GRAPH EMBEDDED DEEP NEURAL OPERATOR FOR STRESS FIELD PREDICTION IN FIBER-REINFORCED COMPOSITES

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ABSTRACT

Accurate analysis of stress fields in composite materials is pivotal for designing resilient real-world systems. As an initial step towards this goal, we consider the task of stress field prediction within fiber-reinforced composite materials. Till date, traditional methods like the finite-element approach (FEA) have achieved huge success in solving the governing partial differential equations (PDE) for material systems, although at an increased computational cost. However, recent research in ML-based methodologies has opened up new horizons, focusing on the utilization of deep neural networks (DNNs) to learn operators capable of mapping infinite-dimensional function spaces, and has taken the computational mechanics domain to a new height in terms of generalization abilities of the framework. One popular approach in the umbrella of neural operators is the deep operator network (DeepONet), which is inspired by the universal approximation theorem for operators. The DeepONet architecture consists of two DNNs, the branch network and the trunk network. The branch network takes as an input the representation of varying conditions across the learning problem (initial condition, boundary condition, PDE coefficients etc.), while the trunk net takes as input the points that the solution operator would be evaluated. Although both the networks are extremely flexible in their architecture, the branch network usually employs a convolutional neural network for high-dimensional inputs; thereby limiting the description of the input function on a lattice mesh. To overcome this limitation, we propose graph neural network (GNN)-based DeepONet, which considers a GNN architecture in the branch network, aiming to generalize the input space representation and enable irregular topology inputs in the DeepONet architecture. To demonstrate the efficiency and applicability of our proposed framework, we study the prediction of the stress field in fiber-reinforced composites. The branch network takes as input the irregular geometrical representation of the composite to output a latent representation produced by the graph layers. Using our proposed GNN-DeepONet framework, a generalized stress field is learned from the latent representations and proves to be computationally efficient that the current available methods.

REFERENCES

[1] Bathe, Klaus-Jürgen. *Finite Element Procedures*. Klaus-Jurgen Bathe, 2006.

[2] Bhaduri, Anindya, Ashwini Gupta, and Lori Graham-Brady. "Stress field prediction in fiber-reinforced composite materials using a deep learning approach." *Composites Part B: Engineering* 238 (2022): 109879.

[3] Maurizi, Marco, Chao Gao, and Filippo Berto. "Predicting stress, strain and deformation fields in materials and structures with graph neural networks." *Scientific reports* 12.1 (2022): 21834.

[4] Lu, Lu, et al. "Learning nonlinear operators via DeepONet based on the universal approximation theorem of operators." *Nature machine intelligence* 3.3 (2021): 218-229.

[5] Li, Zongyi, et al. "Fourier neural operator for parametric partial differential equations." *arXiv preprint arXiv:2010.08895* (2020).

[6] Goswami, Somdatta, et al. "Physics-informed deep neural operator networks." *Machine Learning in Modeling and Simulation: Methods and Applications*. Cham: Springer International Publishing, 2023. 219-254.