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Existence, Uniqueness, and Hyers–Ulam’s Stability of the Nonlinear Bagley–Torvik Equation with Functional Initial Conditions

The nonlinear Bagley–Torvik equation is of fundamental importance, as it captures a realistic and intricate interplay among memory effects, nonlinearity, and functional dependence—making it a powerful model for a wide range of natural and engineered systems. Its analysis contributes significantly to both the theoretical development of fractional differential equations and their practical applications across science and technology. In this paper, we employ the inverse operator method, the multivariate Mittag-Leffler function, and several classical fixed-point theorems to establish sufficient conditions for the existence, uniqueness, and Hyers–Ulam stability of solutions to the nonlinear Bagley–Torvik equation with functional initial conditions. Finally, we present several examples by explicitly computing values of the multivariate Mittag-Leffler functions to illustrate the main results.