APPENDIX B

OTHER BOOKS ON KALMAN FILTERING

> Of making many books there is no end, and much study wearies the body.
> —Solomon [Ecclesiastes 12:12]

Many books have been written over the years that include Kalman filtering. In this appendix, we give a brief review of some of these books in approximately chronological order.

The earliest book that includes Kalman filtering is probably the one by Richard Battin [Bat64]. His book deals primarily with orbital dynamics and spacecraft guidance, but also includes a chapter titled "Recursive navigation theory," which essentially provides an independent derivation of the Kalman filter and applies it to spacecraft navigation. Battin's book includes an interesting section that discusses the determination of the measurement schedule that minimizes the state estimation-error covariance. Richard Lee's book [Lee64], published a few months later, gives more extensive coverage of the Kalman filter, also referred to in the book as the "Wiener–Kalman filter." Ralph Deutsch's book [Deu65] mostly deals with least squares estimation of constants and Wiener filtering, essentially an expanded version of Chapter 3 of the present book. Deutsch's book is notable in that it contains one chapter on "Kalman and Bucy's recently provided alternate approach to the Wiener–Kolmogorov theory which has certain inviting features." Deutsch's book also contains an interesting chapter that reproduces part of Karl Gauss's orig-

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inal work on least squares estimation. Other early books that include coverage of Kalman filtering include those by Masanao Aoki [Aok67] and Paul Liebelt [Lie67]. Richard Bucy and Peter Joseph's book [Buc68] deals mostly with continuous-time filtering. It also discusses the second-order Kalman filter for nonlinear systems (see Section 13.3 of the present book) and includes a lot of material related to aerospace applications. James Meditch's book [Med69] was the first to include extensive coverage of both Kalman filtering and its dual, linear quadratic control. These early books on estimation theory are interesting because they were written when a lot of linear systems material that we take for granted today (state-space descriptions, observability, controllability, etc.) were relatively new concepts in the engineering literature.

Andrew Jazwinski's book [Jaz70] emphasizes the Bayesian approach to optimal filtering and includes much material on nonlinear filtering. Andrew Sage and James Melsa's book [Sag71] includes a chapter on decision theory, which is closely related to (but distinct from) estimation theory. Arthur Gelb's book [Gel74] is still considered a classic in the field, probably because it was the earliest readily accessible text on the topic (in terms of mathematical clarity). The book is dated by now, but still continues to provide a good introduction to Kalman filtering. Gerald Bierman's book [Bie77b] is an excellent reference on square root filtering and related topics. He gives a one chapter review of the Kalman filter, and then spends the rest of the book delving into topics such as matrix factorizations and transformations, square root filtering, and U-D filtering. Mark Davis's brief book [Dav77] includes an interesting section on Kalman filtering for distributed parameter systems (i.e., systems with an infinite number of states). Thomas Kailath's edited volume [Kai77] contains reprints of 20 historically important papers on the topics of Wiener filtering and Kalman filtering. Brian Anderson and John Moore's book [And79] has been an important text and reference for many students of optimal filtering, and is noted for its mathematical rigor.

Peter Maybeck wrote a three-volume series covering state estimation and optimal control [May79, May82, May84] that is another classic in the field. The first volume covers the standard linear filtering material, along with one of the earliest discussions of Kalman filtering for GPS/INS integration. The second volume covers more advanced topics in Kalman filtering, such as smoothing, model uncertainties, and nonlinear estimation. The third volume deals with optimal control.

Harold Sorenson's text [Sor80] includes interesting notes about the historical development of parameter estimation techniques, starting with Babylonian astronomers in 300 BC, continuing with least squares estimation in the 18th and 19th centuries, and concluding with the development of Kalman filtering in the 1960s. Sorenson's later edited volume [Sor85] includes reprints of 45 historically important papers in the area of Kalman filtering. It includes reprints of Swerling's paper [Swe59], Kalman and Bucy's papers [Kal60, Kal61], and many other foundational papers. Frank Lewis's book on state estimation [Lew86b] is notable for the amount of material devoted to connections between Wiener filtering and Kalman filtering. Charles Chui and Guanrong Chen's book [Chu87] has a good discussion of decoupled Kalman filtering, which can reduce computational effort (without necessarily using a steady-state filter). Donald Catlin's book [Cat89] is interesting in that it covers Kalman filtering more from a mathematical and statistical point of view rather than from a systems and engineering point of view.

Athanasios Antoulas's edited volume [Ant91] is also worth mentioning. It was published as a tribute to Rudolf Kalman on the occasion of his 60th birthday. It contains 31 papers on topics that were invented or largely influenced by Kalman, such as system theory, Kalman filtering, optimal control, system realization, and system identification. Guanrong Chen's edited volume [Che93] contains a sequence of chapters that deal with Kalman filtering when the underlying assumptions of the filter are not exactly satisfied. These situations include nonlinear systems (see Chapter 13 of the present book), unknown initial conditions, and unmodeled system information. Bozic's brief book [Boz94] presents a treatment of Kalman filtering within the context of digital signal processing. George Siouris's book [Sio96] is quite useful and contains a chapter on decentralized Kalman filtering, and also includes several flowcharts and Fortran code listings for various algorithms. Robert Brown and Patrick Hwang's excellent book [Bro96], currently in its third edition, is an extensive treatment of Kalman filtering and contains two chapters showing how it can be applied to navigation problems. Yaakov Bar-Shalom, X.-Rong Li, and Thiagalingam Kirubarajan's books [Bar98, Bar01] include extensive discussion of tracking and navigation examples, including adaptive estimation and target tracking. They also include companion software that is an interactive MATLAB-based Kalman filter design tool. Eli Brookner's book [Bro98] deals mostly with tracking applications and includes a lot of discussion of the α-β and α-β-γ filters (see Section 7.3 of the present book). It also includes detailed discussions of the transformations that are required for square root filtering (see Section 6.3 of the present book), and concludes with an appendix written by Peter Swerling that compares his work with Kalman's. Thomas Kailath, Ali Sayed, and Babak Hassibi's compendious volumes [Has99, Kai00] are well worth the effort for the serious researcher. Their first book is more of a research monograph, while their second book is more suitable for general classroom use and self-study. Their material is mostly restricted to linear filtering, and is motivated by the Krein space approach that they pioneered. They also scatter a lot of complementary historical background throughout the text.

Paul Zarchan and Howard Musoff's book [Zar00] is light on theory but is full of practical, real-world examples illustrating applications of the Kalman filter. Mohinder Grewal and Angus Andrews's book [Gre01] contains a useful chapter on practical considerations in Kalman filter implementations. John Crassidis and John Junkins's highly recommended book [Cra04] includes a chapter discussing the duality between Kalman filtering and optimal control (see Section 8.5 of the present book). They also have a Web site with MATLAB code for the examples in the book.

Other books that focus on the topic of Kalman filtering include [Sch73, McG74, Kai81, Goo84, Kri84, Che85, Ott85, Ruy85, Bal87, Men87, Cai88, Min93, Bra89, Har89, Ste94], In addition to all of these texts, there are many other books on topics such as optimal control, signal processing, and time series analysis that include chapters or sections devoted to Kalman filtering.