Systems & Control: Foundations & Applications

Jon H. Davis

Foundations of Deterministic and Stochastic Control

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Jon H. Davis
Department of Mathematics and Statistics
Queen's University
Kingston, Ontario
K7L 3N6 Canada

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To my parents

Preface

This textbook is intended for use in courses on linear control and filtering and estimation at a variety of advanced levels. It is reasonably self-contained, and is aimed primarily at advanced students and researchers in the areas of automatic control and communications. Among the special topics covered are realizations, least squares regulators, stability, stochastic modeling, and recursive estimation algorithms in communications and control.

A major purpose of the book is an introduction to both deterministic and stochastic control and estimation. The topics discussed have a wide range of applicability. In addition to the standard finite-dimensional linear regulator problems, we also discuss control of distributed parameter systems (systems governed by partial differential equations) based on the framework of linear-quadratic-Gaussian optimization problems. Our approach to these problems utilizes methods (based on Wiener-Hopf integral equations) that provide direct derivation of the basic results, and emphasize parallels between the finite- and infinite-dimensional versions of such control problems.

Communications and stochastic control models have a common model basis, as both can be framed as state variable model estimation problems. Of course, for control purposes, the estimation is part of a larger objective to generate a system control design. For communication models, the estimate is the end in itself, as it typically represents the received message. Communications models can also (especially in the digital communications case) rely on models of a more discrete character than those encountered in the standard stochastic control context.

State variables are the mathematical model for processes that exhibit "memory" in their sequential behavior. Such things occur in the control of systems subject to random disturbances, or tracking flight paths on the basis of noisy measurements.

Other models with a state variable character occur in various communication models. To say that a communication channel has memory essentially means that there is a state variable model for the behavior of the signals in the channel. Another source of state variable models in communications is the operation of encoders, particularly convolutional encoders. The "memory" of the encoder is the source of redundancy in the encoded source stream.

The treatment of the material emphasizes vector space, and in particular inner product space, methods. The required analytical level is comparable to that of contemporary texts on stability theory (*Feedback Systems: Input-Output Properties,* by C. A. Desoer and M. Vidyasagar [25]) and optimization (*Optimization By Vector Space Methods,* by D. G. Luenberger [51]).

The state-space modeling of distributed systems requires some familiarity with semigroups of operators and evolution equations. Our approach to infinite time linear regulators and stationary filtering problems is based on Wiener-Hopf methods, and is applicable to the distributed parameter case. The results can be construed as covering the finite-dimensional case by reading "semigroup generator" as the coefficient matrix.

We also use results (due to Gohberg and Krein) on convolution and Wiener-Hopf integral equations. These are directly applicable to both input-output stability, and least squares control and estimation problems. The background and basic results of this theory are discussed.

Topics are treated in both their continuous and discrete time versions throughout. It is useful to understand the extent to which the problems and answers are "the same", although the detailed formulas differ. Treating the problems through a linear mapping and inner product space framework leads naturally to covering both cases.

The results presented rely for practical application on the availability of algorithms for spectral factorization. In the final chapters we discuss iterative algorithms which follow naturally from the methods employed in the earlier chapters.

The book was produced using a variety of open source and freely available software, including LaTeX2e, ghostview, and the GNU gpic and m4 programs, all running under GNU/Linux.

Thanks are finally due to my editor Ann Kostant and her staff at Birkhäuser who handled the manuscript, and to my wife Susan who supported the project with good humor.

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