

Preface

The purpose of this reference and handbook is to describe and to derive the analytic solutions of the equations of satellite motion perturbed by extraterrestrial and geopotential disturbances of the second order. The equations of satellite motion perturbed by extraterrestrial disturbances are solved by means of discretization and approximated potential function as well as Gaussian equations. The equations perturbed by geopotential disturbances are solved by symbolic mathematical operations. The traditional problem of singularity in the solutions is solved by so-called singularity-free orbit theory. Simplified disturbed equations of motion are proposed to simplify the solutions. Applications of the theory for analytic orbit determination are also discussed. Indeed, this is the first book since the satellite era, which describes systematically the orbit theory with analytical solutions, with respect to all of extraterrestrial and geopotential disturbances of the second order, and the solutions are free of singularity. Based on such a theory, the algorithms of orbit determination can be renewed; deeper insight into the physics of disturbances becomes possible; the way to a variety of new applications and refinements is opened.

My primary knowledge of the orbit theory came from my education of mathematics while studying physics and theoretical mechanics (1981). My first practical experience with orbit came from the research activity at the Technical University (TU) Berlin on orbit corrections of the satellite altimetry data (1988–1992). The extensive experience on orbit came from the GPS/Galileo software development for orbit determination and geopotential mapping at the GFZ (2001–2004). The traditional adjustment model of the solar radiation used in numerical orbit determination is investigated and considered not reasonable physically; and a new adjustment model is proposed in the user manual of the Multi-Functional GPS/Galileo software (MFGsoft) (Xu, 2004), which is also reported in the 2nd edition of the book *GPS – Theory, Algorithms and Applications* (Xu, 2007). Indeed, one of the ways to obtain the solutions of the extraterrestrial disturbances of the satellite motion is found during that investigation. However, it has not been realised until two scientists, Dr. Xiaochun Lu and Dr. Xiaohui Li of the National Time Service Center (NTSC) in Xi'an, came to visit and to cooperate with me at GFZ. We discussed the virtual navigation system and tried to solve the stability problem of the 3-D positioning of

the system. By considering what is significant in theory and, what is more important than our numerical study, the idea of solving the disturbed equations of motion was obtained, and the solutions of the extraterrestrial disturbances of the equation of satellite motion were found. Because of the importance of the geopotential disturbances, great efforts were then made to derive the related solutions. Thereafter, alternative solutions of the extraterrestrial disturbances were found by using different means (besides the discretization, also approximated potential function and Gaussian disturbed equations). To simplify the solutions, the simplified disturbed equations were proposed. To solve the problem of singularity, the singularity-free theory was also developed.

After publishing my book, *GPS – Theory, Algorithms and Applications*, in 2003, I did not want to ever write another scientific book because this process took more than two years extreme hard work. However, I must finish this book because some of the scientists have contributed their lifetime to the theoretical solutions of the geopotential disturbances of the equation of satellite motion and now the results are here. The solutions of the extraterrestrial disturbances of the orbit motion are of extreme importance for practice, but they are rarely investigated because they are highly complex. From the theory, a special confusion related to the solar radiation from the pure numerical orbit determination has been cleared. Many interesting applications will follow soon. To make the process of writing easy, a small portion of the basic contents of my GPS book is partly modified and imported or rearranged and used.

The book includes ten chapters. After a brief introduction, the coordinate and time systems are described in the second chapter. The third chapter is dedicated to the Keplerian satellite orbits – the orbits of the satellite under the attraction of the central force of the Earth.

The fourth chapter deals with perturbations of the orbit. Perturbed equations of satellite motion are derived. Perturbation forces of the satellite motion are discussed in detail, including the perturbations of the Earth's gravitational field, Earth tide and ocean tide, the sun, the moon and planets, solar radiation pressure, and atmospheric drag, as well as coordinate perturbation.

The fifth chapter covers the analytic solution of \bar{C}_{20} perturbation, including the complete formulas of the long term, and long and short periodic terms. The derivation also gives the algorithm and model of the orbit correction. The solutions of other geopotential disturbances of higher order and degree are described in the sixth chapter. As examples, solutions of disturbances of \bar{C}_{30} , D_{21} and D_{22} are given. General solutions of disturbance of D_{lm} are derived. Symbolic operation software for deriving solutions of geopotential disturbances of any order and degrees are designed and used.

The seventh chapter covers the solutions of extraterrestrial disturbances such as solar radiation pressure, atmospheric drag and the disturbances of the sun, the moon and planets. The principle and strategy that lead to the solution are described. The solutions are derived via discretization and approximated potential function as well as Gaussian perturbed equations of motion. Simplified disturbed equations are

proposed and used partly. The ephemeris of the sun, the moon and planets are given for practical use.

The eighth chapter is dedicated to numerical orbit determination, including its principle, the algebraic solutions of the variation equations, and the numerical integration and interpolation algorithms, as well as the related derivatives.

The ninth chapter describes the principle of analytical orbit determination based on the proposed new solutions. Real time ability and properties of the analytic orbit solutions are discussed.

The final chapter includes algorithms that lead to singularity-free orbit theory and the equations of motion in non-inertial frame as well as discussions concerning the further development of the orbit theory and its applications as well as comments on some remaining problems.

The book has been subjected to an individual review of chapters and sections and a general review. I am grateful to reviewers Prof. Markus Rothacher of GFZ, Prof. Dieter Lelgemann of TU Berlin, Prof. Yuanxi Yang of the Institute of Surveying and Mapping (ISM) in Xi'an, Dr. Jianfeng Guo of Information Engineering University (IEU) in Zhengzhou, Prof. Xuhai Yang of NTSC in Xi'an, Dr. Junping Chen of GFZ. A grammatical check of technical English writing has been performed by Springer Heidelberg.

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