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*Editorial*

## Special issue “Numerical Analysis of Differential Equations with Real-world Applications”

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Numerical analysis of differential equations plays an essential role in addressing a wide range of challenging problems in science and engineering, where analytical solutions are often unavailable due to nonlinearity, complex geometries, multiscale effects, or uncertainty. This Special Issue, Numerical Analysis of Differential Equations, was conceived as a platform for original contributions that develop, analyze, and apply robust numerical methods, while advancing the theoretical understanding and computational reliability of models arising from ordinary, partial, delay, fractional, and integro-differential equations.

The papers published in this Special Issue reflect this dual objective of methodological innovation and rigorous analysis. They span stochastic and deterministic differential equations, singular perturbation theory, delay and fractional-order systems, soliton dynamics, and energy-stable numerical schemes, together with control-theoretic and stability analyses for complex dynamical models. The contributions address a broad spectrum of problems, ranging from nonlinear wave propagation and chaos in dispersive equations to integro-differential formulations, oscillation criteria, and high-order numerical algorithms for stiff and non-smooth systems. Despite this diversity, the papers share a common perspective: carefully designed numerical methods, supported by rigorous analytical frameworks, are essential for accurately capturing multiscale dynamics, ensuring stability and convergence, and enabling reliable simulation, analysis, and control of complex systems governed by differential equations.

In the first group of papers, the emphasis is on nonlinear wave dynamics and soliton behaviour

under deterministic and stochastic effects. Mohra Zayed et al. investigate the stochastic dynamics of solitary waves in a damped modified Korteweg–de Vries equation by incorporating multiplicative noise through a Wiener process. By combining analytical soliton solutions with numerical simulations, the study elucidates how stochastic perturbations influence waveform stability, amplitude modulation, and long-term evolution. Complementing this perspective, Muhammad Shakeel et al. analyze the nonlinear dynamics of the Boussinesq equation, deriving a variety of soliton solutions and exploring bifurcation structures, multistability, and weak chaotic behaviour through Lyapunov analysis. Further extending the wave-dynamics theme, Musawa Yahya Almusawa and Hassan Almusawa examine fractional nonlinear waves governed by the fifth-order KdV and Kawahara equations under the Caputo operator, demonstrating the effectiveness of Aboodh-based analytical methods in capturing fractional-order effects on dispersive wave propagation.

A second set of contributions focuses on high-accuracy numerical and spectral methods for boundary value and integro-differential problems. Chaoyue Guan and Jian Zhang propose a quasi-Newton reproducing kernel method for nonlinear high-order boundary value problems, achieving improved computational efficiency by avoiding Schmidt orthogonalization while retaining second-order convergence in the maximum norm. Ali H. Tedjani, Sharifah E. Alhazmi, and Samer S. Ezz-Eldien develop an operational spectral collocation approach based on shifted Jacobi polynomials for one- and two-dimensional high-order multi-pantograph Volterra integro-differential equations, effectively reducing the governing equations to algebraic systems and demonstrating accuracy through comparative studies. In a related numerical–spectral framework, Waleed Mohamed Abd-Elhameed, Omar Mazen Alqubori, and Ahmed Gamal Atta introduce a collocation procedure for the FitzHugh–Nagumo equation using generalized Gegenbauer polynomials related to Chebyshev polynomials, providing convergence analysis and numerical validation for this biologically motivated nonlinear system.

Several papers address challenges arising from singular perturbations, non-smoothness, and the presence of boundary or interior layers, and propose layer-adapted numerical schemes. Ruby, Vembu Shanthi, and Higinio Ramos study a quasilinear parabolic convection–diffusion problem with a discontinuous source term, in which interior layers arise due to singular perturbation effects. By employing a Shishkin mesh in space and a backward Euler discretization in time, the authors establish parameter-uniform convergence properties supported by numerical experiments. In a related vein, M. Chandru et al. develop an almost second-order parameter-uniformly convergent finite difference scheme for a two-parameter singularly perturbed problem with discontinuous convection coefficients and source terms, demonstrating superior accuracy when compared with standard upwind methods.

The Special Issue also includes contributions on fractional-order, stochastic, and delay differential equation models motivated by real-world applications. Feliz Minhós, Ali Raza, and Umar Shafique formulate and analyze a stochastic fractional delayed heroin model incorporating artificial decay, rigorously establishing positivity, boundedness, stability, and extinction conditions, and validating the theoretical results through non-standard finite difference simulations. Zuhur Alqahtani et al. derive new oscillation criteria for a class of third-order quasilinear delay differential equations using comparison principles and Riccati transformations, thereby extending existing analytical frameworks for delayed systems.

In the area of control, stability, and performance analysis, Junghoon Kim and Jung Hoon Kim present an  $L_1$ -induced norm analysis for linear multivariable differential equations by constructing

computable upper and lower bounds through polynomial approximations, with parallel results for corresponding difference equations. Hyung Tae Choi and Jung Hoon Kim propose a delay-independent  $L_\infty$  performance control framework for linear time-delay systems with time-varying delays, using ellipsoidal invariance and linear matrix inequalities to design output-feedback controllers whose parameters are independent of delay characteristics. Finally, Tian Xu and Ailong Wu investigate the stabilization of nonlinear hybrid stochastic time-delay neural networks with Lévy noise, establishing discrete-time feedback control criteria for stability, asymptotic stability, and exponential stability, supported by numerical illustrations.

This Special Issue received a strong response from the research community, with submissions spanning applied mathematics, and computational mechanics. All manuscripts were evaluated through the standard rigorous peer-review process of AIMS Mathematics, ensuring both scientific quality and thematic coherence. Following careful review and revision, a selected set of high-quality papers was accepted for publication.

As Guest Editors, we express our sincere gratitude to all contributing authors for their valuable research, to the reviewers for their thorough and constructive assessments, and to the editorial team of AIMS Mathematics for their professional support throughout the review and publication process.

We hope that this Special Issue will serve as a useful reference for researchers and practitioners working on numerical methods for differential equations and related applications, and that it will stimulate further developments in mathematically rigorous modelling approaches with broad relevance across science and engineering.

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### Conflict of interest

The Guest Editors declare no conflicts of interest.



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