Preface

The purpose of this book is twofold. First, it attempts to develop a thorough understanding of the *fundamental concepts* incorporated in stochastic processes, estimation, and control. Furthermore, it provides some experience and insights into *applying* the theory to realistic practical problems.

The approach taken is oriented toward an *engineer* or an engineering student. We shall be interested not only in mathematical results, but also in a *physical interpretation* of what the mathematics means. In this regard, considerable effort will be expended to generate graphical representations and to exploit geometric insights where possible. Moreover, our attention will be concentrated upon eventual implementation of estimation and control algorithms, rather than solely upon rigorous derivation of mathematical results in their most general form. For example, all assumptions will be described thoroughly in order to yield precise results, but these assumptions will further be *justified* and their *practical implications* pointed out explicitly. Topics where additional generality or rigor can be incorporated will also be delineated, so that such advanced disciplines as functional analysis can be exploited by, but are not required of, the reader.

Because this book is written for engineers, we shall avoid measure theory, functional analysis, and other disciplines that may not be in an engineer's background. Although these fields can make the theoretical developments more rigorous and complete, they are not essential to the practicing engineer who wants to *use* optimal estimation theory results. Furthermore, the book can serve as a text for a first-year graduate course in estimation and stochastic control, and these advanced disciplines are not generally studied prior to such a course. However, the places where these disciplines do contribute will be pointed out for those interested in pursuing more rigorous developments. The developments in the text will also be motivated in part by the concepts of analysis and functional analysis, but without requiring the reader to be previously familiar with these fields. In this way, the reader will become aware of the kinds of questions that have to be answered in a completely rigorous derivation and will be introduced to the concepts required to resolve them properly.

This work is intended to be a text from which a reader can *learn* about estimation and stochastic control, and this intent has dictated a format of presentation. Rather than strive for the mathematical precision of a theorem–proof structure, fundamentals are first motivated conceptually and physically, and then the mathematics developed to serve the purpose. Practical aspects and eventual implementation of algorithms are kept at the forefront of concern. Finally, the progression of topics is selected to maximize learning: a firm foundation in linear system applications is laid before nonlinear applications are considered, conditional probability density functions are discussed before conditional expectations, and so forth. Although a reference book might be organized from the most general concepts progressively to simpler and simpler special cases, it has been our experience that people grasp basic ideas and understand complexities of the general case better if they build up from the simpler problems. As generalizations are made in the text, care is taken to point out all ramifications—what changes are made in the previous simpler case, what concepts generalize and how, what concepts no longer apply, and so forth.

With an eye to practicality and eventual implementations, we shall emphasize the case of continuous-time dynamic systems with *discrete-time* data sampling. Most applications will in fact concern continuous-time systems, while the actual estimator or controller implementations will be in the form of software algorithms for a digital computer, which inherently involves data samples. These *algorithms* will be developed in detail, with special emphasis on the various *design tradeoffs* involved in achieving an efficient, practical configuration.

The corresponding results for the case of continuously available measurements will be presented, and its range of applicability discussed. However, only a formal derivation of the results will be provided; a rigorous derivation, though mathematically enriching, does not seem warranted because of this limited applicability. Rather, we shall try to develop physical insights and an engineering appreciation for these results.

Throughout the development, we shall regard the digital computer not only as the means for eventual implementation of on-line algorithms, but also as a *design tool* for generating the final "tuned" algorithms themselves. We shall develop means of synthesizing estimators or controllers, fully evaluating their performance capabilities in a real-world environment, and iterating upon the design until performance is as desired, all facilitated by software tools.

Because the orientation is toward engineering applications, *examples* will be exploited whenever possible. Unfortunately, even under our early restrictions of a linear system model driven by white Gaussian noises (these assumptions will be explained later), simple estimation or control examples are difficult to generate—either they are simple enough to work manually and are of little value, or are useful, enlightening, and virtually impossible to do by hand. At first, we shall try to gain *insights* into algorithm structure and behavior by solving relatively simple problems. Later, more complex and realistic problems will be considered in order to appreciate the *practical aspects* of estimator or controller implementation.

This book is the outgrowth of the first course of a two-quarter sequence taught at the Air Force Institute of Technology. Students had previously taken a course in applied probability theory, taught from the excellent Chapters 1–7 of Davenport's "Probability and Random Processes." Many had also been exposed to a first control theory course, linear algebra, linear system theory, deterministic optimal control, and random processes. However, considerable attention is paid to those fundamentals in Chapters 2–4, before estimation and stochastic control are developed at all. This has been done out of the conviction that system modeling is a critical aspect, and typically the "weak link," in applying theory to practice.

Thus the book has been designed to be self-contained. The reader is assumed to have been exposed to advanced calculus, differential equations, and some vector and matrix analysis on an engineering level. Any more advanced mathematical concepts will be developed within the text, requiring only a willingness on the part of the reader to deal with new means of conceiving a problem and its solution. Although the mathematics becomes relatively sophisticated at times, efforts are made to motivate the need for, and stress the underlying basis of, this sophistication. The objective is to investigate the theory and derive from it the tools required to reach the ultimate objective of generating practical designs for estimators and stochastic controllers.

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