Preface

The practice of science could be described as the process of observation followed by the construction of verbal or mathematical models to explain the observations, or vice-versa. The use of the mathematical models implies that the observations are quantitative, that they involve numbers used to specify the observations. The successful application of any science depends on the use of an appropriate mixture of principles, techniques and approaches. Sometimes principles are easily understood, sometimes so difficult as to be opaque. Often some rejection takes root in the dry mathematical form in which the subject is presented, unrelated to observation, quite irrelevant to life, and lacking any form of interest. Setting problems based on a wide variety of experience should engage interest, challenge and intelligence and even stimulate curiosity. The wealth of detail offered should not lull the reader into thinking that the material can be meaning by leafing through the book. As much time as possible it should be devoted to going through the calculations and solving problems.

Analytical solutions to nonlinear differential equations or linear differential equations with variable coefficients play an important role in the study of nonlinear dynamical systems, but sometimes it is difficult to find these solutions, especially for nonlinear problems with strong nonlinearity. In general, the known analytical methods are restricted to limited cases depending on the parameters which appear in the governing equations and are valid only for nonlinear problems with weak nonlinearity.

Dynamical systems are a vast subject. It is often found that the going gets easier as one goes deeper, learning the mathematical connections tying together the various phenomena. The material of this book can be included in courses covering the theory of nonlinear oscillations, the theory of electrical machines, classical and fluid mechanics, thermodynamics or even biology.

The prerequisites for studying dynamical systems using this book are undergraduate courses in linear algebra, real and complex analysis, calculus, dynamics, and ordinary differential equations, classical physics of oscillations, knowledge of a computer language would be essential. Also, it is assumed that the reader knows basic notions about nonlinear systems of differential equations as well as the plotting of phase portraits, analysis of nonlinear systems, and graphical representation of errors and so on.

This book is informed by the research interest of the authors, which are currently nonlinear differential equations. Some references include recently published research articles. Our work has very hands-on approaches and takes the reader from the basic methods right through to recently published research material.

Most of the material in every chapter is at postgraduate level and has been influenced by the authors' own research interest. These chapters are especially useful as reference material for senior undergraduate project work.

The text is aimed to undergraduate students in accelerated programs, working scientists in various branches of engineering, natural scientists or applied mathematicians.

The whole book consists of concrete examples from various domains of nonlinear dynamical systems. The authors believe that the problem of motion of different dynamical systems can be assimilated only by working with the differential equations applied to concrete examples. Nearly all the sections of this book are followed by comparisons with numerical results or with other known results in the literature.

The aim of this book is to present and extend different known methods in the literature, especially Lindstedt-Poincaré method, the method of harmonic balance, the method of Krylov-Bogolyubov and the method of multiple scales, to solve different types of strong nonlinearities. A better knowledge of these methods lead to a better choice of the so-called "base functions" which are absolutely necessary to obtain the auxiliary functions present in the last Chapters, devoted to some optimal analytical approaches. These auxiliary functions are cornerstone of the optimal methods and also, ensure the conditions of convergence of the solutions obtained by different approaches. Unlike all previous analytic approaches, these few optimal methods provide us with a simple way to control and adjust the convergence region of solutions of nonlinear dynamical systems. These new optimal methods show one step in the attempt to develop a new nonlinear analytical technique working in the absence of small or large parameters. Actually, the capital strength of our optimal procedures is the fast convergence, since after only two or three iterations, or sometimes after only one iteration, it converges to the exact solution, which proves that these optimal methods are very efficient in practice.

The text begins with some known procedures, presented in Chaps. 1–4: the Lindstedt-Poincaré method, the method of harmonic balance, the method of Krylov-Bogolyubov and the method of multiple scales. All these techniques suppose the presence of a small parameter into the governing nonlinear equations. There are presented some alternatives and examples to each of these approaches, such as the use of perturbation method for strong parameter, the rational harmonic balance method, a combination of the method of Krylov-Bogolyubov and iteration method. The last four chapters, from 5 to 8 are devoted to optimal approaches such as: the Optimal Homotopy Asymptotic Method, the Optimal Homotopy Perturbation Method, the Optimal Variational Iteration Method and the Optimal Parametric Iteration Method. The validity of the proposed procedures has been demonstrated on some representative examples and very good agreement was found between the approximate analytic results and numerical simulations. The convergence of the approximate solutions obtained by each of these new methods is greatly influenced by the convergence-control constants which are optimally determined.

The examples presented in this book lead to the conclusion that the accuracy of the obtained results is growing along with increasing the number of constants in the auxiliary functions. These methods are very rapid and effective and show their validity and potential for the solution of nonlinear problems arising in dynamical systems.

Finally, our main aim is to inspire the reader to appreciate the beauty as well as the usefulness of the optimal analytical techniques in the study of nonlinear dynamical systems.

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