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A DEEP LEARNING–BASED ADVANCED SOLVER FOR FRACTIONAL PHASE-FIELD DYNAMICAL MODELS

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ABSTRACT

Deep learning has emerged as a powerful tool for modeling, solving complex scientific and engineering problems. Physics-informed neural networks (PINNs) enhance neural network models by embedding physical laws to solve differential equations. However, standard PINNs often face challenges when applied to fractional differential equations due to the nonlocal nature of fractional derivatives and the use of fixed activation functions, which can limit their accuracy for complex nonlinear problems. To address these limitations, we adopt the Kolmogorov–Arnold Network (KAN) as a neural network solver. Unlike conventional fully connected neural networks used in PINNs, which rely on fixed activation functions, KAN uses learnable activation functions, allowing for a more flexible and expressive modeling of complex nonlinear relationships. The KAN architecture is inspired by the Kolmogorov–Arnold representation theorem, which provides a theoretical foundation for expressing multivariate functions as compositions of univariate functions. We apply the KAN framework to solve a nonlocal time phase-field model governed by the Allen–Cahn and Cahn–Hilliard equations, and to perform parameter estimation. Nonlocal phase-field models are widely used to describe complex physical phenomena such as phase separation and interfacial dynamics. Numerical results demonstrate that the proposed method consistently outperforms standard PINNs in terms of reduced error and improved accuracy when approximating solutions of nonlinear and nonlocal governing equations.

Keywords Scientific Machine Learning · Deep Learning · Kolmogorov–Arnold Network · Fractional Differential Equation · L1 Difference Scheme.

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