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Two stage multiobjective topology optimization method via SwinUnet with enhanced generalization

Cheng Xiang[1,2], Airong Chen[2], Hua Li[3], Dalei Wang[2], Baixue Ge[2] & Haocheng Chang[2]

Topology optimization is a critical tool for modern structural design, yet existing methods often prioritize single objectives (e.g., compliance minimization) and suffer from prohibitive computational costs, especially in multi-objective scenarios. To address these limitations, this paper introduces a novel two-stage multi-objective topology optimization (MOTO) method that uniquely integrates data-driven learning with physics-informed refinement, and both stages are implemented within nearly identical network frameworks, ensuring simplicity and consistency in execution. Firstly, a MOTO mathematical model based on the constraint programming method that considers competing objectives of compliance, stress distribution, and material usage was constructed. Secondly, a novel neural network that incorporates shifted windows attention mechanism and lightweight modules was developed to enhance feature extraction while maintaining computational efficiency. Finally, the proposed model was trained in two stages: In Stage-1, utilizing adaptive input tensors, the network predicts near-optimal geometries across variable design domains (including rectangular and L-shaped configurations) and diverse boundary conditions in real time, requiring only 1,650 samples per condition. In Stage-2, the near-optimal structures from Stage-1 were physically optimized to achieve optimal performance. Experimental results demonstrate that the method's capability to generate high-accuracy, computationally efficient solutions with robust generalization capabilities. It effectively tackles challenges associated with multi-scale design domains and non-convex geometries, various and even untrained boundary conditions while significantly reducing data dependency, a critical advancement for data-driven topology optimization. The novel approach offers new insights for multi-objective structural design and promotes advancements in structural design practices.

Keywords Topology optimization, Deep learning, Multi-object optimization, Self-attention mechanism, Physics-informed neural networks, Generalization ability

Structural optimization seeks to pursue structures with higher efficiency (such as higher performance, lower costs, lightweight, etc.)[1]. Within the field of structural optimization, topology optimization (TO) is dedicated to identifying the optimal distribution of material within a given design domain (DD) under different constraints. Over the past few decades, TO has experienced rapid development, leading to the emergence of numerous numerical methods, such as SIMP[2,3], evolutionary approaches[4], level-set method[5,6], and moving morphable components method (MMC)[7]. Despite their widespread adoption, traditional methods for solving TO are hindered by their computational expense, necessitating a large number of design variables and iterations during the optimization process. Each iteration requires finite element analysis (FEA) and sensitivity analysis to inform updates to the design variables[8]. This computational inefficiency significantly hampers the practical application of TO, highlighting the urgent need for new methods to enhance its efficiency and practicality.

With the growing popularity of deep learning (DL), significant advancements have been made across various fields. In recent years, several DL-based TO methods have emerged to mitigate computational burdens. Early approaches in this area primarily focused on developing end-to-end TO frameworks that aimed to directly map design constraints to optimal topologies, emphasizing real-time prediction of optimized structures. For examples, Sosnovik and Oseledets[9] pioneered the integration of TO and DL by framing TO as an image segmentation task. Using the convolutional encoder-decoder architecture, the near-optimal structures can be obtained without iterative processes. With a carefully designed initial physical field input tensor, Wang et al.[10,11] developed a deep CNN with perceptible generalization ability for TO, which can rapidly predict the 2D or 3D optimized structures

[1]College of Civil Engineering, Fuzhou University, Fuzhou 350116, China. [2]Department of Bridge Engineering, Tongji University, Shanghai 200092, China. [3]Fujian Transportation Planning and Design Institute Co. LTD., Fuzhou 350004, China. email: changhc16@tongji.edu.cn

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