

GRAPH NEURAL NETWORKS FOR CFD SPACE AND TIME PREDICTION: AN APPLICATION TO SOLAR PANELS

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ABSTRACT

Modeling the complex aerodynamics of solar power plants with precision is crucial for ensuring their safety in wind flow. Factors like scale, positioning, and wind exposure significantly affect the complexity of simulations, making it more challenging to accurately capture the behavior of turbulent wind interactions in large-scale panel arrays. In power plants using solar trackers, the variable tilt of the panels and fluctuating wind conditions further complicate the problem, especially when time-dependent and directional wind changes are considered [1]. While Computational Fluid Dynamics (CFD) simulations offer high-fidelity modeling, their computational cost increases significantly with the mesh resolution required for large-scale configurations, limiting their feasibility in industrial applications.

To overcome these computational challenges, we apply advanced machine learning methods, specifically Graph Neural Networks (GNNs), as efficient and scalable surrogate models capable of capturing the spatial and temporal complexity of wind flow on large-scale solar panel arrays. GNNs are well-suited for representing graph-based systems such as those found in mesh-based CFD simulations [2], scaling effectively with the number of mesh elements. We explore a GNN architecture inspired by [3], which introduces a novel masking approach for handling large graph domains and incorporates transformers to account for time-dependent behaviors. The model also uses self-attention mechanisms within the message passing blocks and dynamic mesh pruning based on self-attention scores to reduce the number of nodes needed without sacrificing accuracy.

We demonstrate the model's accuracy using comprehensive 2D datasets that simulate the behavior of large-scale solar arrays in wind flow. Our approach replicates with satisfying results the aerodynamic behavior observed in high-fidelity CFD simulations, with inference times at a fraction of the CFD computational cost, motivating its scalability to 3D datasets representative of real-world solar power plant designs. This advancement enables the prediction of wind loads for large-scale solar power plants, paving the way for their real-time safety assessments and potentially their real-time aerodynamic control.

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