Deep Learning Approaches for Predicting Strain Energy in Heterogeneous Materials

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Abstract

With the development of economy and society, large elastic heterogeneous materials such as composites, biomaterials, functional materials, and foams, are widely used in various fields due to their unique structures and functions. Therefore, it is of great significance to understand, predict and optimize the mechanical properties of these materials. In this study, the Mechanical MNIST dataset (containing 60,000 28×28-pixel images from the large uniaxial deformation simulation samples) were used to explore machine learning approaches, especially deep learning (DL) models, as an efficient alternative method to predict the mechanical responses (strain energy) of heterogeneous materials under uniaxial tension. The performance of classical methods (Simple Linear Regression, Random Forest, and Gradient Boosting) and advanced DL methods (Convolutional Neural Networks (CNN) and Residual Networks (ResNet)) were compared. The advanced DL methods (CNN and ResNet) achieved superior performance with mean squared errors (MSE) between 4.21 and 4.33, and coefficients of determination (R^2) of about 0.98. These DL methods can automatically learn spatial relationships from pixel-based representations without manual feature extraction, demonstrating their feasibility in real-time or large-scale simulations. DL methods can significantly reduce computational expenses in iterative design, optimization tasks, and large-scale simulations, and are an effective alternative modeling technique that can accelerate mechanical design and optimization processes.

Keywords

Convolutional neural networks, deep learning, heterogeneous materials, residual networks, strain energy.