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Book Reviews

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Optimal Estimation of Dynamic Systems

John L. Crassidis and John L. Junkins, CRC Press, Boca Raton, FL, 2004, xiv + 591 pp.

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The authors advertise *Optimal Estimation of Dynamic Systems* as a pain reliever, stating in the preface that "The primary motivation of this text is to make a significant contribution toward minimizing the painful process most newcomers must go through in digesting and applying the theory." Accordingly, their approach, targeted toward senior undergraduate, first-year graduate, and self-study students, emphasizes readability over mathematical formality, preferring to develop intuition by heuristics and practice rather than by lengthy theoretical discussion. The book is the most recent addition to a family of general estimation texts including Gelb et al. [1], Maybeck [2], Stengel [3], and Bar Shalom et al. [4]. Its unique contribution lies in the detail of its examples and applications. These are drawn from the authors' experience in aerospace and mechanical engineering and range from satellite attitude estimation to target tracking of aircraft. The examples and surrounding qualitative discussion provide the framework for the pain-reduced introduction to estimation that the authors intend.

In addition to basic material, each of the book's eight chapters includes a large set of exercises and a long list of references, and many of the chapters include an advanced topics section. Mathematical notation is generally clean and sensible, with very few typographical errors (a total of 36 corrections in the November 2006 errata). Matrix properties, probability fundamentals, and parameter optimization concepts are removed to the three appendices, allowing the reader to get an immediate start with the powerful concept of least squares. A closer look at the first chapter illustrates the authors' teaching style.

Without pausing even to derive the formulas presented, the authors engage the reader from the outset with a curve fitting example, demonstrating the power of least squares and the perils of modeling errors. The introduction here reads almost like a book on magic tricks: first the effect and then the secret. This effective teaching technique is used again in Chapter 5.

Chapter 1 continues with the development of least squares and gives a brief discussion on observability, whose early introduction reflects the authors' goal of making estimation intuitive. The usual variations on least squares follow, with the mechanization of nonlinear least squares presented in a flow chart for convenient programming. A summary of formulas is given at the end of the chapter for the same purpose. An especially useful feature of the book is the MATLAB code (available on the book's Web site) that accompanies every example presented—a feature that underscores the authors' emphasis on gaining insight through practice. Chapter 1 concludes with an advanced topics section for least-squares methods that covers relevant matrix factorizations, the Levenberg–Marquardt method, and a geometrical interpretation. The advanced topics section provides a natural partitioning of primary and esoteric material. The book is obviously structured to present estimation concepts in an engaging and accessible manner.

The remaining chapters are ordered in a natural sequence: Chapter 2 lays out the probabilistic foundations of estimation, Chapter 3 reviews dynamical systems, Chapters 4 and 7 present several applications of estimation, Chapter 5 develops sequential estimation, and Chapter 6 gives an unusually thorough development of smoothing, which it designates as batch estimation. In Chapter 8, the authors develop optimal control methods for linear systems and solve the linear-quadratic-Gaussian problem, thereby demonstrating how an estimator can be used to generate signals for real-time feedback control.

The advanced topics sections include discussions on ridge estimation, total least squares, square-root techniques, adaptive filtering, and unscented filtering. With the exception of particle filtering, for which only references are provided, the book appears technically up-to-date. Although particle filtering is often too expensive computationally when the state dimension is larger than 2, the up-to-date estimation engineer should have a rudimentary knowledge of this subject [5].

Two full chapters (4 and 7) of interesting, in-depth applications are the book's most valuable offering. For example, the GPS positioning application in Chapter 4 is a simple and relevant demonstration of nonlinear parameter estimation. Consider also the 14 pages devoted to attitude estimation in Chapter 7. A straightforward application of the extended Kalman filter to quaternion-based attitude estimation is problematic because of the quaternion normalization constraint. The authors explain this and provide a clear development of a better approach: the multiplicative quaternion formulation. This is followed by a computationally efficient variation on the multiplicative attitude estimator and a section on steady-state covariance analysis. Such a comprehensive synthesis of attitude estimation techniques is unrivaled in other texts on estimation and will surely be a time-saver for newcomers to the subject.

The requisite background material for the applications chapters is furnished by a comprehensive review of dynamical systems in Chapter 3. Linear and nonlinear systems are treated in both continuous and discrete time, followed by subsections covering attitude kinematics and dynamics, orbital mechanics, aircraft flight dynamics, and vibration. A possible weakness of the presentation of dynamical systems is the discussion of observability. The authors derive the standard observability criterion for linear time-invariant systems and note in passing that an extension to nonlinear systems "is possible" (p. 140). A large class of estimation problems involves nonlinear models (as the authors note on p. 285), and students should be taught to use linearization and the linear time-varying observability criterion as an approximation for evaluating nonlinear observability [6].

The book's mathematical informality is potentially troublesome. The structural development of the Kalman filter—a crucial component of any estimation textbook—rests upon a first-order example that, in turn, develops the observer structure based on the adage "when in doubt, use feedback!" (p. 244). A more satisfactory justification for the Kalman filter structure can be had by invoking the Bayesian conditional mean criterion developed in Chapter 2. The authors' use of the linear feedback measurement update and the covariance trace-minimization approach is equivalent to a Bayesian-based minimum mean-square error approach, but an explicitly Bayesian approach has the beneficial effect of developing the reader's understanding of the relationship between probability density functions and estimates. Such an understanding is useful for motivating the gain choice in the Kalman and unscented Kalman filters, and it is essential for the development of optimal nonlinear estimation. The authors' approach is no doubt intended to keep the book accessible to senior undergraduates, but inquisitive newcomers may be unsatisfied with the book's seemingly arbitrary pronouncements about what constitutes an optimal estimator.

The book has no treatment of the multiple model approach, and it gives only a brief introduction to hypothesis testing for purposes of checking Kalman filter consistency [4]. The multiple model approach will likely find increasing future application as hybrid system models, which consider both continuous and discrete uncertainties, become more popular.

The presentation of the square-root information filter would be improved if it included a derivation and an extension to the square-root information smoother. Bierman's formulation would greatly simplify the derivation and mechanization of the propagation step [7].

The reviewers are confident that both newcomers and practitioners of model-based estimation will find much to value in this book. The authors have succeeded in presenting a text with examples and qualitative discussion that make estimation's learning curve less formidable.

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Todd E. Humphreys and

Mark L. Psiaki
Cornell University