Guide for First Edition Readers

Paul D. Groves

1	Introduction	R-1
2	Coordinate Frames, Kinematics, and the Earth	R-1
3	The Kalman Filter	R-2
4	Inertial Sensors	R-2
5	Inertial Navigation	R-2
6	Satellite Navigation Systems	R-2
7	Satellite Navigation Processing, Errors, and Geometry	R-2
8	Advanced Satellite Navigation	R-3
9	Terrestrial Radio Navigation	R-3
10	Dead Reckoning, Attitude, and Height Measurement	R-3
11	Feature Matching	R-3
12	INS/GNSS Integration	R-3
13	INS Alignment and Zero Velocity Updates	R-3
14	Multisensor Integrated Navigation	R-4
15	Fault Detection and Integrity Monitoring	R-4
16	Appendices	R-4
17	Other New Material	R-4

The second edition of *Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems* is almost a new book. It is about 60% larger than the first edition and has been restructured with eight chapters new or substantially rewritten and the remaining ten chapters thoroughly revised. There is a CD as well, containing the appendices, problems and exercises, worked examples, and MATLAB software. To make room for even more material in the book, some items from the first edition have been relegated to the appendices on the CD.

The notation and terminology from the first edition has largely been retained. However, there are changes, particularly concerning GNSS notation.

This document summarizes the changes and is structured in the order of the first edition to help those readers moving over from that edition find what they are looking for in the new book.

1 Introduction

The introductory chapter has been completely rewritten to emphasize the fundamental concepts and taxonomy of navigation systems. Most of the historical notes have been taken out. Instead, navigation history is covered by Section E.4 of Appendix E, Section G.2 of Appendix G, and all of Appendix K on the CD.

2 Coordinate Frames, Kinematics, and the Earth

All of the second chapter has been retained in the new edition. Attitude representations have been split into a separate section; otherwise, the structure is unchanged. The new chapter is 50% larger with new topics including motion with respect to a rotating reference frame, Earth tides, and projected coordinates.

3 The Kalman Filter

All of the Kalman filter chapter has been retained except for the Schmidt-Kalman filter, which is now in Appendix D on the CD. Sections on the unscented Kalman filter and the particle filter have been added and more space devoted to examples.

4 Inertial Sensors

The inertial sensors chapter is similar to the first edition. The error characteristics section has been expanded, while spinning-mass gyros have been moved to Appendix E on CD. New material in the appendix includes notes on new sensor technologies and all-accelerometer IMUs.

5 Inertial Navigation

The inertial navigation chapter also retains most of the content and structure of the first edition. A substantial introduction and sections on the indexed IMU and partial IMU have been added. The navigation equations precision section has been restructured and the error propagation section expanded. The platform INS and notes on iteration rates have been moved to Appendix E on CD. New material in the appendix includes descriptions of the quaternion attitude update and local tangent-plane frame navigation equations, and a discussion of the effects of timing errors.

6 Satellite Navigation Systems

The introduction to GNSS and descriptions of the constituent systems are now in Chapter 8. This has been completely restructured and is now organized by theme instead of by system. The fundamentals section has also been re-ordered. Details of the space and control segments, historical notes and some of the notes on the signal designs have been moved to Appendix G on CD, as they are of less interest to readers of a book on integrated navigation. However, they have also been expanded. The description of the first-generation Beidou system has been moved to Appendix F.

7 Satellite Navigation Processing, Errors, and Geometry

Sections 7.2 to 7.5 of the first edition now comprise Chapter 9 of the second edition. Most of Section 7.1 has been moved to the new Chapter 8, with additional material in Appendix G on CD. The effect of signal geometry on positioning accuracy is now at the end of Chapter 9. Vector tracking has moved to the new Chapter 10. Some of the material on C/N_0 from the first edition is now in Appendix G. Within Chapter 9, the acquisition section has been expanded and there is more on BOC tracking, the ionosphere, troposphere, multipath, diffraction, and NLOS reception, supplemented by further new material in Appendix G.

Some changes to the GNSS notation have been implemented to make it clearer:

- Range is denoted by r instead of ρ_T;
- ADR is denoted by Φ instead of $\Delta\rho_{ADR}$;
- For pseudo-ranges, a superscript is used to denote the transmitting object and a subscript to denote the receiving object;
- The range error due to a clock is now denoted generically by $\delta\rho_c$, with a superscript used to denote the object containing the clock;
- The notation used to denote the various GNSS error sources has changed; subscripts I, T, and M, denote ionosphere, troposphere, and multipath, respectively, while tracking errirs are denoted by w_ρ for pseudo-range, w_r for pseudo-range rate, and w_Φ for ADR;
- The notation $\Delta\rho$ is no longer used to denote a correction, instead estimated errors, denoted by a carat, '^', are used, which generally have the opposite sign to corrections;
- The geometry matrix is denoted by **H** instead of **G**, as it is the same as the measurement matrix used in Kalman filter-based and least-squares estimation.

8 Advanced Satellite Navigation

Advanced GNSS comprises Chapter 10 of the second edition. The differential GNSS section from the first edition has been retained. The carrier-phase positioning and attitude section has been rewritten and expanded with additional material in Appendix G on CD. The sections on poor signal-to-noise environments and multipath mitigation have been reorganized and expanded to incorporate the latest techniques with some material, both old and new in Appendix G. Aiding and assistance are now described in a separate section, together with orbit prediction. The section on signal monitoring has moved to the new Chapter 17, while semi-codeless tracking has moved to the new Chapter 9. A new section on shadow matching has been added.

9 Terrestrial Radio Navigation

Coverage of terrestrial radio navigation has been substantially expanded and spans three chapters in the second edition. Chapter 7 describes the underlying principles of radio positioning, many of which also apply to GNSS. Chapter 11 describes long- and medium-range radio navigation. It includes expanded coverage of DME, mobile phone positioning, and positioning using television and radio broadcasts. The Loran section has been updated and subsections on future air navigation systems, Iridium positioning, and marine radio beacons added. The instrument landing system and Position Location Reporting System have moved to Appendix F on the CD, which also includes new descriptions of the microwave landing system and a number of radio tracking systems. Chapter 12 describes short-range positioning using radio and other types of signal. Coverage of pseudolites, UWB, short-range communication systems, and underwater acoustic positioning has been expanded, while ultrasound, infrared, optical, and magnetic positioning are also discussed.

10 Dead Reckoning, Attitude, and Height Measurement

Chapter 10 of the first edition, covering dead reckoning, attitude, and height measurement, is Chapter 6 of the second edition. The sections on odometry and pedestrian dead reckoning using step detection have been expanded, while additional attitude measurement methods have been added. In the second edition, image processing and landmark tracking are incorporated within Chapter 13's image-based navigation section.

11 Feature Matching

Chapter 11 of the first edition is incorporated within Chapter 13 of the second, which is more than twice as big. The section on TRN and subsections on stellar navigation, gravity gradiometry, and magnetic field variation have been retained and updated. The map matching and image matching sections have been replaced by much larger sections that are both broader and deeper. The descriptions of SMAC and CVN have moved to Appendix H on CD, which also discusses some alternative environmental features that could be used for navigation in the future.

12 INS/GNSS Integration

Chapter 14 of the second edition is an expanded version of Chapter 12 of the first, retaining the same structure. More space is devoted to deeply coupled integration (called deep integration in the first edition), state observability, additional error states, system noise modeling, initialization, carrier-phase positioning, and GNSS attitude. In addition, Appendix I on CD adds several alternative formulations of the integration algorithms.

13 INS Alignment and Zero Velocity Updates

The transfer alignment and quasi-stationary alignment sections from Chapter 13 of the first edition are retained in Chapter 15 of the second with alternative formulations added in

Appendix I on CD. The new Chapter 15 contains an expanded and rewritten section on zero updates and a new section on vehicle and pedestrian motion constraints.

14 Multisensor Integrated Navigation

Chapter 16 is a substantially revised and expanded version of the multisensor integration chapter. It is almost twice the size of the first edition's Chapter 14. The integration architectures section includes expanded coverage of single-epoch integration architectures and new sections on primary and reversionary moding, and on context-adaptive moding. The remainder of the chapter, describing the integration of dead reckoning, attitude, height, and position-fixing measurements has been restructured and deepened. Terrestrial radio navigation and environmental feature-matching measurements are now described together according to measurement type: position, range, angular measurement, and line fix. Subsections on feature tracking and mapping, and aiding have been added. Appendix I on CD adds descriptions of the integration of velocity and range-rate measurements and presents alternative formulations of the system and measurement models presented in Chapter 16.

15 Fault Detection and Integrity Monitoring

Chapter 15 of the first edition is incorporated within Chapter 17 of the second. The introduction and the section on certified integrity monitoring have been revised to clarify some of the definitions. A discussion on the effect of measurement geometry on consistency checking has been added.

16 Appendices

Appendix A on vectors and matrices and Appendix B on statistical measures have moved from the book to the accompanying CD. Appendix B has been greatly expanded to include probability, random processes, and hypothesis testing.

17 Other New Material

A new section on testing has been added to Chapter 17, supported by Appendix J on CD, which provides an overview of the issues to consider when designing a software simulation of a navigation system.

The final chapter, Chapter 18 is entirely new. It begins with a discussion of the design and development process for navigation systems. It then discusses how the technology described in the book may be deployed in a variety of applications in the air, on land, on and in the sea, and in space. It then concludes by discussing future trends in navigation and positioning technology.

On the CD, Appendix C discusses position representations, transformations, and conversions, supporting Chapter 2. Appendix D includes a derivation of the least-squares estimation algorithm and further information on particle filtering. Appendix K provides descriptions of historical systems including Transit, Omega, Decca, and earlier versions of Loran. A set of more than a hundred problems and exercises, with answers are provided. There are also worked examples, which are editable using Microsoft Excel and MATLAB software simulating INS, GNSS, and their integration.