllers. The result of the nearly optimal solutions can be considered as an extension to nonlinear systems from linear systems. This book examines some fundamental modern control problems of nonlinear systems (continuous-time version and discrete-time version) such as optimal control design, H_2/H_∞ design, and constrained-input controllers including minimum-time design, to name a few.

The book starts with an explicit description of nonlinear control systems, neural networks, and function approximation. For nonlinear control systems, various control problems are stated. These problems include stability, controllability, stabilizability, dissipativity, optimal control, zero-game, etc. With this preliminary knowledge explicitly described, the book proceeds to address nonlinear H_2/H_∞ constrained feedback control for continuous-time and discrete-time nonlinear systems. More specifically, the book is organized into the following eight chapters.

Chapter 1 of the book presents basic concepts and background material related to the analysis and control of nonlinear systems. This preliminary material will be referenced throughout the remainder of the book.

Chapters 2–5 investigate policy iterations and nonlinear state feedback control and provide nearly optimal neural network controls for constrained-input systems. Specifically, Chapters 2 and 3 discuss H_2-related control and Chapters 4 and 5 deal with H_∞-related control.

Chapter 2 introduces the application of a policy iteration method to the Hamilton–Jacobi–Bellman (HJB) equation whose solution is the constrained optimal control of nonlinear systems. The suggested policy iteration method not only can improve a given initial stabilizing control policy but also can reduce to the well-known Kleinman iteration method for solving the algebraic Riccati equation for linear systems using a sequence of Lyapunov equations. Two optimal controllers are discussed for constrained-input control systems. One is the optimal regulator and the other is the minimum-time optimal controller.

Chapter 3 is devoted to combining the policy iteration method with neural networks to obtain nearly-H_2-optimal solutions of constrained-input nonlinear systems. Not only the convergence of the method is fully established, but also the method is shown to be efficient, practical, and computationally tractable via several numerical examples. The chapter also covers an alternative policy iteration method that does not require solving a Lyapunov equation.

Chapter 4 addresses the Hamilton–Jacobi–Isaacs (HJI) equation for constrained-input systems and finds its solution by using an iterative optimization technique on the corresponding zero-sum game in the form of H_∞ control.

Chapter 5 uses a neural network least-square-based algorithm to practically solve the HJI equation for constrained-input systems. The stability and convergency of the algorithm is well demonstrated. Moreover, the proposed algorithm is successfully applied to the rotational/translational actuator (RTAC) nonlinear benchmark problem under actuator saturation.

Chapters 6 and 7 develop a systematic approach to the solution of the HJI equation for zero-sum games in continuous-time and discrete-time systems, respectively. The solution is obtained without using neural networks or iterative optimization techniques. In particular, Chapter 6 provides an approximation approach to solve the HJI equation in terms of the Taylor series. The coefficients of the Taylor series are governed by a Riccati equation and a sequence of linear algebraic equations from which an iterative algorithm is developed. Chapter 7 provides an approximation approach to solve the discrete HJI equation in terms of the Taylor series, where the discrete HJI equation is an extension of the discrete algebraic Riccati equation arising in the linear discrete H_∞ control problem. Similar to the continuous-time case, the coefficients of the Taylor series are governed by a Riccati equation and a sequence of linear algebraic equations for which a systematic

S. Hu is with the Division of Epilepsy and Electroencephalography, Department of Neurology, Mayo Clinic, Rochester, MN 55905 USA (e-mail: Hu.Sanqing@mayo.edu).

D. Liu is with the Department of Electrical and Computer Engineering, University of Illinois at Chicago, Chicago, IL 60607 USA (e-mail: dliu@ece.uic.edu).

Digital Object Identifier 10.1109/TAC.2008.911794

algorithm is synthesized. In both chapters, the algorithm is efficiently applied to continuous-time and discrete-time rotational/translational actuator systems.

Chapter 8 studies H_∞ static output feedback design for linear time-invariant systems. The H_∞ static output feedback control can be achieved under the derived necessary and sufficient conditions which include two coupled matrix design equations. The two equations can be solved by a numerically efficient solution algorithm that is successfully applied to the design of an F-16 acceleration controller.

The book is very well written. The topics chosen are all fundamental control problems and are treated in depth. The primary objective of this book is to apply neural networks to obtain nearly optimal solutions for HJ equations with some guaranteed performance properties of the controllers for continuous-time and discrete-time nonlinear systems. Without doubt this book represents a significant contribution to the important research topic of analysis and design for constrained input/output nonlinear control systems. The results included in the book, along with an extensive bibliography will prove to be an important resource for researchers in this area as well as researchers interested in entering this area. The nonlinear H_2/H_∞ constrained feedback control design approaches in the book will prove equally valuable to practicing engineers with different backgrounds and can be viewed as one of the available tools that a control designer should have in his/her control toolbox. Although the mathematics involved in the book is on the heavy side, all the analysis and design algorithms are explicit. All the results are illustrated with fully worked out examples and/or simulation.

This book is particularly a good text for a graduate or advanced undergraduate course. Short courses or training courses for control engineers to gain knowledge in nonlinear control systems would be another avenue for this book.

REFERENCES

[1] M. Krstic, I. Kanellakopoulos, and P. Kokotovic, *Nonlinear and Adaptive Control Design*. New York: Wiley, 1995.
[2] H. Mekki, M. Chtourou, and N. Derbel, "Stochastic approximation based adaptive neural control for a class of nonlinear systems," *Control Intell. Syst.*, vol. 33, pp. 190–198, 2005.
[3] D. Walker, G. Froyland, K. Judd, and A. Mees, "Controller for nonlinear systems using normal forms," *Int. J. Bifurcation Chaos*, vol. 13, no. 2, pp. 459–465, 2003.
[4] C. Won, "State feedback optimal controllers for deterministic nonlinear systems," in *Proc. Amer. Control Conf.*, Portland, OR, Jun. 2005, pp. 858–863.

Supervisory Control of Concurrent Systems: A Petri Net Structural Approach—Marian V. Iordache and Panos J. Antsaklis (Birkhäuser: Boston, 2008). *Reviewed by Feng Lin*

The theory of supervisory control of discrete event systems studies various control problems in discrete event systems. Petri nets are a powerful model for complex and concurrent discrete event systems. This book provides a nice presentation of supervisory control of discrete event systems using a Petri net model. It covers a wide range of topics on supervisory control in the framework of Petri nets.

To put this book in perspective, let us briefly review the history and theory of supervisory control of discrete event systems. The supervisory control theory of discrete event systems was born in the University of Toronto in the 1980s. The first paper on the theory was written by Ramadge and Wonham. The full version of the paper was published in 1987 [6], and the conference version was published early in 1984. In the paper, Ramadge and Wonham proposed an automaton model for discrete event systems and a supervisory control mechanism, which is enablement and disablement. The event set is divided into controllable events (those that can be disabled) and uncontrollable events (those that cannot be disabled). Controllability was introduced to capture the necessary and sufficient conditions for the existence of a supervisor. Controllability is defined for a legal or desired language K with respect to a plant language L(G) which corresponds to all possible trajectories of the uncontrolled system. Controllability of K with respect to L(G) essentially requires that all events to be disabled by the supervisor must be controllable. All events are assumed to be observable in [6]. To consider the case of supervisory control under partial observation, where events are divided into observable and unobservable events, Lin and Wonham introduced observability. The paper on observability [3] was published in 1988 and the corresponding technical report in 1986. In [3], the observation of a supervisor is described by the projection operator P that erases all unobservable events in a trajectory or string. In other words, if a string occurs in a system, the supervisor will see its projection. Observability is then defined for a legal language K with respect to the plant language L(G) and the projection P. It requires that if two strings look the same to the supervisor (having the same projection), then the control actions needed by the supervisor after these two strings must be consistent (that is, no event will be enabled after one string but disabled after the other). In other words, the supervisor must have sufficient information to make a control decision on each controllable event. It was proved in [3] that a necessary and sufficient condition for the existence of a partial observation supervisor is controllability and observability. After the establishment of controllability and observability, the next topic investigated in supervisory control was decentralized supervision. Two cases were considered: 1) specifications are given locally and 2) specifications are given globally. Local specifications were discussed by Lin and Wonham in [4]. A property called normality was introduced in [4] to capture the existence condition for local or decentralized supervisors. A legal language K is normal with respect to the plant language L(G) and the projection P if a string belongs to K if and only if it belongs to L(G) and its projection belongs to the projection of K. Global specifications (which are more general than local specifications) were investigated by Rudie and Wonham in [7]. Coobservability was defined for global specifications as follows. A legal language K is coobservable with respect to the plant language L(G) and the sets of locally controllable events and locally observable events if the following conditions are satisfied: 1) if an event is controllable by only one supervisor, then that supervisor must have sufficient information to make a control decision on that event and 2) if an event is controllable by several supervisors, then at least one supervisor must have sufficient information to make control decision on that event. Rudie and Wonham showed in [4] that coobservability, together with controllability, is necessary and sufficient for the existence

F. Lin is with the Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202 USA.
Digital Object Identifier 10.1109/TAC.2008.911788