An Explicit LODM-Radau IIA Framework for Stiff ODEs and a Foundation for Implicit-Explicit Extension

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Abstract

The stiff differential equation arises in various real-world phenomena across diverse scientific domains in physical, chemical, biological, and engineering systems. Solving such equations numerically remains a major challenge in computational mathematics. This paper presents a numerical approach that reformulates the widely-used 3-stage Radau IIA implicit Runge-Kutta method by coupling it with the Laplace Optimized Decomposition Method (LODM) for solv ing stiff ordinary differential equations. The proposed technique replaces the computationally expensive Newton iteration, typically required for solving the nonlinear implicit Radau stage equations, with an LODM-based series expansion. The paper introduces a local linearization constant that is directly derived from the Jacobian and naturally extends to vector-valued sys tems. It also provides a comprehensive analysis of the consistency, convergence, and linear stability properties of the resulting schemes. Numerical experiments on representative stiff scalar problems validate the theoretical findings and demonstrate the practical viability of the approach. This work offers a practical, computationally efficient solver for mildly stiff systems by providing an efficient alternative to Newton-based Radau implementation. Moreover, it es tablishes a robust foundation for developing advanced implicit-explicit hybrid strategies capable of tackling large-scale stiff phenomena in future research.

Keywords

Implicit-explicit methods, Laplace optimized decomposition method, Radau IIA method, Stiff differential equations.