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BOOK REVIEW

SYSTEMS AND CONTROL, Stanislaw H. Żak, Oxford University Press, New York, 2003, 704pp. ISBN 0195150112

A brief information about the author is first provided. S. H. Żak is Professor of Electrical and Computer Engineering at Purdue University (Indiana, U.S.A.). He has worked in various areas of control, optimization, and neural networks. In addition to this book, he is a coauthor of Selected Methods of Analysis of Linear Dynamical Systems (1984, in Polish) and An Introduction to Optimization, second edition (2001). Furthermore, he has also contributed to the Comprehensive Dictionary of Electrical Engineering (1999).

The present book is one of the Oxford Series in Electrical and Computer Engineering (Series Editor: Adel S. Sedra). As also introduced in the book's preface, its main objective is to familiarize the readers with the basics of dynamical system theory while, at the same time, equipping the readers with the tools necessary for various control system design. A remarkable feature of the book is that the emphasis is on the design in order to show how dynamical system theory fits into practical applications. Therefore, the book is a precious addition to the control literature of bridging modelling and control of dynamical systems.

The book consists of 11 chapters and an appendix reviewing the mathematical background. There is an interesting message in the start of every chapter, which is reminiscent of the essence of the chapter's contents. For example, the message for Chapter 4 (Stability) is: 'Examine each question in terms of what is ethically and aesthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise'. It is an enjoyment to read the messages before going into other elegant parts concerning systems and control.

Chapter 1 introduces the notion of a system, describes the interrelations between the components contained within the system and the system boundaries that separate the components within the system from the components outside. The state description is in accord with the one in Reference [1]: 'A dynamical system consists of a set of possible states, together with a rule that determines the present state in terms of past states'. There are numerous examples illustrating in detail the 'work and energy' concept, and the mathematical modelling of dynamical systems by ordinary differential/difference equations. As a preliminary knowledge, the Lagrange Equation of Motion is derived in an intelligible way. Then, the models of pendulum, robot manipulator, centrifugal governor, ground vehicle, stepper motor, etc., are precisely described. Many other models are provided in the exercises. Other sources concerning system modelling are stated in the Notes, which include Kalman's article [2] and Sontag's book [3]. Chapter 2 is devoted to the analysis of modelling equations. The first class of methods involving state-space analysis is mainly focused on the method of *isoclines*, where Bendixson's theorem is used for the existence of a limit cycle. Then, several numerical techniques, Taylor Series Method, Euler's Method, Predictor–Corrector Method, Runge's Method, are explained with examples, and linearization principle/method is then considered. In the end of this section, an interesting method, called *Describing Function Method*, is described. This method allows us to apply familiar domain techniques, used in the linear system analysis, to the analysis of a class of nonlinear dynamical systems. As pointed out in the book, it can be viewed as an extension of the Nyquist stability criterion to nonlinear systems. For in-depth treatment of the describing function method, the author refers to Graham and McRuer [4].

Chapter 3 deals with linear system theory, starting with a description of linearity by Feigenbaum [5]: 'Linearity means that the rule that determines what a piece of a system is going to do next is not influenced by what is doing now'. Then, the basic concepts from linear systems are reviewed, involving reachability/controllability, observability, controller and observer, state feedback and controller–estimator compensator, etc. For further reading on the subject of linear system theory, the author as well as the reviewer recommends [6–8]. Chapter 4 presents a thorough stability analysis as well as the essentials of the Lyapunov theory for both linear and nonlinear systems, in both continuous-time and discrete-time cases. The theorems and the proofs are very well organized, and the figures help the reader greatly in understanding the difficult parts. With the last several sections on discontinuous robust controllers, uniform ultimate boundedness, Lyapunov-like analysis, and LaSalle's Invariance Principle, the reader also gets acquainted with some advanced knowledge on the application and the extension of Lyapunov theory.

Chapter 5 is dedicated to the optimal control of dynamical systems. The author mentions in the Notes that regarding the origins of optimal control, Sussman and Willems [9] declared in 1977: 'Optimal control was born in 1697 in Groningen, a university town in the north of The Netherlands, when Johann Bernoulli, professor of mathematics at the local university, published his solution of the *brachystochrone problem*'. The book first gives a brief introduction to the calculus of variations, which helps equipping the reader with the necessary tools required for the rest of the chapter. After that, linear quadratic regulator, dynamic programming and Pontryagin's Minimum Principle are in order with detailed proofs and calculation for examples. The book by Lee and Markus [10] is recommended for advanced optimal control.

Variable structure systems (VSSs) are discussed and the design of sliding mode controllers is illustrated in Chapter 6. As is known, a VSS can be viewed as a system composed of independent structures together with a switching logic between each of the structures. This chapter first gives several simple VSS examples with simple sliding mode controller. Then, the ideal and non-ideal sliding models are described, and sliding surface design is considered. In the end, the sliding modes in solving optimization problems are introduced with some new results. In Chapter 7, vector field methods are discussed for controller construction for a class of nonlinear dynamical systems. The control design process involves the following three steps: design a state feedback law; design a state observer; combines the first two steps to obtain a combined controller–estimator compensator. The so-called *feedback linearization* method is used in the first step, where the controller consists of two components: one component cancels out the plant's nonlinearities, and the other controls the resulting linear system.

Chapter 8 provides a comprehensive discussion of fuzzy systems. After the motivation and basic definitions, the author uses various examples to explain fuzzy relations/models with 'IF $\cdots$ THEN $\cdots$' rules. Then, fuzzy logic control and stabilization using fuzzy models are described vigorously. Finally, adaptive fuzzy robust tracking controllers for a class of uncertain dynamical systems are analysed, where the controllers' construction and analysis involves sliding modes. Chapter 9 is devoted to the study of neural networks. As is well known, the main motivation of neural networks is to build computers/algorithms whose construction would mimic the organization of the brain. The brain is the most complex natural information processing system. It is capable of organizing its building blocks, called *neurons*, to perform computations in a very efficient way. The chapter discusses several mathematical models of the biologic neurons, which are also called the artificial neurons, and then analyses the neural networks which are composed of the artificial neurons. Section 9.9 introduces in detail a class of neural network models, called *the Brain-State-in-a-Box* (*BSB*), which can be used to construct the so-called associative memories. The analysis is also extended to a generalized type of BSB, called *gBSB*, with an interesting example in pattern recognition.

Genetic algorithms, introduced by Holland [11] in the 1960s, have been originally proposed to model adaptive processes. Chapter 10 describes two genetic algorithms, i.e. *canonical genetic algorithm* (*GA*) and *simple evolutionary algorithm* (*EA*), and their applications for solving optimization problems. Tracking control of a vehicle is accomplished by using an evolutionary fuzzy logic controller. The author recommends Mitchell's book [12] as an introductory text to genetic algorithms. Chapter 11 discusses the chaotic systems and fractals. The example of the growth of population is used to explain the chaotic behaviour of the logistic equation, and the stability property is analysed. The modelling of *fractals*, which come from the Latin adjective *fractus*, is considered with the von Koch snowflake curve and the Cantor set. Lyapunov components are then defined and used for characterization of chaotic dynamical systems' stability. The control of chaotic systems is illustrated in detail by the example of controlling a bouncing ball on a vibrating plate.

In the end of the book, an appendix is provided on the essentials of mathematical background, which complements the material presented in the book.

As described in the above, the book by S. H. Żak covers a wide area of topics in systems and control theory and their applications. In addition to the analysis of stability and optimal control in both linear and nonlinear systems, the book provides a very good introduction to fuzzy systems, neural networks, genetic algorithms and chaotic systems. Some latest developments are also included for readers to seek advanced knowledge. Also, since the emphasis is on the multidisciplinary role of nonlinear dynamics and control, the book provides various examples where the techniques of fuzzy logic, genetic algorithms and neural networks are used in real control applications, and it also shows how these new approaches are combined into the classical ones. To this end, Lyapunov's stability theory is employed as the common framework of analysis and design. This type of presentation facilitates a deeper and unified understanding of the material in the context of control and stability problem.

The book is valuable to senior or graduate course work and its comprehensive nature makes it also an excellent reference text for people who are interested in dynamical systems and control theory. A basic knowledge of linear algebra and calculus would be sufficient to understand most of the material. The fundamental concepts, results and how they relate to each other are clearly presented. The fully worked out examples, which are mostly taken from practical applications, form an integral part of the book. Many exercises, mostly involving software projects in MATLAB, are also provided at the end of each chapter. The reading seminars of the book in the reviewer's research group and other groups show that most researchers and graduate students are satisfied greatly with the contents and the style.

In conclusion, this book is very well written in a textbook format, offers a thorough and practical treatment of systems and control, and provides a solid foundation for anyone interested in the field and is thus highly recommended.

Finally, as introduced in the book's preface, there is a companion web site for this book, where the current errata are available as well as the MATLAB m-files of examples solved in the book. The URL of the site is 'http://dynamo.ecn.purdue.edu/~zak/systems/Index.html'.

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