

Singular perturbation methods for slow–fast dynamics

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Abstract Recently, geometric singular perturbation theory has been extended considerably while at the same time producing many new applications. We will review a number of aspects relevant to non-linear dynamics to apply this to periodic solutions within slow manifolds and to review a number of non-hyperbolic cases. The results are illustrated by examples.

Keywords Singular perturbations · Slow manifolds · Periodic solutions · Nonhyperbolic

This paper deals with slow–fast initial value problems that are of the form

$$\dot{x} = f(x, y) + \varepsilon \cdots, \quad \varepsilon \dot{y} = g(x, y) + \varepsilon \cdots,$$

or alternatively

$$\dot{x} = \varepsilon f(x, y) + \varepsilon^2 \cdots, \quad \dot{y} = g(x, y) + \varepsilon \cdots.$$

As usual, ε is a small positive parameter, and an overdot denotes differentiation with respect to time. For a number of results, the vector fields f and g explicitly depending on time t present no obstruction. Part of the paper is a tutorial, but there are some new results.

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1 The Tikhonov theorem

In singular perturbations, certain attraction (or hyperbolicity) properties of the regular (outer) expansion play an essential part in the construction of the formal approximation. Remarkably enough, this hyperbolicity does not include the behaviour of the slow equation.

In the constructions, the following theorem provides a basic boundary layer property of the solution.

Theorem 1.1. (Tikhonov, 1952, see [15]) Consider the initial value problem

$$\begin{aligned} \dot{x} &= f(x, y, t) + \varepsilon \cdots, & x(0) &= x_0, & x &\in D \subset \mathbb{R}^n, \\ t &\geq 0, \\ \varepsilon \dot{y} &= g(x, y, t) + \varepsilon \cdots, & y(0) &= y_0, & y &\in G \subset \mathbb{R}^m. \end{aligned}$$

For f and g , we take sufficiently smooth vector functions in x , y and t ; the dots represent (smooth) higher-order terms in ε .

a. We assume that a unique solution of the initial value problem exists and suppose this holds also for the reduced problem

$$\begin{aligned} \dot{x} &= f(x, y, t), & x(0) &= x_0, \\ 0 &= g(x, y, t), \end{aligned}$$

with solutions $\bar{x}(t)$, $\bar{y}(t)$.

Perturbation Methods

**Anatoli V. Skorokhod, Frank C.
Hoppensteadt, Habib D. Salehi**

Perturbation Methods:

Introduction to Perturbation Methods Mark H. Holmes, 2012-12-05 This introductory graduate text is based on a graduate course the author has taught repeatedly over the last ten years to students in applied mathematics engineering sciences and physics Each chapter begins with an introductory development involving ordinary differential equations and goes on to cover such traditional topics as boundary layers and multiple scales However it also contains material arising from current research interest including homogenisation slender body theory symbolic computing and discrete equations Many of the excellent exercises are derived from problems of up to date research and are drawn from a wide range of application areas One hundred new pages added including new material on transcendentally small terms Kummer's function weakly coupled oscillators and wave interactions [Perturbation Methods for Differential Equations](#) Bhimsen

Shivamoggi, 2012-12-06 In nonlinear problems essentially new phenomena occur which have no place in the corresponding linear problems Therefore in the study of nonlinear problems the major purpose is not so much to introduce methods that improve the accuracy of linear methods but to focus attention on those features of the nonlinearities that result in distinctively new phenomena Among the latter are existence of solutions of periodic problems for all frequencies rather than only a set of characteristic values dependence of amplitude on frequency removal of resonance infinities appearance of jump phenomena onset of chaotic motions On the other hand mathematical problems associated with nonlinearities are so complex that a comprehensive theory of nonlinear phenomena is out of the question Consequently one practical approach is to settle for something less than complete generality Thus one gives up the study of global behavior of solutions of a nonlinear problem and seeks nonlinear solutions in the neighborhood of or as perturbations about a known linear solution This is the basic idea behind a perturbative solution of a nonlinear problem [Perturbation Methods in Applied Mathematics](#) J.

Kevorkian, J.D. Cole, 2013-03-09 This book is a revised and updated version including a substantial portion of new material of J D Cole's text *Perturbation Methods in Applied Mathematics* Ginn Blaisdell 1968 We present the material at a level which assumes some familiarity with the basics of ordinary and partial differential equations Some of the more advanced ideas are reviewed as needed therefore this book can serve as a text in either an advanced undergraduate course or a graduate level course on the subject The applied mathematician attempting to understand or solve a physical problem very often uses a perturbation procedure In doing this he usually draws on a backlog of experience gained from the solution of similar examples rather than on some general theory of perturbations The aim of this book is to survey these perturbation methods especially in connection with differential equations in order to illustrate certain general features common to many examples The basic ideas however are also applicable to integral equations integrodifferential equations and even to difference equations In essence a perturbation procedure consists of constructing the solution for a problem involving a small parameter ϵ either in the differential equation or the boundary conditions or both when the solution for the limiting case $\epsilon = 0$

is known The main mathematical tool used is asymptotic expansion with respect to a suitable asymptotic sequence of functions of B

Perturbations James A. Murdock, 1999-01-01 This book gives a thorough introduction to both regular and singular perturbation methods for algebraic and differential equations

Singular Perturbation Methods for Ordinary Differential Equations Robert E., Jr. O'Malley, 2012-12-06 This book results from various lectures given in recent years Early drafts were used for several single semester courses on singular perturbation methods given at Rensselaer and a more complete version was used for a one year course at the Technische Universität Wien Some portions have been used for short lecture series at Universidad Central de Venezuela West Virginia University the University of Southern California the University of California at Davis East China Normal University the University of Texas at Arlington Università di Padova and the University of New Hampshire among other places As a result I've obtained lots of valuable feedback from students and listeners for which I am grateful This writing continues a pattern Earlier lectures at Bell Laboratories at the University of Edinburgh and New York University and at the Australian National University led to my earlier works 1968 1974 and 1978 All seem to have been useful for the study of singular perturbations and I hope the same will be true of this monograph I've personally learned much from reading and analyzing the works of others so I would especially encourage readers to treat this book as an introduction to a diverse and exciting literature The topic coverage selected is personal and reflects my current opinions An attempt has been made to encourage a consistent method of approaching problems largely through correcting outer limits in regions of rapid change Formal proofs of correctness are not emphasized

Perturbation Methods E. J. Hinch, 1991-10-25 In this book the author presents the theory and techniques underlying perturbation methods in a manner that will make the book widely appealing to readers in a broad range of disciplines Methods of algebraic equations asymptotic expansions integrals PDEs strained coordinates and multiple scales are illustrated by copious use of examples drawn from many areas of mathematics and physics The philosophy adopted is that there is no single or best method for such problems but that one may exploit the small parameter given some experience and understanding of similar perturbation problems The author does not look to perturbation methods to give quantitative answers but rather uses them to give a physical understanding of the subtle balances in a complex problem

Perturbation Methods Ali H. Nayfeh, 2024-11-12 The Wiley Classics Library consists of selected books that have become recognized classics in their respective fields With these new unabridged and inexpensive editions Wiley hopes to extend the life of these important works by making them available to future generations of mathematicians and scientists Currently available in the Series T W Anderson The Statistical Analysis of Time Series T S Arthanari Yadolah Dodge Mathematical Programming in Statistics Emil Artin Geometric Algebra Norman T J Bailey The Elements of Stochastic Processes with Applications to the Natural Sciences Robert G Bartle The Elements of Integration and Lebesgue Measure George E P Box Norman R Draper Evolutionary Operation A Statistical Method for Process Improvement George E P Box George C Tiao Bayesian Inference in Statistical Analysis R W

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are outlined but they only provide a foundation and are not the objective of these notes Each chapter concludes with a detailed survey of the pertinent literature supplemental information and more examples to complement the text when necessary for better comprehension The references are intended to provide a guide for background information and for the reader who wishes to analyze any particular point in more detail The main sources referenced are in the fields of differential equations nonlinear oscillations and celestial mechanics Thanks are due to Katherine MacDougall and Sandra Spinacci for their patience and competence in typing these notes Partial support from the Mathematics Program of the Office of Naval Research is gratefully acknowledged

Perturbation Methods in Applied Mathematics Julian D. Cole, 1968

Multiple Scale and Singular Perturbation Methods J.K. Kevorkian, J.D. Cole, 2012-12-06 This book is a revised and updated version including a substantial portion of new material of our text *Perturbation Methods in Applied Mathematics* Springer Verlag 1981 We present the material at a level that assumes some familiarity with the basics of ordinary and partial differential equations Some of the more advanced ideas are reviewed as needed therefore this book can serve as a text in either an advanced undergraduate course or a graduate level course on the subject Perturbation methods first used by astronomers to predict the effects of small disturbances on the nominal motions of celestial bodies have now become widely used analytical tools in virtually all branches of science A problem lends itself to perturbation analysis if it is close to a simpler problem that can be solved exactly Typically this closeness is measured by the occurrence of a small dimensionless parameter ϵ in the governing system consisting of differential equations and boundary conditions so that for $\epsilon \rightarrow 0$ the resulting system is exactly solvable The main mathematical tool used is asymptotic expansion with respect to a suitable asymptotic sequence of functions of ϵ In a regular perturbation problem a straightforward procedure leads to a system of differential equations and boundary conditions for each term in the asymptotic expansion This system can be solved recursively and the accuracy of the result improves as ϵ gets smaller for all values of the independent variables throughout the domain of interest We discuss regular perturbation problems in the first chapter

Perturbation Methods in Science and Engineering Reza N. Jazar, 2021-07-12 *Perturbation Methods in Science and Engineering* provides the fundamental and advanced topics in perturbation methods in science and engineering from an application viewpoint This book bridges the gap between theory and applications in new as well as classical problems The engineers and graduate students who read this book will be able to apply their knowledge to a wide range of applications in different engineering disciplines The book begins with a clear description on limits of mathematics in providing exact solutions and goes on to show how pioneers attempted to search for approximate solutions of unsolvable problems Through examination of special applications and highlighting many different aspects of science this text provides an excellent insight into perturbation methods without restricting itself to a particular method This book is ideal for graduate students in engineering mathematics and physical sciences as well as researchers in dynamic systems

Perturbation Methods, Bifurcation Theory and Computer Algebra Richard H. Rand, Dieter

Armbruster,2012-12-06 Perturbation methods have always been an important tool for treating nonlinear differential equations Now the drudgery associated with them has been eliminated This book offers computer algebra MACSYMA programs which implement the most popular perturbation methods Not only does this avoid the errors associated with hand computation but the increase in efficiency permits more complicated problems to be tackled This book is useful both for the beginner learning perturbation methods for the first time as well as for the researcher Methods covered include Lindstedt s method center manifolds normal forms two variable expansion method method of multiple scales averaging Lie transforms and Liapunov Schmidt reduction For each method the book includes an introduction and some example problems solved both by hand and by machine The examples feature common bifurcations such as the pitchfork and the Hopf The MACSYMA code for each method is given and suggested exercises are provided at the end of each Chapter An Appendix offers a brief introduction to MACSYMA

Perturbation Methods, Instability, Catastrophe And Chaos Man Fong C F Chan,Daniel De Kee,1999-06-01 This important book introduces perturbation and qualitative methods for differential equations in terms understandable to students with only a basic knowledge of calculus and ordinary linear differential equations Theorems are stated clearly with their limitations and restrictions and are applied to solve examples from various disciplines The writing style is informal and new ideas are introduced gradually via concepts already familiar to the reader

Random Perturbation Methods with Applications in Science and Engineering Anatoli V. Skorokhod, Frank C. Hoppensteadt, Habib D. Salehi,2007-06-21 This book develops methods for describing random dynamical systems and it illustrates how the methods can be used in a variety of applications Appeals to researchers and graduate students who require tools to investigate stochastic systems

Introduction to Perturbation Techniques Ali H. Nayfeh,1981-01-19 Similarities differences advantages and limitations of perturbation techniques are pointed out concisely The techniques are described by means of examples that consist mainly of algebraic and ordinary differential equations Each chapter contains a number of exercises

Numerical Methods in Economics Kenneth L. Judd,1998-09-28 To harness the full power of computer technology economists need to use a broad range of mathematical techniques In this book Kenneth Judd presents techniques from the numerical analysis and applied mathematics literatures and shows how to use them in economic analyses The book is divided into five parts Part I provides a general introduction Part II presents basics from numerical analysis on R^n including linear equations iterative methods optimization nonlinear equations approximation methods numerical integration and differentiation and Monte Carlo methods Part III covers methods for dynamic problems including finite difference methods projection methods and numerical dynamic programming Part IV covers perturbation and asymptotic solution methods Finally Part V covers applications to dynamic equilibrium analysis including solution methods for perfect foresight models and rational expectation models A website contains supplementary material including programs and answers to exercises

Perturbation Methods in the Computer Age David C. Wilcox,1995 Nonlinear Dynamics Ardshir

Guran, 1997 This book is a collection of papers on the subject of nonlinear dynamics and its applications written by experts in this field It offers the reader a sampling of exciting research areas in this fast growing field The topics covered include chaos tools to analyze motions fractal boundaries dynamics of the Fitzhugh Nagumo equation structural control separation of contaminations from signal of interest parametric excitation stochastic bifurcation mode localization in repetitive structures Toda lattice transition from soliton to chaotic motion nonlinear normal modes noise perturbations of nonlinear dynamical systems and phase locking of coupled limit cycle oscillators Mathematical methods include Lie transforms Monte Carlo simulations stochastic calculus perturbation methods and proper orthogonal decomposition Applications include gyroynamics tether connected satellites shell buckling nonlinear circuits volume oscillations of a large lake systems with stick slip friction imperfect or disordered structures overturning of rigid blocks central pattern generators flow induced oscillations shape control and vibration suppression of elastic structures All of these diverse contributions have a common thread the world of nonlinear behavior Although linear dynamics is an invaluable tool there are many problems where nonlinear effects are essential Some examples include bifurcation of solutions stability of motion the effects of large displacements and subharmonic resonance This book shows how nonlinear dynamics is currently being utilized and investigated It will be of interest to engineers applied mathematicians and physicists

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