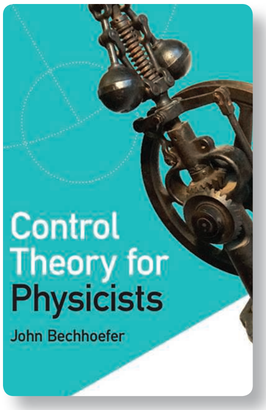
IEEE Control Systems welcomes suggestions for books to be reviewed in this column. Please contact either Scott R. Ploen, Hong Yue, or Thomas Schön, associate editors for book reviews.



Cambridge University Press, 2021,
ISBN: 978-1-107-00118-3,
658 pages, US$79.99.

CONTROL THEORY FOR PHYSICISTS

by JOHN BECHHOEFER

Reviewed by Adilson E. Motter

The origin of control theory is often traced to the work of James Maxwell [1], a physicist. Yet, the theory he seeded never made it to the curriculum of most physics programs. This might be surprising when one considers that his influential work in kinetic theory forms the basis of contemporary research on the thermodynamics of control, where thought experiments such as Maxwell's demon [2] shed light on some of the fundamental limits of control. More than that, thermodynamics itself can be regarded as a control theory [3], where less emphasis is placed on spontaneous changes than on how the state of the system changes when subjected to external interventions. Experimental physicists have long appreciated the use of control tools in their research. However, acquaintance with such tools appear to come more from on-the-job learning than from formal training. Thus, this book is welcome news as it addresses a well-documented need for a comprehensive text tailored to this audience.

The author, Prof. John Bechhoefer from Simon Fraser University, is a physicist with ample experience in experimental implementations of control. His research concerns fundamental and cross-disciplinary aspects of nonlinear dynamics, biophysics, thermodynamics, statistical mechanics, information theory, and control theory. The book builds on his experience as the author of an influential review on control theory for physical scientists [4].

The book is geared toward physicists. Aside from notation and language, how different is it from textbooks for control theorists and engineers? The key differences are threefold. First, the book places emphasis on foundational aspects of control, including physical limitations of control such as causal and information-theoretic limitations. Second, it offers a balanced coverage of topics that takes advantage of concepts familiar to this audience, such as measurement, while elaborating further on concepts that might be less familiar, such as control objectives. Third, the book offers new insights into physical phenomena from a control theory perspective and covers material not usually treated in control theory books, which should nevertheless be of interest to engineers and control theorists. Owing to this structure, the book does well with its promise to "make the strange familiar, and the familiar strange."

CONTENTS

The book is divided into core, advanced, and specialized topics. It begins with an in-depth discussion of the historical development of different branches of control theory covered in subsequent chapters. The presentation is self-contained, with the core material offering the necessary mathematical foundation, including good coverage of the basics of dynamical systems theory. The only hard prerequisites are the standard first few years of college mathematics, as taught to students in the physical sciences and engineering. The narrative is successful in relating pertinent control concepts (such as system identification) with more familiar concepts (such as those associated with measuring and modeling a system's dynamics). The advanced topics include optimal control, robust control, adaptive control, and nonlinear control; they also include stochastic systems, which are of special relevance here, given the emphasis on empirical modeling.

Among the special topics, the sections on control of network systems, quantum control, and thermodynamics are of exceptional interest to current research. In network science, control has received significant attention due to the need to develop scalable methods applicable to large-scale networks and networks with missing information. The control of quantum systems has gained renewed attention in connection with the ongoing surge in quantum information, computation, and communication. Despite the different nature of measurement in quantum systems, many

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implementations of quantum control (for example, in the realization of quantum gates) are not fundamentally different from classical control; accordingly, this portion of the book is a natural continuation of previous chapters. In the discussion about thermodynamics, the reader will note that thermodynamics not only imposes limits to control, but also can be better understood in the context of control.

This is a rare example of a textbook that is concise yet clear, math dense yet very accessible, and rigorous yet beautifully written. The book is written at the upper-undergraduate level but is equally suitable for graduate students and practitioners in general. By also following some of the references cited, the special topics alone can form the basis of a good graduate-level course.

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SUMMARY

This is not the first control book written for physicists. For example, Schulz's volume [5] covers a selection of control topics of relevance to problems considered by physicists at the time it was written, such as the control of chaos. Other books have been written for specialized applications, including [6], which focuses on quantum dynamics, and [7], which is a collection of research articles covering a diverse set of applications.

Notwithstanding, this book is the first to offer comprehensive and broadly accessible coverage of control theory for physicists. In terms of breadth, it compares to [8], albeit with significantly different emphasis. For instance, although the recent second edition of [8] gained a dedicated chapter on limits of control, the focus there is on mathematical limitations, whereas this book emphasizes physical limitations. The treatment throughout prioritizes first-principles descriptions, with an emphasis on not only when control works but also when it fails. It includes well-contextualized examples and well-formulated problems. It is ready for classroom use, with additional resources for instructors—such as a solution manual and associated Mathematica notebooks—available from the publisher. A 100-page supplement on background mathematics is also available on the publisher's website, which provides a comprehensive review of key mathematical topics. As already noted by Hugo Touchette in his back cover endorsement, this book may indeed lead more departments to include control theory in their curriculum.

REVIEWER INFORMATION

Adilson E. Motter (motter@northwestern.edu) is a professor of physics and astronomy at Northwestern University, Evanston, Illinois, 60208, USA. He received his Ph.D. degree in applied mathematics in 2002 and has since focused on the network modeling of complex physical, biological, and engineered systems. His research uses a combination of tools from statistical mechanics, nonlinear dynamics, control theory, and data science. The research topics pursued in his group include control and observability of network systems, cascading dynamics, spontaneous synchronization, and symmetry phenomena; quantum networks, machine learning applied to network problems, and data-driven discovery in network science; and applications to quantitative biology, biomedical research, renewable energy, smart power grids, microfluidics, and metamaterials.

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