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Abundant closed-form wave solutions and dynamical structures of soliton solutions to the (3+1)-dimensional BLMP equation in mathematical physics

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ABSTRACT

The physical principles of natural occurrences are frequently examined using nonlinear evolution equations (NLEEs). Nonlinear equations are intensively investigated in mathematical physics, ocean physics, scientific applications, and marine engineering. This paper investigates the Boiti-Leon-Manna-Pempinelli (BLMP) equation in (3+1)-dimensions, which describes fluid propagation and can be considered as a nonlinear complex physical model for incompressible fluids in plasma physics. This four-dimensional BLMP equation is certainly a dynamical nonlinear evolution equation in real-world applications. Here, we implement the generalized exponential rational function (GERF) method and the generalized Kudryashov method to obtain the exact closed-form solutions of the considered BLMP equation and construct novel solitary wave solutions, including hyperbolic and trigonometric functions, and exponential rational functions with arbitrary constant parameters. These two efficient methods are applied to extracting solitary wave solutions, dark-bright solitons, singular solitons, combo singular solitons, periodic wave solutions, singular bell-shaped solitons, kink-shaped solitons, and rational form solutions. Some three-dimensional graphics of obtained exact analytic solutions are presented by considering the suitable choice of involved free parameters. Eventually, the established results verify the capability, efficiency, and trustworthiness of the implemented methods. The techniques are effective, authentic, and straightforward mathematical tools for obtaining closed-form solutions to nonlinear partial differential equations (NLPDEs) arising in nonlinear sciences, plasma physics, and fluid dynamics.

1. Introduction

The study of nonlinear partial differential equations (NPDEs) is used to describe nonlinear complex phenomena in diverse fields of nonlinear sciences, such as plasma physics, ocean physics, fluid dynamics, hydrodynamics, marine engineering, and many more. Many researchers and mathematicians use numerical and analytical methods to study nonlinear PDEs and construct closed-form solutions, travelling wave solutions, solitary wave solutions, and the dynamics of solitary wave solutions. Exact closed-form solutions allow us to understand the characteristics and features of solitary wave solutions of complex physical phenomena and the dynamical behavior of established results for higher-dimensional nonlinear evolution equations. Many powerful methods for examining exact closed-form solutions of NPDEs have been introduced in recent decades by utilizing symbolic computation, such as the Hirota bilinear technique, the Darboux transformations technique, the improved F-expansion technique, the solitary wave ansatz technique, the simple equation technique, the Lie symmetry method, the extended Tanh method, the unified method, and the extended Kudryashov method, and so on [1–42].

This work focuses on the study of the (3+1)-dimensional Boiti-Leon-Manna-Pempinelli (BLMP) equation, which was proposed by Darvishi et al. [43]

$$u_{yt} + u_{zt} + u_{xxxy}u_{xxxz} - 3u_x(u_{xy} + u_{xz}) - 3u_{xx}(u_y + u_z) = 0, \tag{1}$$

where $u = u(x, y, z, t)$. This equation is an expansion of the (2+1) dimensional equation that represents the (3+1)-dimensional interaction of the Riemann wave propagating along two spatial dimensions, x-axis, and y-axis [49,50]. Darvishi et al. [43], who used multiple exp-function methods to study the double-waves, single-waves, and multiple solution solutions for the (3+1)-dimensional

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