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BOOK REVIEW

CONTROLLING CHAOS AND BIFURCATIONS IN ENGINEERING SYSTEMS, Guanrong Chen, Boca Raton, FL: CRC Press, 2000, ISBN 0-8493-0579-9.

1. INTRODUCTION

In the 1970s and 1980s, we saw phenomenal advancement in nonlinear science, which had led to remarkable improvement in our understanding of the world around us. Many of the discoveries in nonlinear science are not only new, but also revolutionary in the sense that some of our traditional beliefs of system behaviour were relentlessly challenged [1–4]. Most striking of all, simple deterministic systems can behave in a "random-like" fashion and their solution trajectories can deny "long-term predictability" even if the initial conditions are practically known. Such behaviour is now termed *chaos*, which underlies the *complexity* and subtle *order* exhibited by physical systems. Thanks to the concerted efforts of scientists, mathematicians and engineers over more than two decades, we now have a better understanding of why many physical systems behave in a complex fashion and how such complexity arises out of some system's built-in properties known collectively as *nonlinearity*. Precisely, without exception, all systems in the real world are nonlinear. Perhaps we need no mention of the adjective "nonlinear" for any physical system since it is really the default type.

More than 30 years of studying physical phenomena in the context of chaotic dynamics have brought us a much improved understanding of the real world. We now know how chaos occurs in a variety of physical and engineering systems. Most importantly, we have learnt about chaos to a point where we are confident about the consequences of its presence under certain given conditions: whether it is safe or disastrous, useful or useless, etc. A natural step forward is to develop means to control chaos so that it does not happen when it is not wanted [5], or to "anti-control" it so that it is deliberately made to occur [6].

Indeed, the past decade has seen heightened interest in the exploitation of chaos for useful applications and in controlling/anti-controlling chaos in physical and engineering systems. At the time of writing, research in chaos control is still emerging, and many publications describing significant advancement have been scattered in journals across various fields [7–10], although the methods employed are similar and it is not uncommon that a method used in one field is in fact equally applicable to a different field. We may assert that this emerging field has a multi-disciplinary feature, yet the methods are universally applicable. It would therefore be highly desirable if researchers from different scientific and engineering disciplines can build upon one another's work. The question is how relevant information and research results can be gathered in such a way that researchers can quickly review the essentials and state-of-the-art developments when they need to develop chaos control methods. Because information is scattered across publications of different disciplines, a well-organized collective publication in book form would be a viable temporary relief. Of course, such a publication will also have good tutorial and archival value if the contents are carefully selected to include the fundamentals as well as to record the present status of the field. The book being reviewed here, *Controlling Chaos and Bifurcations in Engineering Systems* (Boca Raton, FL: CRC Press, 2000), edited by Guanrong Chen, represents an attempt to collect some important advancements in the field of chaos control with emphasis on engineering applications. In the following, we will try to give a general review of this book, evaluating its merits and possible demerits as a reference and/or graduate text.

2. BOOK REVIEW

From what has been said in the foregoing, chaos control is an important emerging area which finds applications in a broad range of engineering systems and physical phenomena. In general terms, this area includes the study of all kinds of innovative methods for controlling chaos as well as putting chaos to engineering use. Because research results in chaos control appear in a multitude of scientific, mathematical and engineering journals, researchers in different disciplines do not readily know what latest advances have been achieved if such advances do not originate in their own research field. With these in mind, a book that bridges the multi-disciplinary gap will be welcomed by researchers who wish to "control and use chaos" in their own discipline. Taking into account its likely purposes, such a book may be evaluated on the basis of the following criteria:

- Timeliness
- Relevance
- Breadth of coverage
- Tutorial value
- Readability as a multi-disciplinary publication
- Suitability as a graduate text
- Suitability as a graduate and/or research reference.

The book *Controlling Chaos and Bifurcations in Engineering Systems* (Boca Raton, FL: CRC Press, 2000), edited by Guanrong Chen, appears to be a very timely addition to the literature, having been published at a time when research in chaos has matured to a point where useful applications have begun to be conceived. Our review of this book begins with grouping the chapters under several major topics and evaluating their timeliness, relevance and coverage. We will then discuss separately the tutorial value, readability, etc., of the book as a whole.

1. *Chaotic signal processing and applications* — In Chapters 1, 2, 13, 19–24, a number of salient topics in chaotic signal processing and related applications are expounded, ranging from signal reconstruction, chaos synchronization, noise–chaos separation, to chaos-based communication systems. The topics all seem to well represent the latest advances and are highly relevant to the central theme of "controlling and using chaos". The material in Chapters 1 and 2 contains important fundamental concepts relevant to processing chaotic signals, and covers the latest status of research in this field. It is particularly useful that key problems and difficulties are clearly explained so that the readers can quickly become familiar with the current status of the research in signal reconstruction. Chaos synchronization is another prominent area of development, to which five chapters are devoted (Chapters 13, 19, 20, 23 and 24). Moreover, these five chapter address quite diverse topics related to the general synchronization phenomena. It is particularly pleasing to see that some chapters take on a chaos perspective (e.g., in terms of coupling and drive-response concepts), while others allow readers with conventional system theory background to grasp the salient concepts (e.g., in terms of adaptive system and observer concepts). This diverse presentation is especially important since taking a pure chaos perspective can sometimes create confusion [11]. Precisely, Chapters 19 and 20 represent excellent complements to the usual "chaos perspective" of synchronization. Therein the authors use a traditional *observer* perspective of control theory to examine chaos synchronization. Finally, some engineering applications relevant to chaotic signal processing are collected in Chapters 21 and 22 in which the use of chaos for communications and some prominent associated problems are discussed. Although these chapters cover only the noise filtering problem and a few digital chaos communication techniques, they serve the purpose of highlighting the potential benefits and shortfalls of using chaos for communication. The level of exposition and tutorial value of these two chapters are high, despite the narrow coverage.
2. *Control system design* — Since the main theme of the book is *chaos control*, the design of control systems for controlling chaos is undeniably a topic about which most readers would have much expectation. To no one's disappointment, this topic is very well covered in this book. Nine chapters (Chapters 3–7, 9–12) are devoted to the basic theory of controlling chaos. These chapters cover the major developments in the past decade, with varied levels of generality and specialisation. At this point, a major difficulty in editing a book as such can be appreciated. Specifically, it is very difficult, if not impossible, to present a single self-contained body of theory for controlling nonlinear systems because nonlinear systems may take a variety of forms and limited common features can be found between two distinct nonlinear systems. Any attempt to present a single body of theory would inevitably require a very general system formulation which can hardly be of any practical use. Indeed, nonlinearity often denies generality. It is therefore practical to expose just a few representative control methodologies for a selected range of systems. In this respect, this book has done an

admirable job. First of all, a particularly readable introductory account is provided in Chapter 3 which, though being focused on the classic OGY method, offers an excellent exposition of the basic problems and solution approaches in the control of chaos. Chapters 9–12, in the same spirit as Chapter 3, expose several chaos control methods for a few selected types of systems, namely, frequency domain methods (for stabilizing forced oscillators), harmonic balance (for controlling limit cycles in the vicinity of degenerate Hopf bifurcations), time-delayed feedback methods (for systems described by time-delayed differential equations), and a few variants of time-delayed feedback controls (for general autonomous systems). The approaches taken in these chapters are mathematical. They are more suited for the advanced readers. On the other hand, for readers who wish to get a practical feel of how chaos control is done, Chapters 4–7 describe a few case studies in applying chaos control to some physical systems, including some mechanical systems, an inverted pendulum, systems with spatio-temporal dynamics (formulated by PDEs) and wave motion. These chapters involve mathematics to a much less extent, compared to the more theoretical exposition in Chapters 9–12, and are quite readable by engineers. Overall, the coverage on control system design is wide and the materials selected reflect the latest advances in research in this field.

3. *Predictions leading to control of bifurcations in engineering systems* — Chaotic systems are characterised by their sensitive dependence upon initial conditions and the bifurcation behaviour that gives rise to sudden change of qualitative behaviour when subject to some parameter changes. These features have significant impact on the reliability of engineering systems, eg., an engineering system may catastrophically fail if it operates in a range that contains a deadly bifurcation. It is thus of practical importance to predict and control bifurcation behaviour. In this area, the book has a fair coverage. Firstly, Chapter 8 illustrates lucidly some basic problems associated with sensitivity to initial conditions in terms of a simple electronic phase-locked-loop circuit. Though based on a specific example, this chapter succeeds in exposing the various tools relevant to predicting the behaviour of chaotic systems. In addition, Chapter 14 is devoted to an overview of the theory of controlling (and anti-controlling) bifurcation in dynamical systems through adjusting some desired properties. This chapter explains the basic idea with some selected bifurcation control cases, e.g., Pitchfork and Hopf, and illustrates the application of a particular scheme to the Rayleigh–Bénard convection system. Furthermore, Chapters 17, 18 and 25 expound, quite independently, the issue of bifurcation control in several different dynamical systems. The particular systems addressed include systems with a single uncontrollable mode, switching (non-smooth) dynamical systems, and classical feedback controlled systems. Overall, this area deserves deeper treatment than what the book has covered. Nonetheless, this book has managed to expound a few interesting cases that may prompt further developments in bifurcation prediction/control methodologies.
4. *Case studies of successful applications of chaos control in engineering systems* — Perhaps the most pleasing part of the book is the description of some successful examples in engineering design in which chaos control has played a crucial role. This not only proves that chaos control is indeed useful in practice, but also illustrates clearly the importance of constructing a formal theory for controlling chaos. Chapters 14–16, and 28 describe some interesting applications in engineering systems. The selected range of applications, from fluid convection, cardiac activity, jet engine, to ecosystem, impress the readers with the high level of practicality of the theory which was once regarded as being only of academic interest. Readers may also appreciate that throughout the book, practical examples are given, from time to time, to illustrate the application of the theory. This remains as a strong feature of the book, qualifying it as a good reference for engineers and scientists.

Having gone through the technical contents of the book, we move on to other aspect of our evaluation. First, the organization of the book allows multiple entry by the readers. One does not need to read Chapter 1 before reading Chapter 2. This makes the book suitable as a (quick) reference for engineers, scientists, researchers and graduate students. The self-containedness of individual chapters also facilitates this multiple entry feature. However, because the book assumes a basic knowledge of readers in dynamical systems and does not

Table I. Graded evaluation.

Criteria	Poor	Satisfactory	Good	Excellent	Outstanding
Timeliness					✓
Relevance				✓	
Coverage				✓	
Tutorial value					✓
Readability					✓
Suitability as graduate text		✓			
Suitability as reference					✓

contain introductory chapters covering the mathematical prerequisites, it is therefore not very suitable to serve as a graduate text.

The book has a high tutorial value, thanks to the lucid writing style of the contributing authors. Readers can quickly update their knowledge in this field without the need to consult a large number of related publications. Furthermore, compared to other books in this field, the level of use of mathematics is considered moderate and hence should be well suited for engineers and graduate students lacking very advanced mathematical training.

Finally, as mentioned earlier, one important objective of the book is to bridge the multi-disciplinary gap. Toward this aim, the book has done an admirable job. The main ingredient is readability. With the exception of a few very specialized chapters, the majority of the book requires no advanced knowledge of the kinds of systems being addressed. For instance, the description on digital communications (Chapter 22) is readily understood by a mechanical engineer, and the observer perspective of synchronization (Chapter 19) is comprehensible by most readers with a basic control background.

Table I summarizes the evaluation of the book under the different criteria discussed above.

3. CONCLUSION

The book *Controlling Chaos and Bifurcations in Engineering Systems* (Boca Raton, FL: CRC Press, 2000), edited by Guanrong Chen, is a timely, relevant, well covered, highly readable book which is devoted to the emerging field of chaos control. To this reviewer's knowledge, there is no similar book published to date. There are, however, texts that treat the subject in an advanced mathematical setting [4, 12, 13], as well as edited volumes that emphasise chaotic phenomena in engineering and physical systems [14–17]. Thus, the book under review represents a quite unique collection of recent representative work in the field, emphasising *control* and *engineering applications*, and demanding no advanced mathematical background of readers. It is a valuable reference for engineers, scientists, researchers and graduate students who have to deal with physical systems, design engineering systems, or "use chaos" for practical purposes.

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