

Numerical Computation of Spectral Solutions for Sturm-Liouville Eigenvalue Problems

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Abstract. This paper focuses on the study of Sturm-Liouville eigenvalue problems. In the classical Chebyshev collocation method, the Sturm-Liouville problem is discretized to a generalized eigenvalue problem where the functions represent interpolants in suitably rescaled Chebyshev points. We are concerned with the computation of high-order eigenvalues of Sturm-Liouville problems using an effective method of discretization based on the Chebfun software algorithms with domain truncation. We solve some numerical Sturm-Liouville eigenvalue problems and demonstrate the efficiency of computations.

1. Introduction

The Sturm-Liouville problem arises in many applied mathematics, science, physics and engineering areas. Many biological, chemical and physical problems are described by using models based on Sturm-Liouville equations. For example, problems with cylindrical symmetry, diffraction problems (astronomy) resolving power of optical instruments and heavy chains. In quantum mechanics, the solutions of the radial Schrödinger equation describe the eigenvalues of the Sturm-Liouville problem. These solutions also define the bound state energies of the non-relativistic hydrogen atom. For more applications, see [1], [2] and [3].

In this paper, we consider the Sturm-Liouville problem

$$-\frac{d}{dx}\left[p(x)\frac{d}{dx}\right]y + q(x)y = \lambda w(x)y, \quad a \leq x \leq b, \quad (1.1)$$

$$c_a y(a) + d_a y'(a) = 0, \quad (1.2)$$

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Numerical Solution of Sturm-Liouville Problems John Derwent Pryce,1993 Sturm Liouville problems SLPs an applied mathematics tool developed in the nineteenth century and a driving force of pure mathematics in the early twentieth century became of vital interest to physicists with the advent of Schrodinger s equations Today s fascinating variety of SL related computations reflects this diverse historical background This book was written for scientists and engineers who desire an introduction to simple SLPs their limitations the algorithms that overcome these limitations and available software Numerical analysts seeking a reference on good SLP methods theory implementation and performance will also want to own a copy of this book Treatments of the underlying mathematical theories and numerous helpful problems round out this superb new volume Sturm-Liouville Problems Ronald B. Guenther,John W Lee,2018-10-25 Sturm Liouville problems arise naturally in

solving technical problems in engineering physics and more recently in biology and the social sciences These problems lead to eigenvalue problems for ordinary and partial differential equations Sturm Liouville Problems Theory and Numerical Implementation addresses in a unified way the key issues that must be faced in science and engineering applications when separation of variables variational methods or other considerations lead to Sturm Liouville eigenvalue problems and boundary value problems *Direct and Inverse Sturm-Liouville Problems* Vladislav V. Kravchenko,2020-07-28 This book provides an introduction to the most recent developments in the theory and practice of direct and inverse Sturm Liouville problems on finite and infinite intervals A universal approach for practical solving of direct and inverse spectral and scattering problems is presented based on the notion of transmutation transformation operators and their efficient construction Analytical representations for solutions of Sturm Liouville equations as well as for the integral kernels of the transmutation operators are derived in the form of functional series revealing interesting special features and lending themselves to direct and simple numerical solution of a wide variety of problems The book is written for undergraduate and graduate students as well as for mathematicians physicists and engineers interested in direct and inverse spectral problems

Numerical Solution of the Inverse Sturm-Liouville Problem Albert Chingkwang Yen,1978 Numerical Solution of Sturm-Liouville Problems Via Fer Streamers Alberto Gil Couto Pimentel Ramos,2016 **High-Precision Methods in**

Eigenvalue Problems and Their Applications Leonid D. Akulenko,2004-10-15 This book presents a survey of analytical asymptotic numerical and combined methods of solving eigenvalue problems It considers the new method of accelerated convergence for solving problems of the Sturm Liouville type as well as boundary value problems with boundary conditions of the first second and third kind The authors also present high **Numerical Solution of Boundary Value Problems for Ordinary Differential Equations** Uri M. Ascher,Robert M. M. Mattheij,Robert D. Russell,1994-12-01 This book is the most comprehensive up to date account of the popular numerical methods for solving boundary value problems in ordinary differential equations It aims at a thorough understanding of the field by giving an in depth analysis of the numerical

methods by using decoupling principles Numerous exercises and real world examples are used throughout to demonstrate the methods and the theory Although first published in 1988 this republication remains the most comprehensive theoretical coverage of the subject matter not available elsewhere in one volume Many problems arising in a wide variety of application areas give rise to mathematical models which form boundary value problems for ordinary differential equations These problems rarely have a closed form solution and computer simulation is typically used to obtain their approximate solution This book discusses methods to carry out such computer simulations in a robust efficient and reliable manner

An Introduction to Numerical Analysis Endre Süli, David F. Mayers, 2003-08-28 Numerical analysis provides the theoretical foundation for the numerical algorithms we rely on to solve a multitude of computational problems in science Based on a successful course at Oxford University this book covers a wide range of such problems ranging from the approximation of functions and integrals to the approximate solution of algebraic transcendental differential and integral equations Throughout the book particular attention is paid to the essential qualities of a numerical algorithm stability accuracy reliability and efficiency The authors go further than simply providing recipes for solving computational problems They carefully analyse the reasons why methods might fail to give accurate answers or why one method might return an answer in seconds while another would take billions of years This book is ideal as a text for students in the second year of a university mathematics course It combines practicality regarding applications with consistently high standards of rigour

Fourier Series and Numerical Methods for Partial Differential Equations Richard Bernatz, 2010-07-30 The importance of partial differential equations PDEs in modeling phenomena in engineering as well as in the physical natural and social sciences is well known by students and practitioners in these fields Striking a balance between theory and applications Fourier Series and Numerical Methods for Partial Differential Equations presents an introduction to the analytical and numerical methods that are essential for working with partial differential equations Combining methodologies from calculus introductory linear algebra and ordinary differential equations ODEs the book strengthens and extends readers knowledge of the power of linear spaces and linear transformations for purposes of understanding and solving a wide range of PDEs The book begins with an introduction to the general terminology and topics related to PDEs including the notion of initial and boundary value problems and also various solution techniques Subsequent chapters explore The solution process for Sturm Liouville boundary value ODE problems and a Fourier series representation of the solution of initial boundary value problems in PDEs The concept of completeness which introduces readers to Hilbert spaces The application of Laplace transforms and Duhamel's theorem to solve time dependent boundary conditions The finite element method using finite dimensional subspaces The finite analytic method with applications of the Fourier series methodology to linear version of non linear PDEs Throughout the book the author incorporates his own class tested material ensuring an accessible and easy to follow presentation that helps readers connect presented objectives with relevant applications to their own work Maple is used

throughout to solve many exercises and a related Web site features Maple worksheets for readers to use when working with the book's one and multi dimensional problems Fourier Series and Numerical Methods for Partial Differential Equations is an ideal book for courses on applied mathematics and partial differential equations at the upper undergraduate and graduate levels It is also a reliable resource for researchers and practitioners in the fields of mathematics science and engineering who work with mathematical modeling of physical phenomena including diffusion and wave aspects

Ordinary Differential Equations and Integral Equations C.T.H. Baker, G. Monegato, G. vanden Berghe, 2001-07-04 homepage sac cam na2000 index.html7 Volume Set now available at special set price This volume contains contributions in the area of differential equations and integral equations Many numerical methods have arisen in response to the need to solve real life problems in applied mathematics in particular problems that do not have a closed form solution Contributions on both initial value problems and boundary value problems in ordinary differential equations appear in this volume Numerical methods for initial value problems in ordinary differential equations fall naturally into two classes those which use one starting value at each step one step methods and those which are based on several values of the solution multistep methods John Butcher has supplied an expert's perspective of the development of numerical methods for ordinary differential equations in the 20th century Rob Corless and Lawrence Shampine talk about established technology namely software for initial value problems using Runge Kutta and Rosenbrock methods with interpolants to fill in the solution between mesh points but the slant is new based on the question How should such software integrate into the current generation of Problem Solving Environments Natalia Borovikh and Marc Spijker study the problem of establishing upper bounds for the norm of the n th power of square matrices The dynamical system viewpoint has been of great benefit to ODE theory and numerical methods Related is the study of chaotic behaviour Willy Govaerts discusses the numerical methods for the computation and continuation of equilibria and bifurcation points of equilibria of dynamical systems Arieh Iserles and Antonella Zanna survey the construction of Runge Kutta methods which preserve algebraic invariant functions Valeria Antohe and Ian Gladwell present numerical experiments on solving a Hamiltonian system of H non and Heiles with a symplectic and a nonsymplectic method with a variety of precisions and initial conditions Stiff differential equations first became recognized as special during the 1950s In 1963 two seminal publications laid the foundations for later development Dahlquist's paper on A stable multistep methods and Butcher's first paper on implicit Runge Kutta methods Ernst Hairer and Gerhard Wanner deliver a survey which retraces the discovery of the order stars as well as the principal achievements obtained by that theory Guido Vanden Berghe Hans De Meyer Marnix Van Daele and Tanja Van Hecke construct exponentially fitted Runge Kutta methods with s stages Differential algebraic equations arise in control in modelling of mechanical systems and in many other fields Jeff Cash describes a fairly recent class of formulae for the numerical solution of initial value problems for stiff and differential algebraic systems Shengtai Li and Linda Petzold describe methods and software for sensitivity analysis of solutions of DAE initial value problems Again in the area of

differential algebraic systems Neil Biehn John Betts Stephen Campbell and William Huffman present current work on mesh adaptation for DAE two point boundary value problems Contrasting approaches to the question of how good an approximation is as a solution of a given equation involve i attempting to estimate the actual error i e the difference between the true and the approximate solutions and ii attempting to estimate the defect the amount by which the approximation fails to satisfy the given equation and any side conditions The paper by Wayne Enright on defect control relates to carefully analyzed techniques that have been proposed both for ordinary differential equations and for delay differential equations in which an attempt is made to control an estimate of the size of the defect Many phenomena incorporate noise and the numerical solution of stochastic differential equations has developed as a relatively new item of study in the area Keven Burrage Pamela Burrage and Taketomo Mitsui review the way numerical methods for solving stochastic differential equations SDE s are constructed One of the more recent areas to attract scrutiny has been the area of differential equations with after effect retarded delay or neutral delay differential equations and in this volume we include a number of papers on evolutionary problems in this area The paper of Genna Bocharov and Fathalla Rihan conveys the importance in mathematical biology of models using retarded differential equations The contribution by Christopher Baker is intended to convey much of the background necessary for the application of numerical methods and includes some original results on stability and on the solution of approximating equations Alfredo Bellen Nicola Guglielmi and Marino Zennaro contribute to the analysis of stability of numerical solutions of nonlinear neutral differential equations Koen Engelborghs Tatyana Luzyanina Dirk Roose Neville Ford and Volker Wulf consider the numerics of bifurcation in delay differential equations Evelyn Buckwar contributes a paper indicating the construction and analysis of a numerical strategy for stochastic delay differential equations SDDEs This volume contains contributions on both Volterra and Fredholm type integral equations Christopher Baker responded to a late challenge to craft a review of the theory of the basic numerics of Volterra integral and integro differential equations Simon Shaw and John Whiteman discuss Galerkin methods for a type of Volterra integral equation that arises in modelling viscoelasticity A subclass of boundary value problems for ordinary differential equation comprises eigenvalue problems such as Sturm Liouville problems SLP and Schr dinger equations Liviu Ixaru describes the advances made over the last three decades in the field of piecewise perturbation methods for the numerical solution of Sturm Liouville problems in general and systems of Schr dinger equations in particular Alan Andrew surveys the asymptotic correction method for regular Sturm Liouville problems Leon Greenberg and Marco Marletta survey methods for higher order Sturm Liouville problems R Moore in the 1960s first showed the feasibility of validated solutions of differential equations that is of computing guaranteed enclosures of solutions Boundary integral equations Numerical solution of integral equations associated with boundary value problems has experienced continuing interest Peter Junghanns and Bernd Silbermann present a selection of modern results concerning the numerical analysis of one dimensional Cauchy singular integral equations in particular the stability of

operator sequences associated with different projection methods Johannes Elschner and Ivan Graham summarize the most important results achieved in the last years about the numerical solution of one dimensional integral equations of Mellin type of means of projection methods and in particular by collocation methods A survey of results on quadrature methods for solving boundary integral equations is presented by Andreas Rathsfeld Wolfgang Hackbusch and Boris Khoromski present a novel approach for a very efficient treatment of integral operators Ernst Stephan examines multilevel methods for the h p and hp versions of the boundary element method including pre conditioning techniques George Hsiao Olaf Steinbach and Wolfgang Wendland analyze various boundary element methods employed in local discretization schemes

Numerical Method for Sturm-Liouville Problems Dhiranuch Bunnag,1999

Computational Methods in Physics Simon Āirca,Martin Horvat,2025-04-01 This textbook provides a compendium of numerical methods to assist physics students and researchers in their daily work It carefully considers error estimates stability and convergence issues the choice of optimal methods and techniques to increase program execution speeds The book supplies numerous examples throughout the chapters that are concluded by more comprehensive problems with a strong physics background Instead of uncritically employing modern black box tools the readers are encouraged to develop a more ponderous and skeptical approach This revised and expanded edition now includes a new chapter on numerical integration and stable differentiation as well as fresh material on optimal filtering integration of gravitational many body problems computation of Poincar maps regularization of orbits singular Sturm Liouville problems techniques for time evolution and spatial treatment of semi infinite domains in spectral methods and phase retrieval It also brings updated discussions of algebraic problems involving sparse matrices and of high resolution schemes for partial differential equations

Spectral Methods for Non-Standard Eigenvalue Problems Călin-Ioan Gheorghiu,2014-04-22 This book focuses on the constructive and practical aspects of spectral methods It rigorously examines the most important qualities as well as drawbacks of spectral methods in the context of numerical methods devoted to solve non standard eigenvalue problems In addition the book also considers some nonlinear singularly perturbed boundary value problems along with eigenproblems obtained by their linearization around constant solutions The book is mathematical posing problems in their proper function spaces but its emphasis is on algorithms and practical difficulties The range of applications is quite large High order eigenvalue problems are frequently beset with numerical ill conditioning problems The book describes a wide variety of successful modifications to standard algorithms that greatly mitigate these problems In addition the book makes heavy use of the concept of pseudospectrum which is highly relevant to understanding when disaster is imminent in solving eigenvalue problems It also envisions two classes of applications the stability of some elastic structures and the hydrodynamic stability of some parallel shear flows This book is an ideal reference text for professionals researchers in applied mathematics computational physics and engineering It will be very useful to numerically sophisticated engineers physicists and chemists The book can also be used as a textbook in review courses such

as numerical analysis computational methods in various engineering branches or physics and computational methods in analysis [Numerical Methods for Nonlinear Engineering Models](#) John R. Hauser,2009-03-24 There are many books on the use of numerical methods for solving engineering problems and for modeling of engineering artifacts In addition there are many styles of such presentations ranging from books with a major emphasis on theory to books with an emphasis on applications The purpose of this book is hopefully to present a somewhat different approach to the use of numerical methods for engineering applications Engineering models are in general nonlinear models where the response of some appropriate engineering variable depends in a nonlinear manner on the application of some independent parameter It is certainly true that for many types of engineering models it is sufficient to approximate the real physical world by some linear model However when engineering environments are pushed to extreme conditions nonlinear effects are always encountered It is also such extreme conditions that are of major importance in determining the reliability or failure limits of engineering systems Hence it is essential that engineers have a toolbox of modeling techniques that can be used to model nonlinear engineering systems Such a set of basic numerical methods is the topic of this book For each subject area treated nonlinear models are incorporated into the discussion from the very beginning and linear models are simply treated as special cases of more general nonlinear models This is a basic and fundamental difference in this book from most books on numerical methods

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