

Numerical Solution of Nonlinear Fractional Boundary Value Problems [†]

Arvet Pedas and Enn Tamme

Institute of Mathematics, University of Tartu; J. Liivi 2, 50409 Tartu, Estonia

Abstract. The numerical solution of boundary value problems for nonlinear fractional differential equations is discussed. Using an integral equation reformulation of the boundary value problem, some regularity properties of the exact solution are derived. Based on these properties and spline collocation techniques, the attainable order of convergence of the proposed algorithms is studied, theoretically and numerically.

Keywords: Nonlinear fractional differential equation, Boundary value problem, Caputo derivative, Piecewise polynomial approximation, Graded grid
PACS: 65L60, 34A08

INTRODUCTION

This paper concerns with the numerical solution of nonlinear fractional boundary value problems of the form

$$(D_t^\alpha y)(t) = f(t, y(t)), \quad 0 \leq t \leq b, \quad 0 < \alpha < 1, \quad y_0 y(0) + y_1 y(b_1) = \gamma, \quad 0 < b_1 \leq b, \quad (1)$$

where $b, b_1, y_0, y_1, \gamma \in \mathbf{R} = (-\infty, \infty)$, $f: [0, b] \times \mathbf{R} \rightarrow \mathbf{R}$ is a given continuous function, $y: [0, b] \rightarrow \mathbf{R}$ is a function to be determined, and $D_t^\alpha y$ is the α -th order Caputo fractional derivative of y with starting point zero. The Caputo differentiation operator D_t^α of order $\alpha \in (0, 1)$ is defined by the formula (see, e.g., [1])

$$(D_t^\alpha y)(t) = \frac{d}{dt} (J^{1-\alpha} [y - y(0)])(t), \quad 0 \leq t \leq b.$$

Here J^λ , the Riemann–Liouville integral operator, is defined for $\lambda > 0$ by

$$(J^\lambda y)(t) = \frac{1}{\Gamma(\lambda)} \int_0^t (t-s)^{\lambda-1} y(s) ds, \quad t > 0, \quad (2)$$

with Γ , the Euler Gamma function. It is well known (see, e.g., [2]) that J^λ for $\lambda > 0$ is linear, bounded and compact as an operator from $L^\infty(0, b)$ into $C[0, b]$. Moreover (see, e.g., [3]), we have for any $y \in L^\infty(0, b)$ that $J^\lambda y \in C[0, b]$, $(J^\lambda y)(0) = 0$ and $D_t^\beta J^\lambda y = J^{\lambda-\beta} y$, $0 < \beta \leq \lambda$ (we set $J^0 = I$ where I is the identity mapping). For existence of a solution of problem (1) see, for example, [1, 8].

In last decades it has been observed an increasing interest in the study of fractional differential equations (see, e.g., [1, 3, 4, 5, 6, 8]). In [5] spline approximations for solving linear fractional boundary value problems have been used. The purpose of the current contribution is to extend the main results of [5] to nonlinear fractional boundary value problems of the form (1) in a situation where the derivatives of the function $f(t, y)$ may be unbounded at $t = 0$.

SMOOTHNESS OF THE SOLUTION

Let $y \in C[0, b]$ be such that $D_t^\alpha y \in C[0, b]$. Introduce a new unknown function $z = D_t^\alpha y$. Then (see, e.g. [1, 3])

$$y(t) = (J^\alpha z)(t) + d, \quad t \in [0, b], \quad (3)$$

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Numerical Solution Of Nonlinear Boundary Value Problems With Applications

P.G. Ciarlet



Numerical Solution Of Nonlinear Boundary Value Problems With Applications:

Numerical Solution of Nonlinear Boundary Value Problems with Applications Milan Kubicek, Vladimir Hlavacek, 2008-01-01 A survey of the development analysis and application of numerical techniques in solving nonlinear boundary value problems this text presents numerical analysis as a working tool for physicists and engineers Starting with a survey of accomplishments in the field it explores initial and boundary value problems for ordinary differential equations linear boundary value problems and the numerical realization of parametric studies in nonlinear boundary value problems The authors Milan Kubicek Professor at the Prague Institute of Chemical Technology and Vladimir Hlavacek Professor at the University of Buffalo emphasize the description and straightforward application of numerical techniques rather than underlying theory This approach reflects their extensive experience with the application of diverse numerical algorithms

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

Numerical Solution of Field Problems in Continuum Physics Society for Industrial and Applied Mathematics, 1970

Initial Value Methods for Boundary Value Problems: Theory and Application of Invariant Imbedding, 1973-08-15 In this book we study theoretical and practical aspects of computing methods for mathematical modelling of nonlinear systems A number of computing techniques are considered such as methods of operator approximation with any given accuracy operator interpolation techniques including a non Lagrange interpolation methods of system representation subject to constraints associated with concepts of causality memory and stationarity methods of system representation with an accuracy that is the best within a given class of models methods of covariance matrix estimation methods for low rank matrix approximations hybrid methods based on a combination of iterative procedures and best operator approximation and methods for information compression and filtering under condition that a filter model should satisfy restrictions associated with causality and different types of memory As a result the book represents a blend of new methods in general computational analysis and specific but also generic techniques for study of systems theory and its particular branches such as optimal filtering and information compression Best operator approximation

Non Lagrange interpolation Generic Karhunen Loeve transform Generalised low rank matrix approximation Optimal data compression Optimal nonlinear filtering **Numerical Solution of Two Point Boundary Value Problems** Herbert B. Keller,1976-01-01 Lectures on a unified theory of and practical procedures for the numerical solution of two point boundary value problems Scientific and Technical Aerospace Reports ,1980 *Proceedings of Fourth International Conference on Soft Computing for Problem Solving* Kedar Nath Das,Kusum Deep,Millie Pant,Jagdish Chand Bansal,Atulya Nagar,2014-12-23 The Proceedings of SocProS 2014 serves as an academic bonanza for scientists and researchers working in the field of Soft Computing This book contains theoretical as well as practical aspects using fuzzy logic neural networks evolutionary algorithms swarm intelligence algorithms etc with many applications under the umbrella of Soft Computing The book is beneficial for young as well as experienced researchers dealing across complex and intricate real world problems for which finding a solution by traditional methods is a difficult task The different application areas covered in the Proceedings are Image Processing Cryptanalysis Industrial Optimization Supply Chain Management Newly Proposed Nature Inspired Algorithms Signal Processing Problems related to Medical and Healthcare Networking Optimization Problems etc

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Complex Analysis - Methods, Trends, and Applications Eberhard Lanckau, Wolfgang Tutschke, 1983-12-31. No detailed description available for **Complex Analysis Methods Trends and Applications**. **Advances in Information and Communication Technology** Phung Trung Nghia, Vu Duc Thai, Nguyen Thanh Thuy, Le Hoang Son, Van-Nam Huynh, 2023-12-12. This book contains four keynote abstracts and 83 best peer reviewed papers selected from the 179 submissions at the 2nd International Conference on Advances in ICT ICTA 2023 which share research results and practical applications in ICT research and education. Technological changes and digital transformation that have taken place over the past decade have had significant impacts on all economic and social sectors. Information and Communication Technology ICT in general and artificial intelligence AI in particular have driven socio economic growth. The topics cover all ICT related areas and their contributions to socio economic development focusing on the most advanced technologies such as AI. Researchers and practitioners in academia and industry use the books as a valuable reference for their research activities teaching learning and advancing current technologies. The Conference is hosted by Thai Nguyen University of Information and Communication Technology ICTU. *The Finite Element Method for Elliptic Problems* P.G. Ciarlet, 1978-01-01. The objective of this book is to analyze within reasonable limits it is not a treatise the basic mathematical aspects of the finite element method. The book should also serve as an introduction to current research on this subject. On the one hand it is also intended to be a working textbook for advanced courses in Numerical Analysis as typically taught in graduate courses in American and

French universities For example it is the author's experience that a one semester course on a three hour per week basis can be taught from Chapters 1 2 and 3 with the exception of Section 3.3 while another one semester course can be taught from Chapters 4 and 6 On the other hand it is hoped that this book will prove to be useful for researchers interested in advanced aspects of the numerical analysis of the finite element method In this respect Section 3.3 Chapters 5 7 and 8 and the sections on Additional Bibliography and Comments should provide many suggestions for conducting seminars

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Scientific Computing John A. Trangenstein, 2018-05-14 This is the third of three volumes providing a comprehensive presentation of the fundamentals of scientific computing This volume discusses topics that depend more on calculus than linear algebra in order to prepare the reader for solving differential equations This book and its companions show how to determine the quality of computational results and how to measure the relative efficiency of competing methods Readers learn how to determine the maximum attainable accuracy of algorithms and how to select the best method for computing problems This book also discusses programming in several languages including C Fortran and MATLAB There are 90 examples 200 exercises 36 algorithms 40 interactive JavaScript programs 91 references to software programs and 1 case study Topics are introduced with goals literature references and links to public software There are descriptions of the current algorithms in GSLIB and MATLAB This book could be used for a second course in numerical methods for either upper level undergraduates or first year graduate students Parts of the text could be used for specialized courses such as nonlinear optimization or iterative linear algebra

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