



Artificial Intelligence Applications in Engineering: Trends, Opportunities, and Challenges

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Abstract: Artificial Intelligence (AI) has emerged as a transformative technology across multiple engineering disciplines, driving innovation in design, optimisation, predictive maintenance, simulation, materials discovery, and education. This paper presents a comprehensive review of recent advancements in AI applications in engineering, highlighting practical implementations in power electronics, digital twins, process systems, and materials engineering. We also analyse the role of generative AI, reinforcement learning, and explainable AI in addressing complex engineering problems. Finally, challenges such as trustworthiness, ethical concerns, data scarcity, and integration with legacy systems are discussed, along with potential research directions.

Keywords: Artificial Intelligence, Engineering Applications, Digital Twin, Reinforcement Learning, Generative AI, Predictive Maintenance, Materials Discovery.

1. INTRODUCTION

The rapid evolution of Artificial Intelligence (AI) has reshaped the landscape of engineering practice. From automating design processes to optimising manufacturing workflows and enabling predictive maintenance, AI provides new tools for engineers to tackle previously intractable problems. According to recent reports, AI-accelerated simulation can deliver results up to 1000 times faster than traditional computational methods, while reinforcement learning controllers demonstrate robust performance in nonlinear systems [1], [2]. This paper reviews the state-of-the-art applications of AI in engineering, categorising them into four domains: Power and Electrical Engineering, Mechanical and Process Engineering, Materials Science and Design, Education and Systems Engineering.

2. AI in Power and Electrical Engineering

AI plays a critical role in power electronics, grid optimisation, and energy systems. Recent advancements include: - Wireless Power Transfer (WPT): A load-independent machine learning-based The WPT system reduced voltage fluctuation from 18% to 5% and improved efficiency to 86.7% [3]. - Reinforcement Learning Controllers: RL-based control strategies for grid-connected multilevel inverters outperform classical model-based methods, offering adaptive handling of nonlinearities [4]. - Smart Grids: AI-driven fault detection and demand forecasting are enabling resilient and sustainable grid operations.

3. AI in Mechanical and Process Engineering

AI enhances simulation, monitoring, and optimisation in process-intensive industries: - AI-Accelerated Simulation: Platforms such as Altair's PhysicsAITM provide near-instant simulation through deep learning surrogates [5]. - Generative AI for Process Systems: LLMs and generative design tools are being deployed for process flow diagram (PFD) generation, hazard analysis (HAZOP), and plant optimisation [6]. - Predictive Maintenance: Digital twin technology enables real-time monitoring, anomaly detection, and failure prediction in manufacturing plants and industrial assets [7].

4. AI in Materials Engineering

Materials science benefits from AI-driven discovery, modelling, and optimisation: - Thermoelectric Materials: Deep neural networks and graph-based models optimise composition and defect structures for high-efficiency thermoelectric devices [8]. - Inverse Design: Generative models are being applied to predict materials with specific optical, thermal, or mechanical properties. - Large-Scale Discovery: DeepMind's GNoME discovered over two million new inorganic materials with a validation success rate of 71% [9].

5. AI in Education and Systems Engineering

AI-driven education tools are shaping the future of engineering training and systems design: - Virtual Labs: Simulation-based AI labs improved student engagement by 30% and conceptual understanding by 20% [10]. - Requirements Engineering: AI assists in transforming natural language requirements into structured engineering specifications, improving collaboration and reducing risk [11].

6. Challenges and Future Directions

Despite significant progress, challenges remain: - Trustworthiness and Explainability: Engineering decisions demand high levels of transparency, which many black-box AI models lack. - Integration with Legacy Systems: Existing industrial systems often lack the infrastructure to incorporate AI solutions seamlessly. - Data Scarcity and Quality: Engineering data can be sparse, incomplete, or biased, limiting model performance. - Ethics and Responsibility: The adoption of AI in safety-critical applications raises concerns about accountability. Future research directions include explainable AI for engineering systems, reinforcement learning for autonomous control, and foundation models tailored to scientific and engineering domains.

7. Conclusion

AI is reshaping engineering practice by enabling faster simulations, smarter materials discovery, efficient energy systems, and improved engineering education. As AI models evolve, their integration into engineering domains will enhance efficiency, creativity, and sustainability. Addressing the challenges of trust, integration, and ethics will be critical to fully realise AI's transformative potential.

References

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