

# 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.

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**Keywords:** Block hybrid discrete scheme; Continuous scheme; System of equations; Two-derivative Runge–Kutta 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),

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

Here  $y : [x_0, T] \rightarrow \mathbb{R}^d$  and  $f : [x_0, T] \times \mathbb{R}^d \rightarrow \mathbb{R}^d$  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  $x_n = x_0 + nh$ ,  $n = 0, 1, 2, \dots, N$  where  $Nh = T - x_0$  and a set of equally spaced points on the integration interval is defined by  $x_0 < x_1 < x_2 < \dots < x_{n+1} = T$ .

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# Implicit Two Derivative Runge Kutta Collocation Methods

**Rachel S Tattersall**



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**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

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## **Table of Contents Implicit Two Derivative Runge Kutta Collocation Methods**

1. Understanding the eBook Implicit Two Derivative Runge Kutta Collocation Methods
  - The Rise of Digital Reading Implicit Two Derivative Runge Kutta Collocation Methods
  - Advantages of eBooks Over Traditional Books
2. Identifying Implicit Two Derivative Runge Kutta Collocation Methods
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Implicit Two Derivative Runge Kutta Collocation Methods
  - User-Friendly Interface
4. Exploring eBook Recommendations from Implicit Two Derivative Runge Kutta Collocation Methods

- Personalized Recommendations
- Implicit Two Derivative Runge Kutta Collocation Methods User Reviews and Ratings
- Implicit Two Derivative Runge Kutta Collocation Methods and Bestseller Lists
- 5. Accessing Implicit Two Derivative Runge Kutta Collocation Methods Free and Paid eBooks
  - Implicit Two Derivative Runge Kutta Collocation Methods Public Domain eBooks
  - Implicit Two Derivative Runge Kutta Collocation Methods eBook Subscription Services
  - Implicit Two Derivative Runge Kutta Collocation Methods Budget-Friendly Options
- 6. Navigating Implicit Two Derivative Runge Kutta Collocation Methods eBook Formats
  - ePub, PDF, MOBI, and More
  - Implicit Two Derivative Runge Kutta Collocation Methods Compatibility with Devices
  - Implicit Two Derivative Runge Kutta Collocation Methods Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Implicit Two Derivative Runge Kutta Collocation Methods
  - Highlighting and Note-Taking Implicit Two Derivative Runge Kutta Collocation Methods
  - Interactive Elements Implicit Two Derivative Runge Kutta Collocation Methods
- 8. Staying Engaged with Implicit Two Derivative Runge Kutta Collocation Methods
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Implicit Two Derivative Runge Kutta Collocation Methods
- 9. Balancing eBooks and Physical Books Implicit Two Derivative Runge Kutta Collocation Methods
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Implicit Two Derivative Runge Kutta Collocation Methods
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Implicit Two Derivative Runge Kutta Collocation Methods
  - Setting Reading Goals Implicit Two Derivative Runge Kutta Collocation Methods
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Implicit Two Derivative Runge Kutta Collocation Methods

- Fact-Checking eBook Content of Implicit Two Derivative Runge Kutta Collocation Methods
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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