Implicit two–derivative Runge–Kutta collocation methods for systems of initial value problems

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Abstract

We introduce a new class of implicit two–derivative Runge–Kutta collocation methods designed for the numerical solution of systems of equations and show how they have been implemented in an efficient parallel computing environment. We also discuss the difficulty associated with large systems and how, in this case, one must take advantage of the second derivative terms in the methods. We consider two modified versions of the methods which are suitable for solving stable systems. The first modification involves the introduction of collocation at the two end points of the integration interval in addition to the Gaussian interior collocation points and the second involves the introduction of a different class of basic second derivative methods. With these modifications, fewer function evaluations per step are achieved, resulting into methods that are cheap and easy to implement. The stability properties of these methods are investigated and numerical results are given for each of the modified version to illustrate the computational efficiency of the modified methods.

1. Introduction

The primary aim of this paper is to introduce a new class of implicit two-derivative Runge–Kutta (TDRK) collocation methods for the numerical solution of initial value problems for systems of ordinary differential equations (ODEs).

$$\begin{cases} y'(x) = f(x, y(x)), & x \in [x_0, T], \\ y(0) = y(x_0). \end{cases} \tag{1}$$

Here $y : [x_0, T] \longrightarrow \mathbb{R}^d$ and $f : [x_0, T] \times \mathbb{R}^d \longrightarrow \mathbb{R}^d$ is assumed to be sufficiently smooth and $y_0 \in \mathbb{R}^d$ is the given initial value. Let $h > 0$ be a constant stepsize and define the grid by $x_n = x_0 + nh$, $n = 0, 1, 2, \ldots, N$ where $Nh = T - x_0$ and a set of equally spaced points on the integration interval is defined by $x_0 < x_1 < x_2 < \cdots < x_{n+1} = T$.

Implicit Two Derivative Runge Kutta Collocation Methods

Lei Huang

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Solving Ordinary Differential Equations I Ernst Hairer,Syvert P. Nørsett,Gerhard Wanner,2008-04-16 This book deals with methods for solving nonstiff ordinary differential equations The first chapter describes the historical development of the classical theory and the second chapter includes a modern treatment of Runge Kutta and extrapolation methods Chapter three begins with the classical theory of multistep methods and concludes with the theory of general linear methods The reader will benefit from many illustrations a historical and didactic approach and computer programs which help him her learn to solve all kinds of ordinary differential equations This new edition has been rewritten and new material has been included *Scientific Computing with Ordinary Differential Equations* Peter Deuflhard,Folkmar Bornemann,2012-12-06 Mathematics is playing an ever more important role in the physical and biological sciences provoking a blurring of boundaries between scientific disciplines and a resurgence of interest in the modern as well as the classical techniques of applied mathematics This renewal of interest both in re search and teaching has led to the establishment of the series Texts in Applied Mathematics TAM The development of new courses is a natural consequence of a high level of excitement on the research frontier as newer techniques such as numeri cal and symbolic computer systems dynamical systems and chaos mix with and reinforce the traditional methods of applied mathematics Thus the purpose of this textbook series is to meet the current and future needs of these advances and to encourage the teaching of new courses TAM will publish textbooks suitable for use in advanced undergraduate and beginning graduate courses and will complement the Applied Mathe matical Sciences AMS series which will focus on advanced textbooks and research level monographs *Exponential Fitting* Liviu Gr. Ixaru,Guido Vanden Berghe,2004-05-26 Exponential Fitting is a procedure for an efficient numerical approach of functions consisting of weighted sums of exponential trigonometric or hyperbolic functions with slowly varying weight functions This book is the first one devoted to this subject Operations on the functions described above like numerical differentiation quadrature interpolation or solving ordinary differential equations whose solution is of this type are of real interest nowadays in many phenomena as oscillations vibrations rotations or wave propagation The authors studied the field for many years and contributed to it Since the total number of papers accumulated so far in this field exceeds 200 and the fact that these papers are spread over journals with various profiles such as applied mathematics computer science computational physics and chemistry it was time to compact and to systematically present this vast material In this book a series of aspects is covered ranging from the theory of the procedure up to direct applications and sometimes including ready to use programs The book can also be used as a textbook for graduate students **State Estimation for Nonlinear Continuous–Discrete Stochastic Systems** Gennady Yu. Kulikov,Maria V. Kulikova,2024-09-06 This book addresses the problem of accurate state estimation in nonlinear continuous time stochastic models with additive noise and discrete measurements Its main focus is on numerical aspects of computation of the expectation and covariance in Kalman like filters rather than on statistical properties

determining a model of the system state Nevertheless it provides the sound theoretical background and covers all contemporary state estimation techniques beginning at the celebrated Kalman filter including its versions extended to nonlinear stochastic models and till the most advanced universal Gaussian filters with deterministically sampled mean and covariance In particular the authors demonstrate that when applying such filtering procedures to stochastic models with strong nonlinearities the use of adaptive ordinary differential equation solvers with automatic local and global error control facilities allows the discretization error and consequently the state estimation error to be reduced considerably For achieving that the variable stepsize methods with automatic error regulation and stepsize selection mechanisms are applied to treating moment differential equations arisen The implemented discretization error reduction makes the self adaptive nonlinear Gaussian filtering algorithms more suitable for application and leads to the novel notion of accurate state estimation The book also discusses accurate state estimation in mathematical models with sparse measurements Of special interest in this regard it provides a means for treating stiff stochastic systems which often encountered in applied science and engineering being exemplified by the Van der Pol oscillator in electrical engineering and the Oregonator model of chemical kinetics Square root implementations of all Kalman like filters considered and explored in this book for state estimation in Ill conditioned continuous discrete stochastic systems attract the authors particular attention This book covers both theoretical and applied aspects of numerical integration methods including the concepts of approximation convergence stiffness as well as of local and global errors suitably for applied scientists and engineers Such methods serve as a basis for the development of accurate continuous discrete extended unscented cubature and many other Kalman filtering algorithms including the universal Gaussian methods with deterministically sampled expectation and covariance as well as their mixed type versions The state estimation procedures in this book are presented in the fashion of complete pseudo codes which are ready for implementation and use in MATLAB or in any other computation platform These are examined numerically and shown to outperform traditional variants of the Kalman like filters in practical prediction filtering tasks including state estimations of stiff and or ill conditioned continuous discrete nonlinear stochastic systems *Proceedings of the Summer Computer Simulation Conference* ,1987 Stability of Runge-Kutta Methods for Stiff Nonlinear Differential Equations Kees Dekker,Jan G. Verwer,1984 The object of this monograph is to present a unified account of all developments concerning stability of Runge Kutta methods for stiff nonlinear differential equations which began in 1975 with Dahlquist s G stability paper and Butcher s B stability paper Designed for the reader with a background in numerical analysis the book contains numerous theoretical and practical results aimed at giving insight into the treatment of nonlinear problems **The Princeton Companion to Applied Mathematics** Nicholas J. Higham,Mark R. Dennis,Paul Glendinning,Paul A. Martin,Fadil Santosa,Jared Tanner,2015-09-15 The must have compendium on applied mathematics This is the most authoritative and accessible single volume reference book on applied mathematics Featuring numerous entries by leading experts and

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