RADemics

Computational Physics in AI-Driven Engineering Applications

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Abstract

The integration of artificial intelligence (AI) with computational physics is rapidly reshaping engineering simulations, offering unprecedented capabilities in optimization, design, and real-time problem-solving. AI-driven approaches provide powerful tools for overcoming the limitations of traditional physics-based models by enhancing accuracy, speed, and adaptability across a wide range of engineering domains. This chapter explores the synergy between AI techniques, such as machine learning and deep learning, and computational physics, focusing on how their convergence leads to more efficient and innovative solutions in complex engineering applications. Key technologies such as hybrid AI-physics models, real-time adaptive simulations, and optimization algorithms are examined in the context of aerospace, automotive, structural engineering, and renewable energy systems. The chapter also highlights the transformative potential of AI in solving large-scale, high-dimensional problems that were once considered computationally infeasible. Future advancements in quantum computing, coupled with AI, are poised to further revolutionize the capabilities of computational models, unlocking new frontiers in engineering design and system optimization. The implications of AI-driven methodologies extend across industries, paving the way for more sustainable, efficient, and intelligent engineering practices.

Keywords: Artificial Intelligence, Computational Physics, Optimization, Hybrid Models, Engineering Design, Real-Time Simulations.

Introduction

The field of computational physics has long been pivotal in solving complex engineering problems, allowing for the simulation of physical systems and the prediction of their behavior under various conditions [1]. By employing numerical methods to solve partial differential equations, computational physics has enabled engineers and scientists to analyze phenomena that are difficult or impossible to observe in real life [2]. Despite its widespread application across diverse engineering disciplines such as fluid dynamics, structural analysis, and thermodynamics, computational physics has limitations when faced with highly nonlinear systems, dynamic environments, and large-scale problems [3]. These limitations often require enormous computational resources and time, making it challenging to solve certain problems with traditional approaches [4]. As the demand for more accurate and efficient solutions grows, the integration of artificial intelligence (AI) into computational physics offers transformative possibilities, bridging these gaps and enhancing the performance of engineering simulations [5].

Artificial intelligence, particularly machine learning (ML) and deep learning (DL), offers powerful tools that complement and augment traditional computational physics methods [6]. AI excels in its ability to learn from data, identify patterns, and predict outcomes with minimal human intervention [7]. By incorporating AI techniques into computational physics, simulations can be optimized to handle larger datasets, complex nonlinearities, and dynamic interactions in real time [8]. AI can also create surrogate models, which act as faster approximations of traditional physics-based simulations, reducing the computational load while maintaining the accuracy of the results [9]. The integration of AI into physics-based models not only accelerates problem-solving but also leads to new insights and more effective engineering solutions [10].

The hybridization of AI and computational physics is particularly beneficial for solving complex multiphysics problems, where multiple physical domains interact with one another [11]. For instance, in aerospace engineering, AI-driven simulations can simultaneously model fluid dynamics, structural behavior, and thermal conditions, providing a more comprehensive understanding of system performance [12]. AI can help optimize design parameters in real-time by learning from previous simulations and adapting the model based on new data [13]. This ability to perform multidimensional, integrated simulations in a computationally efficient manner is a game-changer in industries where precise design and optimization are critical, such as automotive, aerospace, and energy [14]. The impact of AI-driven computational physics extends beyond theoretical models, providing practical applications that improve both product design and operational efficiency [15].