APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN QUANTUM PHYSICS AND COMPUTING: A COMPREHENSIVE REVIEW

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Abstract
This paper explores how artificial intelligence (AI) techniques are being applied within the domains of quantum physics and quantum computing. We aim to show how AI can assist quantum-physics research, how quantum computing can enhance AI, and how the two fields increasingly intersect. First, the paper introduces core ideas of quantum physics and quantum computing in simple terms, and then reviews recent research where AI (for example, machine learning, neural networks) supports quantum experiments, quantum system control, and quantum simulation. We further review how quantum computing frameworks have been used to accelerate AI tasks or propose novel computation models. In the critical analysis we identify themes such as hybrid quantum-classical architectures, physics-informed AI, and quantum-enhanced machine learning. We highlight key gaps: hardware noise, lack of large-scale quantum devices, difficulty in data encoding, and paucity of real-world applications. Finally we conclude that while the synergy is promising, much work is needed—especially in scalable systems, interpretability, and real-world deployment. We suggest future research directions like physics-aware neural networks tailored for quantum many-body problems, AI-driven quantum error correction, and benchmark studies of quantum-AI in real quantum physics labs in Indian context.

Keywords: *artificial intelligence in quantum physics; quantum computing and AI; quantum machine learning; hybrid quantum-classical; quantum system control*

1. Introduction

Quantum physics and quantum computing are two of the most exciting fields in modern science. Quantum physics explores phenomena such as superposition, entanglement and quantum measurement, which challenge our classical intuition. Quantum computing aims to exploit these phenomena to build new kinds of computers, using quantum bits (qubits) instead of classical bits (0/1), and thereby solve problems that classical computers find difficult. Meanwhile, artificial intelligence (AI), especially in the form of machine learning (ML) and neural networks, has made rapid advances across many fields.

The importance of linking AI with quantum physics and quantum computing lies in the fact that quantum systems are complex, data-rich, and often non-intuitive. AI offers methods for pattern recognition, control, optimization, and discovery which can assist quantum-physics research. At the same time, quantum computing offers new computational paradigms that may accelerate AI tasks or enable new types of AI. In the Indian academic context, it is timely for researchers and students to understand this intersection, so as to contribute meaningfully to both quantum science and AI.

In this paper we aim to do the needful by presenting a thorough review of applications of AI in quantum physics and computing. We will survey key literature, critically analyse current trends and gaps, and suggest future directions, all in simple and clear Indian English.

2. Literature Review

In this section we survey major strands of research at the intersection of AI, quantum physics and quantum computing. We organise the review under three themes: (A) AI for quantum-physics tasks; (B) AI for quantum computing control and simulation; (C) Quantum computing and AI/ML synergistic research.

2.1 AI for quantum-physics tasks

Researchers have begun to apply machine learning methods to quantum-physics problems such as state estimation, detection of phases, and experiment design. For example, Ma et al. (2025) show how machine-learning can help estimation and control of quantum systems: they highlight how ML techniques assist calibration and control of quantum hardware. Another example: Huynh et al. (2023) present a survey of quantum-inspired machine learning (QiML) and show how ideas from quantum physics can feed into ML. Also, Melnikov et al. (2017) described how a learning machine could design quantum optical experiments autonomously, discovering entangled-state settings.

2.2 AI for quantum computing control and simulation

In quantum computing hardware, issues such as noise, error correction, calibration, and system control are critical. AI methods are being used to assist these tasks. For example, the study by Genois et al. (2021) on "Quantum-tailored machine-learning characterization of a superconducting qubit" shows how physics-informed ML models improved device parameter estimation. Also, in the survey by Sharma & Ali (2025) on the integration of quantum computing with AI, they note that the dominant AI families in quantum-computing workflows are quantum kernel methods and variational circuits/QNNs.

2.3 Quantum computing and AI/ML synergy

A third strand of research looks at how quantum computing might enhance AI, or how AI techniques might be adapted to quantum settings. The work by Abohashima et al. (2020) on "Classification with Quantum Machine Learning" surveys how quantum versions of classification, clustering are being developed. The article "Quantum Artificial Intelligence: Enhancing Machine Learning with Quantum Computing" (Lohia, 2024) explores quantum support vector machines, quantum neural networks (QNNs) etc. Also, Papakostas (2023) gives an overview of quantum machine learning, noting limitations and potential.

2.4 Review of quantum computing models

To ground the discussion, it is also useful to know about the quantum computing models. For example, the review "A Review on Models and Applications of Quantum Computing" (2025) introduces gate-based, adiabatic, measurement-based models and algorithms like Grover's and Shor's.

2.5 AI in quantum data analytics & quantum computing

Some works examine how AI plus quantum computing can handle big data and analytics. For instance, the article "AI and Quantum Computing: The Future of Data Analytics at Scale" (2025) argues that quantum computing's superposition and entanglement may allow faster training of AI models and better handling of high-dimensional problems. Also, the white paper "Artificial Intelligence and Quantum Computing" (2024) outlines applications such as discovering correlations in quantum experiments.

Together these literatures show that the intersection of AI, quantum physics and quantum computing is active and growing.

3. Critical Analysis and Synthesis

3.1 Thematic / Comparative Analysis

From the literature review we identify several common themes and trends:

- **Hybrid quantum-classical workflows**: Many studies emphasise that purely quantum or purely classical methods are not sufficient as of now; instead hybrid systems, where AI/ML runs classical parts and quantum circuits handle quantum parts, are common. Sharma & Ali (2025) highlight this trend.
- **Physics-informed AI**: AI models that incorporate physical constraints or quantum-domain knowledge perform better (for example in device calibration). The Genois et al. (2021) work exemplifies this.
- **Quantum machine learning (QML) as a concept**: There is a recurring interest in QML, quantum kernels, quantum neural networks, quantum support vector machines. Papakostas (2023) and Lohia (2024) reflect this.
- **Applications in quantum physics experiments**: AI is used for estimation, control, experiment design in quantum systems (Ma et al., 2025).
- **Scalability and real-world gap**: Many authors observe that real advantage over classical methods is yet to be widely demonstrated. The survey by Sharma & Ali (2025) notes empirical "utility" demonstrations exist but mainstream ML advantage remains unproven.

Comparatively, we find that in quantum physics experimentation, the use of AI is more mature (device calibration, control) whereas in quantum computing-AI synergy (i.e., quantum computing accelerating AI), the field is more speculative and early. Also, quantum physics tasks tend to be more domain-specific (for example, Hamiltonian estimation) whereas quantum computing-AI tasks aim generically at classification, clustering and ML algorithm speed-ups.

3.2 Gaps and Critiques

Despite promising advances, there are significant gaps and limitations in current research:

- **Hardware limitations**: Quantum devices are still noisy, have limited qubits, and suffer decoherence. This constrains real-world deployment of quantum-AI systems. Sharma & Ali (2025) point out that trainability remains a core challenge (barren plateaus, noise).
- **Data-encoding bottleneck**: Many quantum-ML methods assume efficient encoding of classical data into quantum states, which is non-trivial and often not addressed in detail. The paper on state preparation techniques (Pushpak et al., 2025) discusses this gap.
- **Lack of large scale empirical evidence of quantum advantage for AI**: While some classification studies (Terashi et al., 2020) show feasibility, they do not yet show clear advantage over best classical methods. The information-theoretic bounds paper (Huang et al., 2021) shows that quantum advantage is possible in principle but requires certain conditions.
- **Interpretability and black-box AI**: In quantum system control, using black-box ML methods hinders trust and interpretability in physics-sensitive domains (Ma et al., 2025).
- **Integration with quantum-physics domain knowledge**: Some AI methods ignore the physics and treat data in a generic way, which may limit performance or miss important structure.
- **Indian research context**: While international research is increasing, there is less visibility of Indian-origin work combining AI + quantum physics + computing, especially in Indian institutions, which signals room for growth.

Together these critiques highlight that while the field is rich with promise, many "real-world" gaps remain, especially for Indian researchers seeking to contribute to impactful projects.

4. Conclusion and Future Research Directions

This paper has surveyed the applications of artificial intelligence (AI) in quantum physics and quantum computing. We reviewed how AI methods help in quantum experiments, quantum system control, and how quantum computing may support AI tasks. We synthesised major themes: hybrid quantum-classical workflows, physics-informed AI, quantum machine learning, and noted the clear but yet-to-fully-realised synergy. We also pointed out key gaps: hardware noise and scalability, data-encoding and training bottlenecks, lack of large-scale empirical quantum advantage for AI, interpretability issues, and limited work in specific regional contexts.

In the Indian academic context, this is an opportune time to engage in this intersection. For future research we suggest the following specific directions:

1. **Physics-aware neural networks for quantum many-body problems**: Develop AI models that embed quantum-physics constraints (such as conservation laws, symmetry) to solve many-body problems or quantum simulation tasks.
2. **AI-driven quantum error correction and calibration**: Use reinforcement-learning or supervised learning to optimise error-correction protocols, calibration of qubits, or control pulses in Indian quantum-hardware test-beds.
3. **Benchmarking studies in Indian context**: Conduct case studies where AI + quantum computing workflows are applied to domain problems (for example, quantum materials simulation, quantum cryptography) in Indian institutions or collaborations, to produce empirical evidence.
4. **Scalable data-encoding and hybrid architectures**: Research efficient encoding of classical data into quantum states, design of hybrid architectures that combine classical AI and quantum components, and evaluate them on realistic problems.
5. **Interpretability and trust in quantum-AI systems**: Especially for quantum-physics applications, explore interpretable AI models that physics researchers can understand, thus bridging AI and physics communities.
6. **Educational and infrastructural initiatives**: In India, promote curricula that integrate AI, quantum physics and quantum computing, and build collaborative labs between departments of physics, computer science and engineering.

In conclusion, the marriage of AI with quantum physics and quantum computing presents a frontier with rich opportunities for Indian researchers and institutions. While the field is still evolving, with hardware, algorithmic and integration challenges, the groundwork is being laid. By taking clear, focused steps—especially in the Indian ecosystem—we can contribute to meaningful advances in this hybrid intelligence frontier.

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