Book Review

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Fundamentals of Kalman Filtering: A Practical Approach. Progress in Astronautics and Aeronautics, Vol. 190

Paul Zarchan and Howard Musoff, American Institute of Aeronautics and Astronautics, 2000, 664 pp., $99.95, ISBN 1-56347-455-7

With the multitude of books and papers available on the subject, it's hard to believe that a new book on Kalman filtering could fill a gap in the literature. But that is precisely what Paul Zarchan and Howard Musoff have done with this refreshing, easy-to-read book. In my opinion, it is the first primer available on the subject, albeit a voluminous one. The text is reflective of the authors' belief that the best way of learning is by doing. Throughout the chapters, the reader is exposed to numerous simplified, but nontrivial, real-world examples which show how to build and analyze Kalman filters. FORTRAN code is listed for all of the examples and a CD-ROM, containing the FORTRAN code and equivalent MATLAB® and True BASIC codes, is provided with the book. In many of the problems, the authors intentionally misdesign the filter to illustrate what happens when a filter is improperly tuned or improperly constructed. While the scope of the book is limited to the fundamental techniques introduced by Kalman in the 1960's, a novice who works through the presented examples will emerge with a tremendous amount of practical design knowledge. Previous to this publication, to jump-start a novice, I would have handed him or her a copy of Art Gelb's *Applied Optimal Estimation*.[1] My current feeling is that Zarchan and Musoff now have the best instructional book on Kalman filter design on the market and even experienced designers may appreciate some of the nuances that emerge from the examples.

The book contains fourteen chapters. Chapter 1 covers the basic techniques that are used throughout the book. Vector and matrix operations, numerical integration of differential equations, noise, random variables, white noise, state-space notation, and the transition matrix are covered in this chapter. Chapter 2 introduces the method of least squares with focus on polynomial signals with noise-corrupted measurements. It is shown that if the filter-based polynomial is of lower order than the signal polynomial, the filter estimate will diverge, and if the filter-based polynomial is of higher order than the signal polynomial, bad estimates may be obtained because the filter polynomial may respond more to the noise than the signal.

Moving closer toward the Kalman filter, recursive least-squares filtering is covered in Chapter 3. For polynomial signals, it is shown how the batch-processing method of least squares can be converted into recursive formulas. Discrete filter equations are provided for one-state, two-state, and three-state filters accompanied by their respective filter gain formulas. This sets up Chapter 4 where state-space equations are introduced and the discrete linear Kalman filter is presented. It is shown through simulation examples that a polynomial Kalman filter with zero process noise and infinite covariance is equivalent to the corresponding recursive least-squares polynomial filter. The use of a priori information to improve performance and the use of process noise to prevent filter divergence are also illustrated using examples.

Chapter 5 addresses Kalman filters in a nonpolynomial world. Several possible filter designs are applied to two nonpolynomic examples and, as in Chapter 4, the benefits of adding process noise to account for mismodeling of the real world are highlighted. Chapter 6 introduces the continuous polynomial Kalman filter. Using the steady-state condition, filter transfer functions are derived which show how the ratio of the process and measurement noise spectral densities affects the filter bandwidth.

The extended Kalman filter (EKF) is presented in Chapter 7 and in both Chapters 7 and 8, various EKF designs are carried out to estimate the altitude and velocity of a falling object subjected to drag. The use of multiple sensors is illustrated in Chapter 9 where both a Cartesian-based EKF and a polar-based EKF are designed for a cannon-launched projectile tracking problem. Additional insight into EKF design is provided in Chapters 10 and 11 through the use of a sine wave tracking problem and a satellite navigation problem, respectively. The satellite navigation problem is also used in Chapter 12 to illustrate how measurement biases can be handled.

The linearized Kalman filter (LKF) is introduced in Chapter 13 where it is demonstrated that the estimates of the LKF will degrade if the nominal trajectory is not accurate. The book is then closed with a miscellaneous topics chapter which addresses increased signal-to-noise ratio, the availability of only a small number of measurements, the detection of filter divergence in the real world, the presence of unobservable states, and sensor aiding.

The book is ideal as a first course in Kalman filtering at either the senior undergraduate level or first-year graduate level. Knowledge gained from this book will enable the student to fully appreciate more theoretical and advanced treatments of the subject. Additionally, this book should be on every senior engineer's desk who may have the task of giving a young engineer on-the-job training in Kalman filtering. Kudos to the authors for an outstanding book.

References

[1]Gelb, A., *Applied Optimal Estimation*, Massachusetts Inst. of Technology Press, Cambridge, MA, 1974.

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