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A second-order operator splitting Fourier spectral method for fractional-in-space reaction-diffusion equations

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Abstract

Fractional differential equations have been proved to be valuable tools for modeling diffusive processes associated with anomalous diffusion or spatial heterogeneity. However, many numerical methods for these equations have limitations in terms of computational efficiency due to the nonlocal nature of the fractional operator, which leads to large, dense matrices. The aim of this paper is to propose a second-order operator splitting Fourier spectral method as an accurate and efficient approach for solving fractional-in-space reaction-diffusion equations. This approach gives a full diagonal representation of the fractional operator and achieves spectral convergence regardless of the fractional power in the problem. In order to achieve second-order time accuracy, we decompose the original equation into linear and nonlinear subequations, and combine a half-time linear solver and a full-time second-order nonlinear solver followed by a final half-time linear solver. We numerically demonstrate the accuracy and efficiency of the proposed method and apply the proposed method to investigate the effect of the fractional power in fractional-in-space reaction-diffusion equations, including the Allen–Cahn, FitzHugh–Nagumo, and Gray–Scott models.

Key words: Fractional-in-space reaction-diffusion equations; Operator splitting method; Fourier spectral method; Second-order convergence

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