Book Review

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Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems, 2nd edition,

Paul D. Groves,

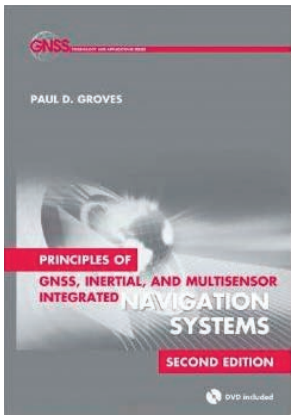
Artech House, Boston/London, 2013,
ISBN-13: 978-1-60807-005-3,
Hardcover: 776 pages (Hard cover) + DVD

Review by Michael Braasch

This second edition of Dr. Grove's book (the original was published in 2008) could arguably be considered a new work. At just under 1,000 pages (including the 11 appendices on the DVD), the second edition is 80% longer than the original. Frankly, the word "book" hardly seems adequate, considering the wide range of topics covered. "Mini-encyclopedia" seems more appropriate. The hardcover portion of the book comprises 18 chapters, and the DVD includes the aforementioned appendices plus 20 fully worked examples, 125 problems or exercises (with answers), and MATLAB routines for the simulation of many of the algorithms discussed in the main text. Here is a brief overview of the contents:

- Chapters 1–3: an overview of the diversity of positioning techniques and navigation systems; fundamentals of coordinate frames, kinematics and earth models; introduction to Kalman filtering
- Chapters 4–6: inertial sensors, inertial navigation, and lower-cost dead reckoning systems
- Chapters 7–12: principles of radio positioning, short-, medium-, and long-range radio navigation, as well as extensive coverage of global navigation satellite systems (GNSS)
- Chapter 13: environmental feature matching.
- Chapters 14–16: various integration topics, including inertial navigation system (INS)/GNSS integration, alignment, zero-velocity updates, and multisensor integration
- Chapter 17: fault detection.
- Chapter 18: applications and trends

As can be surmised from the sheer size of the book, one of its distinguishing features is the depth of treatment given to many of the topics covered. The introductory material (Chapters 1–3) comprises well over 100 pages. Thus, Dr. Groves is able to cover finer points that are ignored by many other books (e.g., the need to use a four-quadrant arctangent function to extract yaw and roll from a body-to-navigation direction cosine matrix). In addition to presenting all of the necessary equations, Dr. Groves frequently calls the reader's attention to issues that must be addressed to succeed in implementing them. For example, in the Kalman filter chapter, he discusses the criticality of the ratio of the initial prediction error covariances (P−) and the measurement error covariances (R) and how the ratio impacts error propagation. Later in the INS/GNSS integration chapter, he provides a very practical treatment of state selection and observability. The reader is clearly shown, for example, why heading error is unobservable in the absence of horizontal acceleration.



The inertial chapters provide overviews of all modern sensing technologies (legacy technologies are covered in the DVD) and error characteristics, along with full development of the mechanization equations. The chapter on the principles of radio positioning provides an excellent treatment of range-based positioning and touches on proximity-based positioning and signal strength-based techniques, including pattern matching, as well as Doppler, differential positioning, and time difference of arrival techniques. The section on resolution, noise, and tracking errors is another example of Dr. Groves' attention to practical details. He explains why noise makes signal peak tracking problematic and why the preferred timing and phase measurement method involves the tracking of signal zero crossings.

Given the proliferation of satellite-based radio navigation systems (global positioning system (GPS): United States; GLONASS: Russia; BeiDou: China; and Galileo: European Union) and augmentation systems (e.g., Wide Area Augmentation System, European Geostationary Navigation Overlay Service, Multi-Functional Satellite Augmentation System, and GPS-aided geo-augmented navigation), it is a challenge simply to present all of the core architectures, constellations, signal types, and data

messages, along with the necessary treatment of satellite position and velocity determination. Nevertheless, this has been done quite satisfactorily in the chapter on GNSS fundamentals. The chapter on GNSS user equipment processing provides an overview of the typical receiver architecture and discusses the signal processing tasks of acquisition, code/carrier tracking, data demodulation, and measurement of pseudorange and carrier phase. This chapter also provides an overview of the various error sources, including those that are satellite-based (clock and ephemeris), atmospheric (ionosphere and troposphere), and receiver based (noise and multipath). Single-epoch and Kalman filter-based position solution techniques are also presented. The GNSS advanced techniques chapter provides an overview of numerous techniques, including differential GNSS, carrier phase-based positioning and attitude determination, interference rejection/mitigation, assisted GNSS, and shadow matching (a technique invented by Dr. Groves).

The long- and medium-range radio navigation chapter touches on terrestrial-based systems, such as the distance measuring equipment, very high frequency omni-range, enhanced Loran, cellular-based ranging and positioning, beacons and amplitude modulation, frequency modulation, and digital television ranging. The short-range positioning chapter provides an overview of pseudolites, ultrawideband positioning and the use of short-range communication systems for positioning (Wi-Fi, wireless personal area networks, and radio-frequency identification, and Bluetooth), and touches on underwater acoustic positioning. The chapter on environmental feature matching provides an introduction to map matching, terrain-referenced navigation, and image-based navigation.

The INS/GNSS integration chapter discusses the three major architectures: loose coupling (position/velocity aiding), tight coupling (pseudorange and carrier-phase aiding), and deep coupling (tracking-domain integration), and the DVD contains example simulations of loose and tight coupling. The alignment chapter discusses not only coarse and fine alignment but also provides a thorough overview of transfer alignment as well. The chapter also touches on zero-velocity and zero angular rate updates along with motion detection. The next chapter addresses multisensor integration and begins with a treatment of the three main integration architectures (cascaded, centralized, and federated). The chapter also discusses attitude and heading reference system processing along with odometry, pedestrian dead reckoning, and integration of various position-fixing measurements.

The chapter on fault detection first provides an overview of failure modes of the various systems described earlier in the book. It goes on to discuss fault detection via monitoring of Kalman filter innovations, as well as receiver autonomous integrity monitoring and also discusses the topics of alert levels and protection levels necessary in civil aviation. The final chapter of the book is focused primarily on overviews of various navigation applications (e.g., aviation, unmanned aerial vehicles, land vehicles, rail, marine, underwater, space, and pedestrian), including application-specific architectures and performance requirements.

By far, the most significant limitation of the book is the paucity of examples. There are no examples provided in the hardcover, nor in the appendices. The DVD does provide, separately, 20 fully worked examples in both Excel and portable document format. The Excel versions have the especially nice feature of being editable. The user can thus change input values and immediately see the effects on the results. However, in a book that spans nearly 1,000 pages and has dozens of algorithms and many hundreds of equations, a mere 20 examples can leave the average reader struggling to understand fully some of the key concepts.

An appendix addresses the topic of simulation, and the MATLAB simulation files on the DVD have demos on various aspects of GNSS and INS (along with ground-based radio positioning, pattern matching, and image-based positioning) and integration. Although the scenarios are somewhat simplified (e.g., GNSS measurement noise is white Gaussian only), the simulations do provide additional examples of how the equations are put into practice. The only glaring omission in this section is the lack of treatment of covariance simulations (e.g., off-line Kalman filter covariance analysis). The appendix presents only run-time-type simulations.

In summary, this book is an excellent reference (with numerous nuggets of wisdom) that should be readily handy on the shelf of every practicing navigation engineer. In the hands of an experienced instructor, the book will also serve students as a great textbook. However, the lack of examples integrated in the main text makes it difficult for the book to serve as a self-study guide for those that are new to the field.◆