Strapdown Inertial Navigation Technology – 2nd Edition

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Anyone exercising outdoor activities as scouting, hunting, or wildlife photographing – not to mention walking in the city – plus those of us engaged with defense activities can state it is more convenient to get lost if one knows where this happens. Perhaps this is one of the key reasons why methods and technologies for navigation have been an area of continuing efforts and interest. After the introduction of fast moving vehicles, and later when defensive or hostile weapons came into use, it was not sufficient to know where the platform was located but it was really vital to be aware of its momentary alignment, of course, in a three dimensional space. New challenges were put to the shoulders of the navigator. When time, equipment, and location allow, navigation relying on external references such as radio beacons on ground or up in the space orbits are often preferred. However, such cooperative systems may not be available, or their performance is inadequate for the short time constants of platform motion. We are thus forced to use autonomous navigation modes. It is here that inertial navigation systems have, for long, been the way to go. First, we had simple gimbals, the mechanical spinning gyroscopes and later came fiber optic laser devices. *"Strapdown Inertial Navigation Technology"* by Prof. David Titterton and Dr. John Weston is a new entry to this complicated field, surely of interest to many *Systems* readers.

A brief quantitative study of this book indicates 558 relatively dense-packed pages containing 15 chapters, four appendices, an alphabetical *Index* of some 1000 words and a *List of Symbols*. The size of individual chapters varies from less than about ten pages to over 60. Line drawings (both graphic presentations of functions and pictures of equipment constructions) and photographs are extensively used so that their total number is roughly 250. Unavoidably a book about navigation gets mathematical in nature and here the amount of equations is close to 390. Matrices, vectors, and integrals are needed constantly. The authors have not followed a strict logic in the internal arrangement. This can be seen in the treatment of tables. The first half of *"Strapdown Inertial Navigation Technology"* has many tables without any numbering, just data and headings placed in small rectangular boxes. However, later the authors have selected conventional numbering and have discarded frames. Due to this, we are unable to give any value for the amount of tabulated information. Most publishers seem to prefer references placed after each chapter. Therefore, even considerable overlapping may occur. Anyhow, the total of references is about 210.

After a very short introduction in Chapter 1, Chapter 2 gives a historical perspective to inertial navigation and briefly defines some of the fundamental concepts. First, *"strapdown"* is the alternative for *"stable."* Systems in this book allow full rotational motion of the sensor at hand, not just linear movements. A more thorough treatment follows in Chapter 3, where we read about rotating and reference frames, inertial mechanizations, attitude representations, and navigation equations. Then, in Chapter 4 we have a description of various mechanical gyroscopes including rate sensors, vibrating gyroscopes, fluid sensors, and fluxgates. Optical sensors are discussed in Chapter 5 where the fiber optic and ring laser devices get a lot of attention. Chapter 6 is about accelerometer and multi-sensor technologies such as solid state accelerometers and inclinometers. Micro Electro Mechanical Sensors, MEMS in brief, are covered in Chapter 7. Various forms of MEMS devices, (pendulous mass, resonant and tunneling) are illustrated. Entire integrated MEMS inertial units are included. Chapter 8 defines means, methods, and practices for testing, calibration, and compensation. Separate sections are devoted to gyroscopes and accelerometers. Then, in Chapter 9 we learn about the main point, strapdown system technology. Interesting elements such as skewed sensor configurations are highlighted. Chapter 10 tells the reader how to align the inertial system, either on the ground, at sea, or in the air. Computation requirements and algorithmic solutions for strapdown inertial systems are outlined in Chapter 11, separately for attitude computation and for acceleration vector transformation. A generalized system performance analysis is in Chapter 12, with a comprehensive discussion of errors, error budgets, and error accumulation. Navigation systems having other sources of location information to supplement inertia are discussed in Chapter 13. Here, a look at Kalman filtering in aided inertial navigation is given as well. A realistic design example, although a rather compact one, is given in Chapter 14. The platform is a surface-launched tactical missile. Finally, Chapter 15 illustrates the growing set of less well-known applications of inertial navigation sensors such as ground vehicle stabilization, artillery pointing, agricultural survey, and geodetic devices. The first Appendix is a dense view of Kalman filtering, Appendix B defines some statistical error budget fundamentals in the form of distributions, Appendix C shows the two fundamental inertial system configurations (stable platform and strapdown) and the last has two tables of comparison for GPS and GLONASS satellite systems. There is also a *Glossary of Principal Terms*.

It is sad indeed that our sister organization in the UK, The Institution of Electrical Engineers, seldom publishes full biographies of their new authors. Or maybe the British authors prefer a "low profile?" As other reliable sources were not available for this review, we are forced to repeat only the very condensed data given by the book's sales promotion material. Professor Titterton works in the British DSTL, a set of UK government laboratories for military scientific research. He holds the DSTL College of Fellows position, based on his merits as a distinguished scientist and is currently a team leader in the field of laser systems. Parallel to this, he is a Professor at the University of Cranfield. Dr Weston is a Principal Scientist at Sperry-Sun in Halliburton. His main research topics at the moment are focused at inertial and gyroscopic systems needed for the surveying of underground pipelines and well bores. He has also worked in the field of missile guidance and control, originally with British Aerospace.

The general appearance of *"Strapdown Inertial Navigation Technology"* is professional. This review revealed no major technical errors. The authors have been able to simultaneously write in an easily understandable way and yet maintain an adequate accuracy of expression. Also a non-native user of the English language – such as this reviewer – should have no major problems in following the text. Playing with vectors in space and multiple differential equations plus coordinate transformations cannot be just elementary school algebra. The reader must concentrate on those parts to get a true understanding. It certainly would have added to the value of this book if selected sections had some worked numerical examples. Now most of the equations remain "dead" as the reader cannot readily get a touch to the respective real world and relevant parameter values. Descriptions of system components and existing hardware are clear and useful, because the authors have been able to find pretty up-to-date designs and products. For this European reviewer, device examples coming not only from the North American continent are a reason for special delight. It cannot be just by accident that the authors have taken in their selected references the original papers of Sagnac from 1913 and Michelson from 1925. This shows a very solid sense of background. Of course, much of the remaining references are more up-to-date. Items after 2000 appear as well.

It looks as if the IEE has a high standard for print quality. Illustrations are not scanned photocopies but I think all of the drawings have been prepared for this book only. Details are meaningful and captions or text inserted into the drawings give valuable information, especially pictures showing the internal – though schematic – arrangements of inertial sensors and systems are of very high quality and help in understanding the topic. Photographs are also used to some extent and many are interesting despite at times the increase in information is not immense. Apparently many graphs containing measured sensor performance characteristics, such as those in Chapter 8, have no scaling due to their classified content. However, it might have been nice to have at least one example with realistic numerical values as well.

Much of the text in the first half of this book deals with general inertial principles and sensor technology fundamentals. It is clear the author's target is true strapdown systems, but possibly the title of the book could have been less restrictive. Maybe *"Fundamentals of Inertial Navigation Technology"* would have been fine. Now there is the risk that potential readers might overlook this book because of the too- narrow title. Otherwise the logic inside the covers looks precise and carefully thought-out. Of course, some of us might consider Appendix C less necessary. Perhaps the authors could have placed this basic discussion in the introduction. The treatment of Kalman things is of adequate depth but one realistic example containing numeric input would have been a fantastic add-on. Speaking about examples, the case in Chapter 14 is very attractive and the authors carefully define the desired target values and discuss various alternative approaches. Unfortunately, the example itself is not really worked through but results seem to pop up from *Alice's Wonderland.* The step-by-step method would have been here a more appropriate way to go. A slight flavor of a too hasty proofreading remains. As mentioned above, tables generally have no numbering. Well, equations occasionally appear without numbers as well, for example in Chapter 7 on page 204. And a couple of photographs, e.g., Fig. 5.12 and Fig. 15.35 suffer from excessive zooming and the original raster comes up.

"Strapdown Inertial Navigation Technology" has many strong sections and details worth studying. The entire Chapter on sensor testing is practical and the authors included lots of useful tips for a first-time gyroscope experimenter. Comparisons between sensor technologies on types in Chapters 4 and 5 look valuable indeed. MEMS pieces are well explained and illustrated – as has been done in other recent books. Those of us currently involved in entire systems, e.g., for the defense sector, may find the generalized analysis tools useful. Also exotic sensor principles and applications, such as the use of cold atoms are discussed. Many drawings of the category "how this works," such as the different variations of fiber optic sensors, are very informative and well documented. A small illustration, showing the scale of factors due to our planet Earth perturbing ring laser gyro measurements, is in its simplicity a very fine example of thorough thinking and a nice educational touch. Circuit diagrams do not exist, design outlines for such are not given and most of the numerical data reflecting device performance is order-of-magnitude only, unsuitable as a dimensioning base. Equipment principles come up in block diagrams. This is a system designer world; others must consider the electronics needed.

Titterton and Weston have done a fine job in the 2nd edition of *"Strapdown Inertial Navigation Technology."* Modern navigation books are not common and technologies mandatory for inertial sensors are generally quite diverse. This book is worth considering, if looking for a comprehensive course text for fourth year university courses (perhaps better for post graduate lectures). A system designer needing inertial sensors but not having own solid experience certainly finds use for this volume.

– Reviewed by Pekka Eskelinen