AIAA JOURNAL
Vol. 43, No. 1, January 2005

Book Reviews

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Optimal Estimation of Dynamic Systems

John L. Crassidis and John L. Junkins, Applied Mathematics and Nonlinear Science Series, Chapman and Hall/CRC, Boca Raton, FL, 2004, 591 pp., $119.95

Estimation of system parameters and states of dynamic systems play an important role in the modeling and control of dynamic systems. This book gives a comprehensive presentation of the estimation theory from the least-squares-based algorithms to the different variations of Kalman filters. A nice feature of this book is that it makes the effort to explain the underlying principles behind the formula for each algorithm; the relationship between different algorithms is equally well addressed. This helps the reader to get a better understanding of each individual algorithm and to construct a high-level view of the enormous reservoir of estimation algorithms.

The book contains eight chapters and four appendices, among which two chapters are devoted to applications. Besides the fundamental theory and algorithms, most of the chapters include a session on advanced topics. The advanced topics could be used as extra reading material for graduate-level classes and are also useful pointers to the state of the art for engineers and researchers. There is a summary session at the end of each chapter that provides an easy review for the readers. Homework problems are also provided for each chapter.

Chapter 1 addresses least-squares approximation algorithms. It starts with a simple curve-fitting example to motivate the importance of choosing the right model for a particular system. Linear estimation algorithms based on both batch and sequential processes are derived. For the batch estimation, the algorithms for linear least squares, weighted least squares, and constrained least squares are presented. This chapter also discusses the nonlinear least-squares estimation with several examples. Basis functions are presented to construct a system model. The advanced topics are devoted to algorithms that could make more efficient computation in the least-squares estimation.

Probability principles in the least-squares methods are studied in Chapter 2. Minimum variance and maximum likelihood estimations are discussed, and their relations to the weighted least squares are interpreted. This chapter introduces the concept of unbiased estimates and the use of the Cramer–Rao inequality to quantify the bound on the expected errors between the estimates and the true values, in particular for testing whether the estimator is efficient. Bayesian estimation is discussed as well. The advanced topics include the analysis of covariance errors, ridge estimation, and total least squares.

Chapter 3 presents an overview of dynamical systems, which lays a good foundation for the state estimation of dynamic systems in the later chapters. The linear system theory is reviewed, the state transition matrix is derived, and solutions to homogeneous and forced linear dynamical systems are given. The analysis of nonlinear dynamical systems is based on linearization along equilibrium points or trajectories. Lyapunov-based stability theory is introduced. Parametric differentiation and system observability are presented as important concepts in estimation theory. In preparation for the application examples in Chapters 4 and 7, this chapter reviews the governing equations for spacecraft dynamics, orbital mechanics, aircraft flight dynamics, and vibration systems.

Chapter 4 is devoted to the application of estimation theory covered in the first two chapters to global positioning system navigation, spacecraft attitude determination from star photography, orbit determination from ground-based sensors, aircraft parameter identification using on-board measurements, and the modal identification of vibratory systems. A comprehensive list of references for the presented real-world applications is provided for interested readers.

Sequential state estimation is the focus of Chapter 5. The connection to estimation methods regarding parameters in algebraic equations in the first two chapters is discussed. Ackermann's formula is introduced first, and then the Kalman filter is derived. Material is presented to show that the two algorithms share the same filter structure but that the associated gains are derived in different ways. The extended Kalman filter is derived for state estimation in nonlinear dynamical models. This chapter presents the different versions of Kalman filter algorithms for the continuous-time, discrete-time, and hybrid measurement and models. The advanced topics include several popular filtering algorithms such as adaptive filtering, unscented filtering, and robust filtering.

Chapter 6 discusses different smoothing algorithms for the batch state estimation. Both continuous-time and discrete-time versions of fixed-interval smoothing, fixed-point smoothing, and fixed-lag smoothing are provided with details. Most algorithms are listed in tables for clear presentation. The advanced topics address the theory of duality between estimation and control and the innovations process.

In Chapter 7, the sequential Kalman filter and batch estimation algorithms are applied to the examples introduced in Chapter 4. Each application example is carefully worked out, and pointers to the right set of references are provided. Chapter 8 gives a short overview of the optimal control and estimation theory. The topics covered include the calculus of variations, Pontryagin's optimality conditions, linear quadratic (Gaussian) regulators, and the loop transfer recovery. A spacecraft example is presented at the end of the chapter. The appendices cover the basics on matrices, probability concepts, and some parameter optimization methods.

The text is a good combination of theory and practice. It will be a valuable addition to references for academic researchers and industrial engineers working in the field of estimation. It will also serve as a useful reference for graduate courses in control and estimation.

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