QUANTUM-ENHANCED CLOUD AI
THE NEXT FRONTIER IN MACHINE LEARNING AND DEEP LEARNING

Editors:
Satveer Kour
Harvinder Singh
Anupam Bonkra
Rupinder Singh

Bentham Books

Quantum-Enhanced Cloud AI: The Next Frontier in Machine Learning and Deep Learning

Edited by

Satveer Kour
Department of Computer Engineering and Technology
Guru Nanak Dev University
Amritsar, Punjab, India

Harvinder Singh
Department of Mechanical Engineering
Chandigarh Engineering College-CGC Landran, Mohali
Punjab, India

Anupam Bonkra
Department of Computer Science and Engineering
Maharishi Markandeshwar (Deemed to be University)
Mullana, Haryana, India

&

Rupinder Singh
Chitkara University Institute of Engineering and Technology
Chitkara University
Rajpura, Punjab, India

Quantum-Enhanced Cloud AI:The Next Frontier in Machine Learning and Deep Learning

Editors: Rupinder Singh, Harvinder Singh, Anupam Bonkra and Rupinder Singh

ISBN (Online): 979-8-89881-321-5

ISBN (Print): 979-8-89881-322-2

ISBN (Paperback): 979-8-89881-323-9

Published by Bentham Science Publishers Pte. Ltd. Singapore, in collaboration with Eureka Conferences, USA.

First published in 2026.

need for a court order if at any point you breach any terms of this License Agreement. In no event will any delay or failure by Bentham Science Publishers in enforcing your compliance with this License Agreement constitute a waiver of any of its rights.

3. You acknowledge that you have read this License Agreement, and agree to be bound by its terms and conditions. To the extent that any other terms and conditions presented on any website of Bentham Science Publishers conflict with, or are inconsistent with, the terms and conditions set out in this License Agreement, you acknowledge that the terms and conditions set out in this License Agreement shall prevail.

Bentham Science Publishers Pte. Ltd.
No. 9 Raffles Place
Office No. 26-01
Singapore 048619
Singapore
Email: subscriptions@benthamscience.net

BENTHAM SCIENCE

CONTENTS

FOREWORD

In an era where data is the new oil and intelligence is the new electricity, the convergence of quantum computing, cloud infrastructure, and artificial intelligence signals a monumental shift in how we process, understand, and interact with information. This book proposal, QuantumEnhanced Cloud AI: The Next Frontier in Machine Learning and Deep Learning, offers a timely and visionary exploration into this transformative landscape.

As machine learning and deep learning have matured, they have increasingly strained the limits of classical computing infrastructure. Massive datasets, high-dimensional models, and real-time decision-making requirements demand computational resources that are not only powerful but also efficient and scalable. Simultaneously, quantum computing has emerged from the realm of theoretical physics into a promising technological frontier—capable of solving complex problems with exponentially less time and energy.

Cloud computing serves as the essential bridge, democratizing access to both AI and quantum technologies by abstracting hardware constraints and enabling scalable, distributed innovation. Together, these pillars form the foundation of a new paradigm—Quantum-Enhanced Cloud AI— where the raw power of quantum systems enhances the intelligence of AI models, and the flexibility of cloud infrastructure ensures accessibility, collaboration, and deployment at scale.

This book does more than just examine the individual technologies; it unites them into a cohesive narrative that looks ahead to their integrated potential. It highlights use cases from quantum-accelerated training to quantum-inspired optimization, discusses architectural frameworks for hybrid quantum-classical AI systems in the cloud, and investigates the implications for industries ranging from healthcare and finance to logistics and cybersecurity.

Whether you're a researcher, practitioner, student, or policymaker, this book offers critical insights and practical pathways to navigate the coming age of intelligent systems powered by quantum and cloud technologies. The future is not just about faster algorithms or bigger datasets—it is about a fundamental rethinking of computation itself. And in that future, the integration of quantum and AI on the cloud may well be the most defining chapter of our digital evolution.

Er. Aruna Rani
Department of Computer Science Engineering and Technology
Lamrin Tech Skills University
Chandigarh, Punjab, India

Preface

Quantum-Enhanced Cloud AI: The Next Frontier in Machine Learning and Deep Learning is a comprehensive book that discusses the traditional computing paradigms, while powerful, are nearing their natural limits in addressing the ever-growing demands of advanced machine learning and deep learning systems. Quantum computing, with its fundamentally different approach to processing information, and cloud computing, with its promise of scalable, accessible infrastructure, are together shaping a new horizon for AI — one that is faster, more powerful, and more transformative than anything we have seen before.

The first chapter addresses the most notable cloud-based platforms for quantum computing and their game-changing impact on the acceleration of AI development and implementation that will define the future of intelligent computing. Chapter two gives a comprehensive overview of quantum algorithms, hybrid quantum-classical models, and real-world implementations. Authors also explore how AI-cloud companies will be affected after major cloud providers enter the world of quantum computing-based business. This book also looks at security challenges, fundamental scalability limitations, and future research directions, with insights into how quantum computing will reshape the AI landscape over the next few decades. Chapter three shows that Quantum AI pertains to the practical feasibility, despite errors, corrections, coherence times, and a lack of algorithm development. This study highlights the importance of continuing to invest in Quantum AI to realize its full potential. Chapter four concludes with a forward-looking scope of AI and ML, considering their potential to transform other industries such as innovation and health, financial services, quantum computing, stock markets, transportation, education, logistics, and sustainable supply chains, impact societal structures, and offer solutions to complex worldwide problems. Chapter five’s main objective is to examine the architectural framework of Cloud Quantum Computing, assess its impact on AI-driven applications, and analyze key challenges and innovations shaping its development. Chapter six evaluates the active Quantum Machine Learning (QML) algorithms while demonstrating their improved functionality compared to usual approaches, and it identifies implementation barriers in real-world scenarios. Chapter seven summarizes the nature of Quantum AI for researchers, experts, and anyone who wishes to venture into the world's next big thing in technology. Chapter eight provides a comparative analysis of human protein function prediction through machine learning techniques and is further enhanced by using the QML approach.

Chapter nine discusses difficulties, further study prospects, and prospects for Quantum AI in the domains of Natural Language Processing and Computer Vision. Chapter ten explores the advancements in quantum computing as well as the development of edge intelligence, which are being set to transform industries by creating high levels of efficiency, security, and automation in real-time operations. Chapter eleven discusses the comparative analysis of unsupervised machine learning techniques for agricultural data analysis. Chapter twelve presents an AI/ML-based framework that uses a wearable smart band that will help people in maintaining social distances, tell whom to meet and whom to avoid having symptoms like body temperature above normal, coughing, and sneezing. Chapter thirteen gives an elaborate overview of the relevance of Quantum AI in healthcare, finance, and cybersecurity, which defines the trend of intelligent and secure computing systems. Chapter fourteen designed a protocol to be scalable and cloud-compatible, paving the way for secure integration with quantum-enhanced cloud AI healthcare systems. Chapter fifteen provides valuable insights into the evolving role of Quantum AI in web accessibility evaluation, offering a foundation for future advancements in automated assessment techniques. Chapter sixteen proposed two architectures from a unified framework that addresses both communication efficiency and security in next-generation Internet of Vehicles systems. Chapter seventeen highlights the revolutionary possibility of combining AI and QC in WSNs. This review focuses on the revolutionary potential of integrating AI and QC in WSNs and proposes future research areas, such as AI-based optimisation models, scalable quantum-secure communication protocols.

Satveer Kour
Department of Computer Engineering and Technology
Guru Nanak Dev University
Amritsar, Punjab, India

Harvinder Singh
Department of Mechanical Engineering
Chandigarh Engineering College-CGC Landran, Mohali
Punjab, India

Anupam Bonkra
Department of Computer Science and Engineering
Maharishi Markandeshwar (Deemed to be University)
Mullana, Haryana, India

&

Rupinder Singh
Chitkara University Institute of Engineering and Technology
Chitkara University
Rajpura, Punjab
India

List of Contributors

Aditi Dutta	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Akshit Patyal	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Aman Modgil	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Amanpreet Singh	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India
Anil Kumar	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Anupam Bonkra	Department of Computer Science and Engineering, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
Arun Kumar Rana	Department of Computer Science and Engineering (CSE), Galgotias College of Engineering and Technology, Greater Noida, Uttar Pradesh, India
Bhawandeep Kaur	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Davinder Kaur	Department of Computer Applications, Algoma University, Brampton Campus, Ontario, Canada
Gurpreet Singh	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Harleen Kaur	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Harvinder Singh	Department of Mechanical Engineering, Chandigarh Engineering College-CGC Landran, Mohali, Punjab, India
Hatem Salem Abu Hamatta	Department of Applied Sciences, Al-Balqa Applied University, Aqaba, Jordan
Indu Bharti Jain	Department of Law, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
Ishpreet Singh Virk	Department of Computer Science & Engineering, Chandigarh Engineering College (CEC) Landran, Mohali, Punjab, India
Jagdeep Singh Sappal	Department of Transport Engineering Deployment, Telus Corporation, Edmonton, Alberta, Canada
Jasjit Singh Samagh	Department of Computer Science and Engineering, Chaudhary Devi Lal University, Sirsa, Haryana, India
Jaspreet Kaur	School of Computer Science and Engineering, Lovely Professional University, Punjab, India
Jaspreet Singh	Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India
Jaswinder Singh	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India

Jyoti Jyoti	Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India
Karan Sood	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Kashif Nisar	School of Arts and Sciences, The University of Notre Dame Australia, Sydney, New South Wales, Australia
Kirandeep Kaur	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Komal Komal	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Kumari Sarita	Department of Computer Science, Guru Nanak Dev University, Amritsar, Punjab, India
Kunjana Mittal	Department of Law, Maharishi Markandeshwar University (deemed to be University), Mullana, Ambala, Haryana, India
Manish Sharma	Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India
Manuraj Moudgil	Department of Computer Science and Engineering, Bhai Gurdas Institute of Engineering & Technology, Sangrur, Punjab, India
Megha Bhushan	Department of Computer Languages and Systems, University of Seville, Seville, Andalusia, Spain
Mohammad Tabrez Quasim	College of Computing and Information Technology, University of Bisha, Bisha, Asir, Saudi Arabia
Mustafa Ali Khan	Compunnel Software Group Inc, Compunnel Software Group Inc, Phoenix, Arizona, USA
Noor Adnan	Department of Computer Science, College of Science for Women, University of Baghdad, Baghdad, Iraq
Omar Mbrouk	Department of Nano-Chemistry and its Environmental Applications, Environmental Studies and Research Institute, University of Sadat City, Sadat City, Menofia, Egypt
Palwinder Singh	Department of Computer Science and Applications, BBK DAV College for Women, Amritsar, Punjab, India
Paramjot Kaur Sarao	Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India
Pardeep Tiwana	Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India
Parwinder Kaur Dhillon	Department of Computer Science, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India
Piyush Samant	Department of Data Science, Mirxes Labs Pte Ltd., Kuala Lumpur, Malaysia
Pratibha Pratibha	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India
Preet Kamal Sharma	Department of Computer Applications, Post Graduate Government College for Girls, Chandigarh, Punjab, India

Pummy Dhiman	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India
Ritu Ritu	Department of Computer Science & Engineering, Chandigarh College of Engineering- CGC Jhanjeri, Mohali, Punjab, India
Rupinder Singh	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India
Sandeep Sood	Department Computer Science & Engineering, Guru Nanak Dev University, Amritsar, Punjab, India
Satinder Kaur	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Satveer Kour	Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Sayed Abid Hussain	Department of Computer Science and Engineering, Bakhtar University, Kabul, Afghanistan
Sheetal Kalra	Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India
Sudha Sudha	Department of Computer Applications, Gian Jyoti institute of Management and technology, Chandigarh, Punjab, India
Suman Devi	Department of Computer Science and Engineering, Chaudhary Devi Lal University, Sirsa, Haryana, India
Sumit Kumar	Department of Computer Science and Engineering, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
Sunil Kumar Chawla	Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India
Sunny Sharma	Department of Computer Science And Applications, Hindu College, Affiliated to Guru Nanak Dev University, Amritsar, Punjab, India
Vineeta Gulati	Department of Computer Science and Engineering (CSE), Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
Zaki Ahmad Khan	Department of Computer Science, University of Worcester, Worcester, United Kingdom

CHAPTER 1

Quantum-Powered AI in the Cloud: Unleashing the Future of Intelligent Computing

Jaspreet Kaur[1,*], **Satveer Kour**[2], **Megha Bhushan**[3] and **Harvinder Singh**[4]

[1] *School of Computer Science and Engineering, Lovely Professional University, Punjab, India*

[2] *Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India*

[3] *Department of Computer Languages and Systems, University of Seville, Seville, Andalusia, Spain*

[4] *Department of Mechanical Engineering, Chandigarh Engineering College-CGC Landran, Mohali, Punjab, India*

Abstract: Emerging technologies like quantum computing and Artificial Intelligence (AI) are radically changing how we approach computing technology. The fusion of these disciplines within cloud systems offers incredible computing power, which boosts effectiveness and flexibility. Productivity in almost every area – be it optimization, data processing, or machine learning – undergoes a significant transformation. This chapter offers an in-depth study of quantum AI in the scope of the cloud with respect to its basics, sophisticated integration frameworks, and advanced-level practical applications. It also outlines the limits of this new domain, such as hardware and software development, and other secondary issues like safety defects. In addition, this chapter addresses the most notable cloud-based platforms for quantum computing and their game-changing impact on the acceleration of AI development and implementation that will define the future of intelligent computing.

Keywords: AI ethics, Amazon braket, Cloud AI, Cybersecurity, Economics, Entanglement, IBM quantum, Intelligent computing, Microsoft azure, Quantum cloud platforms, Quantum computing, Quantum machine learning, Quantum neural networks, Qubits, Security, Superposition.

INTRODUCTION

Quantum computing uses superposition and entanglement, concepts interlaced with quantum mechanics, to execute sophisticated computations at astonishing speeds that far exceed classical computing systems. As reported by the Boston Consulting Group 2024, quantum computing may provide an economic value of

* **Corresponding author Jaspreet Kaur:** School of Computer Science and Engineering, Lovely Professional University, Punjab, India; E-mail: jaspreet.sliet@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

as much as $850 billion every year by 2050 in a variety of fields like pharmaceuticals, finance, and materials science [1]. The merger of quantum computing with Artificial Intelligence (AI) has the potential to transform the field of data optimization and machine learning algorithm training, as well as data processing speed. This combination allows for more efficient processing. Frankly, this simultaneous processing of high-dimensional datasets and complex models opens new frontiers in AI research and development [2].

By providing scalable infrastructure at a low cost, quantum technology can now be accessed easily using remote services. As per the latest forecasts, the market for cloud quantum computing is estimated to grow from $682 million in 2023 to about $1.5 billion by 2025, and nearly $4 billion by 2030, growing annually at a rate of 30% (CAGR forecast) as shown below (Table **1**) [3]. The cloud enables quantum AI, which offers businesses, developers, and researchers the capabilities to test and deploy quantum algorithms without actually purchasing and maintaining the complex hardware. IBM, Google, and Microsoft have invested heavily in cloud quantum AI systems, which have high-performance hybrid computing with classical and quantum compute cores for optimized processing power delivered through the cloud [4].

Table 1. Projected market growth of cloud-based quantum computing.

Year	Market Size (USD)	CAGR (%)
2023	$682 million	-
2025	~$1.5 billion	30%
2030	~$4 billion	30%

The unification of AI, quantum computing, and cloud systems is set to create huge innovations within industries of all varieties. For instance, in drug development and AI augmented quantum computing has the chance to shrink the time it takes to uncover new medications by an astonishing 80% and in turn save billions in R&D funding [5]. In the finance sector, quantum AI is projected to improve risk analysis accuracy by 40%, leading to more precise decision-making processes [6]. Cybersecurity faces an urgent challenge, with a 100% urgency level for adopting post-quantum encryption solutions to safeguard data against quantum attacks [7]. Moreover, materials science is expected to benefit from 70% advancements in quantum simulations, enabling the growth of new things with unprecedented properties. These projected impacts are summarized (Table **2**) and visually represented (Fig. **1**), highlighting the transformative potential and critical urgency of quantum AI across key sectors.

With the ongoing progress of quantum computing, its integration with AI in cloud environments is expected to redefine the future of intelligent computing, enabling breakthroughs in problem-solving and decision-making capabilities. With advancements in quantum hardware and cloud infrastructure, the next decade could witness a shift from experimental quantum AI applications to real-world implementations that transform industries on a global scale [8].

Table 2. Quantum AI's projected impact and urgency across industries.

Industry	Impact (%) or Urgency Level
Pharmaceuticals	80% reduction in drug discovery time
Finance	40% improvement in risk analysis accuracy
Cybersecurity	Urgent need for post-quantum encryption (100%)
Materials Science	70% advancements in quantum simulations

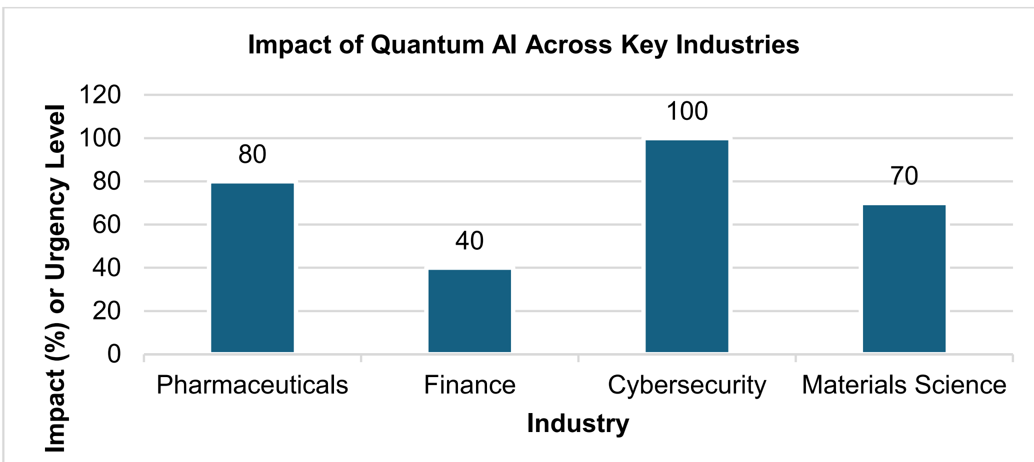

Fig. (1). Quantum AI's projected impact and urgency across industries.

FUNDAMENTALS OF CLOUD-BASED QUANTUM AI

Quantum Computing Basics

Quantum computing utilizes the fundamental principles of quantum mechanics to handle information in ways beyond the capabilities of classical computers. Unlike conventional bits that represent either 0 or 1, quantum bits (qubits) exploit superposition, enabling them to exist in multiple states at once. This allows quantum computers to complete parallel computations, greatly increasing efficiency as well as problem-solving speed.

CHAPTER 2

Revolutionize AI: Quantum-Cloud Delves into Integration Strategies, Benefits, and Future Prospects

Vineeta Gulati[1,*], **Arun Kumar Rana**[2] and **Kashif Nisar**[3]

[1] *Department of Computer Science and Engineering (CSE), Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India*

[2] *Department of Computer Science and Engineering (CSE), Galgotias College of Engineering and Technology, Greater Noida, Uttar Pradesh, India*

[3] *School of Arts and Sciences, The University of Notre Dame Australia, Sydney, New South Wales, Australia*

Abstract: Quantum Computing (QC) has emerged as a breakthrough technology with the potential to revolutionize Artificial Intelligence (AI) applications. By leveraging quantum mechanics principles, QC exponentially increases computational capacity, enabling accelerated data processing and optimization. The cloud availability of quantum computers facilitates their integration with existing cloud AI services, potentially offering the most promising route to exploit quantum algorithms within current cloud infrastructures. This chapter explores the interactions between quantum computing and cloud-based AI services, summarizing recent advances in implementation and the unique advantages of QC services compared to traditional cloud-based AI services. It also calls attention to open questions and potential areas of development. The authors give a comprehensive overview of quantum algorithms, hybrid quantum-classical models, and real-world implementations. The authors also explore the ways AI-cloud companies will be affected after major cloud providers enter the world of quantum computing-based business. This chapter also looks at security challenges, fundamental scalability limitations, and future research directions, with insights into how quantum computing will reshape the AI landscape over the next few decades.

Keywords: AI ethics, Cloud AI, Classical computing, Google quantum, Hybrid computing, IBM Quantum, Intelligent computing, Microsoft azure, Quantum computing, Quantum machine learning, Material science, Quantum neural networks, Qubits, Superposition.

* **Corresponding author Vineeta Gulati:** Department of Computer Science and Engineering (CSE), Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India; E-mail: vineetaarora04@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

Cloud AI has advanced significantly with quantum computing, and it's a fusion of fields that could have a long-term impact on computation. The use of cutting-edge concepts of quantum mechanics, such as superposition and entanglement, aims to increase the processing speed and efficiency of the AI models [1, 2]. Accompanying data of this nature and scale requires unprecedented computational capacity, as exemplified by this intersection of quantum computing and cloud-based AI platforms, which allows organizations to leverage state-of-the-art computational power without the cost of maintaining extensive hardware infrastructure, providing advancement and economic value in a world where data is becoming increasingly salient to our day-to-day [3, 4]. In addition to enabling the solving of complex problems that cannot be tackled with classical computing, this amalgamation also raises significant ethical and societal issues. Deployment of quantum-boosted AI tools is raising questions about data privacy, security, and potential inequality [5, 6]. As researchers and policymakers navigate these challenges, establishing robust ethical frameworks will be vital to ensuring fair access and responsible utilization of these transformative technologies. The implications of this integration are illustrated in vital use cases. For example, quantum AI in medicine could accelerate the drug discovery process by enabling a faster analysis of molecular interactions, while in finance, it could lead to more precise risk assessments and fraud detection [7, 8]. Logistics, among many other industries, stands to benefit from optimized routing and inventory management with quantum-enhanced AI applications—there's tremendous potential for quantum-enhanced AI applications to enable better decision making and efficiencies [9]. Even though quantum computing combined with cloud AI holds so much promise, there are some issues that need to be resolved. To achieve its full potential, technical limitations on scalability and resource requirements, and the need for cross-disciplinary collaboration around its use, must be addressed [10, 11]. While the potential for quantum computing and AI to collaborate is enormous, there are clear obstacles ahead of us.

Motivation and Problem Statement

Rapidly evolving AI technologies require ever-increasing computational capabilities that cloud-based infrastructures cannot keep up with. Largely driven by principles derived from quantum mechanics, quantum computing has the power to exponentially improve the processing capabilities of classical computing systems, which looks to be a promising solution to these computational bottlenecks. But quantum cloud AI is just in the early stages; there are still many technical, ethical, and scalability issues to resolve.

In this research, the authors focus on the critical question of how quantum computing can be seamlessly integrated into cloud-based AI systems to provide optimal computational benefits and new possibilities. Though the potential advantages of quantum algorithms are evident, current literature offers piecemeal insights into the topic of their usage for business, and there is a general lack of an overall structure for implementation and quantification of impact. This chapter seeks to fill this gap by investigating integration strategies, evaluating existing use cases, and determining the challenges that need to be overcome in order to allow a smooth transition to quantum-enhanced AI systems.

Research Contribution

- Examining some possible practical integration strategies for quantum computing and cloud-based AI, given the difficulties of executing the strategies in practice.
- In contrast, examine the quantum-enhanced AI services versus regular traditional cloud-based AI offerings, emphasizing what cannot be achieved through classical means.
- Detection of potential security threats and ethical issues related to quantum-cloud AI and suggesting mechanisms to mitigate them.

FUNDAMENTALS OF QUANTUM COMPUTING

QC is essentially a paradigm shift in terms of computing, using the laws of quantum physics to compute in quasi-mathematically infeasible ways. The quantum bit is then the elementary unit of quantum information, and one of the main components for this technology.

Basics of Quantum Mechanics

Quantum mechanics is the area of physics that describes the behavior of matter and energy at the atomic and subatomic levels. In classical computing, a unit of information (0 or 1) is known as a bit. The same thing occurs when you handle qubits that are a superposition of the bits positioned 0 and 1 simultaneously. Taking advantage of this property exponentially improves the capability of quantum systems to process data points in parallel over classical systems on large datasets [6, 7].

Superposition and Entanglement

Quantum Computing The wave-particle duality, the particle and waver nature of all matter, has many applications in quantum physics. In contrast, while the value of a classical bit can either be 0 or 1, a qubit can simultaneously represent both states, allowing for more advanced computations than classical bits. Quantum computers are formed by devices called qubits , and an n-qubit quantum

CHAPTER 3

Applications of Quantum AI in Healthcare, Finance, and Cybersecurity

Amanpreet Singh[1,*], **Rupinder Singh**[1], **Jaswinder Singh**[1], **Jaspreet Singh**[2] and **Hatem Salem Abu Hamatta**[3]

[1] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[2] *Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India*

[3] *Department of Applied Sciences, Al-Balqa Applied University, Aqaba, Jordan*

Abstract: Quantum Artificial Intelligence (Quantum AI) suits quantum computing and artificial intelligence to tackle complex issues such as multi-dimensional optimization and massive volumes of information more proficiently than classic strategies. Quantum AI utilizes quantum phenomena like superposition, entanglement, and tunneling, among others, to realize a speedup of several orders of magnitude compared to classical AI algorithms. Quantum AI is capable of being implemented for healthcare, finance, and cybersecurity. Whereas quantum simulations are used for accelerating drug discovery and for improving the accuracy of molecular modeling, they also benefit precision medicine through advanced genomic analysis as well as diagnostics, including precision diagnostics, through the precision testing of natural disease biomarkers, active and inactive metabolites, and toxic blood chemistry. Quantum AI in finance enhances trading profitability by accelerating the prediction of real-time market trends, optimization of the portfolio, and financial fraud detection, while processing vast datasets. Quantum cryptography, *e.g.*, quantum key distribution, provides security in cybersecurity, whereas quantum algorithms, such as Shor, bring threats to encryption, and thus post-quantum cryptography is developed. This chapter shows that Quantum AI pertains to practical feasibility, despite error correction, coherence times, and a lack of algorithm development. What we show is about how Quantum AI can transform these sectors, what the stumbling blocks are, hardware scalability, and algorithm efficiency, in addition to quantum computing reliability. This study, therefore, highlights the importance of continuing to invest in Quantum AI so that it can be fully realized.

* **Corresponding author Amanpreet Singh:** Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India; E-mail: Amanpreet.singh@chitkara.edu.in

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

Keywords: AI ethics, Cloud AI, Cybersecurity, Economics, Entanglement, Finance, Frameworks, Google quantum, Healthcare, Hybrid computing, Intelligent computing, Quantum computing, Quantum machine learning, Quantum mechanics, Quantum AI.

INTRODUCTION

Quantum Artificial Intelligence (QAI) is the combination of quantum computing and Artificial Intelligence (AI), which solves complex problems that classical computing cannot solve. Industries that require high computational efficiency have shown great promise in adopting Quantum Artificial Intelligence (QAI) [1]. The application of QAI leverages quantum phenomena, such as superposition, entanglement, and parallelism to achieve enhanced computational power. Industries are starting to take advantage of quantum superposition, quantum entanglement, and parallelism. This chapter shares details of how QAI can be applied to three critical domains, such as healthcare, finance, and cybersecurity. It is based on quantum mechanics principles, such as superposition and entanglement, as ways of improving AI decision-making using quantum AI [2]. Qubits in quantum computing reside in multiple states at once to offer the impressive payoff of classical binary computing [3]. One such feature is that it allows Quantum AI to solve complex optimization problems, to simulate a quantum system, and to improve machine learning models beyond classical capabilities [4].

Data from the healthcare industry is vast and cannot be handled by simple analyses involving diagnosis and treatment optimization. Quantum AI is a response to accelerating drug discovery, bettering medical imaging, and personal medicine. The development of a new drug is a costly and time-consuming process that often spans several years. Quantum AI can, however, drastically shrink this timeline since quantum computers perform molecular interactions more efficiently than classical computers. Quantum Machine Learning (QML) algorithms can process large datasets of molecular structures to obtain possible drug candidates and the interaction between the drug candidates and human proteins [5]. Specifically, companies such as IBM and Google are actively researching quantum applications in pharmacology.

Quantum AI improves pattern recognition refinement in MRI analysis to a level comparable to human perception. It also enhances anomaly detection, allowing the precise identification of which particle, even in a tiny sample, triggers a particular behavioral response in a rat. Radiologists build a better understanding of health outcomes in patients with diseases like cancer by amplifying machine learning with quantum enhancement to better detect the disease at earlier stages with higher accuracy [6]. Prepping vast genetic datasets to arrive at the optimal treatment strategies for everyone requires genomic sequencing. Quantum AI will speed up this process by identifying genetic mutations and predicting how patients will react to specific therapies. This has particularly exciting potential for the treatment of cancer, rare genetic disorders, or neurodegenerative diseases.

Molecular simulations accelerate in quantum computing (bypassing the long, expensive traditional process of drug discovery), and therefore, researchers can discover possible drug candidates faster [7]. Quantum computing prepared by AI is better than using medical data and can identify diseases such as cancer and neurological disorders [8]. The achievements to which I refer make global healthcare more precise, efficient, and accessible. With their recent developments, quantum AI is changing the face of the financial industry by transforming how people manage portfolios, reduce risk in analysis, and detect all forms of fraud [9]. Quantum-enhanced AI can process huge amounts of data in real time and on a time scale that classical models of finance would find hard or even impossible [10]. Quantum algorithms that solve complex risk-reward trade-offs of portfolio optimization with higher efficiency than conventional models are useful for that [11]. Fraud detection has also made leaps and bounds, one of which is that quantum machine learning can determine transaction anomalies that look like fraud more quickly than classical systems [12]. The capabilities aid financial institutions in making better decisions and becoming more efficient and more secure.

Quantum AI is an opportunity and a challenge in terms of cybersecurity. On the offensive side, quantum cryptography, especially Quantum Key Distribution (QKD), is available as a means of secure communication immune to classical hacking methods [13]. However, current encryption methods are vulnerable to large-scale quantum computers, as Shor's algorithm and other quantum algorithms can solve them efficiently [14]. Therefore, researchers are developing post-quantum cryptography algorithms to come up with encryption mechanisms that are immune to quantum attacks [15]. AI-based quantum-driven networks for cybersecurity further strengthen the cyber threat detection in the analysis of massive data at an unprecedented velocity, which makes the cyber nets more proactive and robust [16]. This integration into these domains means that we are moving to new problems and new problems that come with it. With the advancement of quantum hardware and the imperfections of the quantum algorithms improving, the role of Quantum AI is set to grow more with the impact across the industries and the quantum technological capabilities in the coming years [17]. The aim of this paper, then, is to explore these developments, glean the latest advancements and challenges, and look forward to the future directions of quantum AI in healthcare, finance, and cybersecurity. Statistical techniques are used to undertake traditional assessments of the risks and to optimize investment portfolios. Quantum AI can not only process market data as efficiently, but it can

CHAPTER 4

Cloud Quantum Computing for AI: Innovations, Challenges, and Applications

Jaspreet Singh[1,*], **Paramjot Kaur Sarao**[1], **Manish Sharma**[1], **Davinder Kaur**[2], **Rupinder Singh**[3] and **Mohammad Tabrez Quasim**[4]

[1] *Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India*

[2] *Department of Computer Applications, Algoma University, Brampton Campus, Ontario, Canada*

[3] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[4] *College of Computing and Information Technology, University of Bisha, Bisha, Asir, Saudi Arabia*

Abstract: Cloud Quantum Computing (CQC) is a paradigm shift in computer science that has the potential to revolutionize Artificial Intelligence (AI) by utilizing the computational capabilities of quantum mechanics. The primary objective of this chapter is to examine the architectural framework of CQC, assess its impact on AI-driven applications, and analyze key challenges and innovations shaping its development. It focuses on critical aspects of CQC, such as qubit fidelity, quantum error correction, and hybrid quantum-classical models. The chapter also incorporates the practical uses of CQC, highlighting its benefits in areas such as optimization, cryptography, and machine learning. The key findings of this chapter are that although CQC offers significant advantages in computational efficiency and problem-solving capabilities, it is still hindered by hardware limitations, noise interference, and algorithmic complexity. Innovations in error correction techniques and hybrid models are crucial for overcoming these barriers. By leveraging the power of quantum computing through cloud platforms, CQC has the potential to revolutionize AI and computational science.

Keywords: AI model optimization, Cloud quantum computing, Data privacy, ML, Parallelism, Quantum algorithms, Quantum circuits, Quantum cryptography, Qubit fidelity, Quantum software, Quantum simulation, Simulation.

* **Corresponding author Jaspreet Singh:** Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India; E-mail: jaspreetrajal@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

Cloud Quantum Computing (CQC) uses quantum mechanics to improve computational efficiency, optimization capabilities, and sophisticated data analysis techniques [1]. Quantum computing revolutionizes AI, necessitating the optimization of large-scale datasets and the complexity of machine learning algorithms. The traditional AI technique depends on classical computer architectures, which often struggle with large datasets. Researchers can remove the computational constraints by leveraging opportunities in data processing, pattern recognition, and problem-solving. Researchers and enterprises can resolve these opportunities by incorporating quantum computing into artificial intelligence. Peer algorithms struggle to analyse large data sets during AI developments. Classical computing systems are inherently limited when they start handling high-dimensional optimization tasks, complicated probabilistic techniques, and big datasets, despite their improvements.

Quantum computing uses quantum bits, which are capable of existing in many states at once because of the entanglement and superposition. The ability of quantum computers to perform parallel calculations can exponentially speed up data processing activities that would take classical computers an excessively long period to complete [2]. Cloud systems enable researchers, businesses, and developers to work with quantum algorithms without the hassle of physical equipment by making quantum processing units available. Businesses can now explore quantum-enhanced AI models for sophisticated simulations, natural language processing, optimization issues, and predictive analytics due to the democratization of quantum computing.

Numerous fields, such as cybersecurity, healthcare, banking, and logistics, can apply CQC and AI [3]. Quantum-enhanced optimization algorithms have the potential to boost risk assessment, fraud detection, and portfolio management tactics in the financial industry. Similarly, quantum computing can resolve complex scheduling and routing issues that traditional AI finds difficult to optimize in supply chain management and logistics.

Furthermore, the combination of quantum computing and artificial intelligence will redefine artificial intelligence. As cloud quantum computing advances, its integration into AI-driven applications will lead to significant breakthroughs, enhancing the strength, effectiveness, and problem-solving capabilities of AI models [4].

This chapter highlights the key innovations, challenges, and applications of cloud quantum computing for AI.

Motivation

The motivation behind writing this article is to explore how cloud and quantum computing work together to overcome the drawbacks of traditional computing. It can be used to solve high-dimensional, complex, artificial intelligence-based challenges. Data optimization, machine learning, and large-scale data processing, further with quantum parallelism, can be used in quantum computing. Quantum computing-based resources become more accessible with cloud-based access, as it eliminates hardware constraints and permits smooth AI interaction across various fields of computer science.

Key Components of AI with Cloud Quantum Computing

Quantum Computing

The basic ideas of quantum mechanics are superposition, entanglement, and quantization. Quantum computing uses parallelism to handle more complex calculations than traditional computers. Quantum bits, on the other hand, can exist in more than just two states—0 and 1—depending on their physical position [5]. This feature significantly enhances processing performance by allowing quantum computers to process a large number of possibilities at once. Complex AI models can exchange information at very high speeds and solve issues very efficiently. Quantum concurrency allows us to study multiple solutions to a problem at once. Quantum computers are particularly adept at optimization, pattern recognition, and large-scale data analysis [6]. It shows the capacity to transform machine learning, neural network training, and optimization methodologies within the domain of Artificial Intelligence (AI). Large datasets can be processed quicker by quantum-enhanced AI models, improving tasks, *i.e.*, predictive analytics, image processing, and Natural Language Processing (NLP). Additionally, quantum-based algorithms like Quantum Boltzmann Machines (QBM) and Quantum Support Vector Machines (QSVM) can make calculations easier, which could greatly speed up how fast AI models are trained [7].

Cloud Computing

Cloud computing acts as an essential element of quantum computing, offering the necessary infrastructure for storage and ensuring that Quantum Processing Units (QPUs) are accessible online. It makes quantum computing resources more accessible by eliminating the need for enterprises to invest in high-rate and specialized quantum infrastructure. Cloud-based systems enable researchers and AI developers to test quantum algorithms, optimization challenges, and machine learning models without the need for physical QPUs. The first inventors of cloud-based computing were Google, Microsoft, and IBM. IBM's Quantum Experience,

CHAPTER 5

Quantum Algorithms for Machine Learning

Davinder Kaur[1,*], **Preet Kamal Sharma**[2], **Manuraj Moudgil**[3], **Jaspreet Singh**[4], **Rupinder Singh**[5] and **Zaki Ahmad Khan**[6]

[1] *Department of Computer Applications, Algoma University, Brampton Campus, Ontario, Canada*

[2] *Department of Computer Applications, Post Graduate Government College for Girls, Chandigarh, Punjab, India*

[3] *Department of Computer Science and Engineering, Bhai Gurdas Institute of Engineering & Technology, Sangrur, Punjab, India*

[4] *Department of Computer Science and Engineering, Chandigarh University, Mohali, Punjab, India*

[5] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[6] *Department of Computer Science, University of Worcester, Worcester, United Kingdom*

Abstract: Through the integration of machine learning techniques with the computational power of quantum computing, quantum algorithms greatly improve the processing and analytical capabilities of systems. In contrast to traditional techniques, quantum computing effectively manages large and intricate datasets, providing answers to issues that conventional systems are unable to handle. Quantum Machine Learning (QML) has shown promise in a variety of fields, such as large-scale optimization, image recognition, and natural language processing. Because it can produce better and faster results, QML is positioned to revolutionize industries that depend on insights from data. The implementation of QML faces operational and scalability complications when used in healthcare applications and other fields of practical use. This study evaluates the active QML algorithms while demonstrating their improved functionality compared to usual approaches, and it identifies implementation barriers in real-world scenarios.

Keywords: AI ethicsAutomationComputer visionData encoding, Data privacy, Deep learning, Entanglement, Linear regression, ml, Pattern recognition, Predictive analysis, Quantum computing, Quantum data processing, Quantum neural networks, Quantum speedup, Superposition..

* **Corresponding author Davinder Kaur:** Department of Computer Applications, Algoma University, Brampton Campus, Ontario, Canada; E-mail: davinder.kaur@algomau.ca

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

Quantum computing exhibits disruptive power in computing through its exceptional methods to overcome problems that could not be solved by classical methods. The application of quantum computing elements called qubits produces valuable abilities to solve complex problems that regular computers cannot handle. The most successful optimization fields, alongside machine learning, potentially receive rapid and intelligent answers from quantum systems. These concepts remain difficult to implement in practice, especially regarding Quantum Machine Learning (QML).

The article analyzes the complex structure of quantum computing as it investigates vital optimization methods, including quantum annealing and VQE, and QAOA. These tools serve purposes in machine learning frameworks, as shown by this illustration. The researcher aims to clarify how quantum technology influences data science, as well as chemistry and logistics, and artificial intelligence by merging theoretical knowledge with contemporary practical methods [1].

Overview of Quantum

Quantum computing is a paradigm of computation that leverages the properties of quantum mechanics to control the behavior of atomic and photonic particles for processing information. The qubit elements serving as fundamental components of quantum computing systems allow the devices to maintain dual states of 0 and 1 at the same time, thus distinguishing them from traditional computing systems. The fundamental attribute of quantum computers enables exceptional mathematical processing through a mechanism called superposition is presented below (Fig. **1**).

Traditional Computing: [0] or [1]

Quantum Computing: [0] and [1] at the same time (Superposition)

Fig. (1). Traditional *vs.* quantum computing.

The illustration depicts how quantum computers implement dual-purpose qubits instead of traditional computers' binary bit system, which functions as 0 or 1.

Quantum Computing's Power

Quantum computers gain their power through the capability called entanglement, as shown below (Fig. **2**). When qubits become entangled, the state of one qubit depends on the state of another, no matter how far apart they are. This allows quantum computers to solve problems in parallel, vastly increasing their computational power. Quantum computing is still in early development, but it has the potential to solve problems that are too complex for traditional computers to handle [2].

Entangled Qubits: [Qubit 1] -> [Qubit 2] (Linked together)

Fig. (2). Entanglement in quantum computing.

In this diagram, entangled qubits influence each other even when separated, making it easier to solve complex problems together.

Impact on Machine Learning

A computer analytical technique uses data-learning methods to produce predictions and make decisions. Old machine learning methods experience processing delays when dealing with extensive datasets or intricate calculations because large datasets make them test their capabilities. Traditional image recognition operations involving millions of pixels require long processing times for each image due to large datasets. Through quantum computing, operations can be expedited due to improved performance in data analysis as well as optimization and pattern recognition tasks [3]. The operation of quantum algorithms leads to accelerated data learning capabilities, which produce more accurate predictive and decision-making capabilities for machines.

Traditional data processing methods fall short due to excessive data sizes. Quantum computing has the potential to accelerate drug discovery research through the acceleration of the process by which scientists discover promising drug candidates.

QUANTUM COMPUTING ARCHITECTURE: A LAYERED APPROACH

Quantum computing architecture consists of multiple layers that work together to process quantum information, as shown below (Fig. **3**). Each layer has a specific role in ensuring efficient quantum computation. The following is the breakdown of layers:

CHAPTER 6

Quantum-Driven AI: The Intersection of Quantum Computing and Machine Learning Algorithms

Pardeep Tiwana[1,*], **Karan Sood**[1], **Harleen Kaur**[1], **Aman Modgil**[1], **Indu Bharti Jain**[2], **Komal**[1] and **Jagdeep Singh Sappal**[3]

[1] *Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India*

[2] *Department of Law, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India*

[3] *Department of Transport Engineering Deployment, Telus Corporation, Edmonton, Alberta, Canada*

Abstract: Quantum Computing and AI can be integrated in a manner that will boost machine learning by eliminating obstacles presented by ordinary systems. This chapter delves into the relationship between Quantum Computing and Machine Learning, offering a critical examination of how quantum mechanics boosts conventional AI algorithms. The chapter starts by defining the basics of Quantum Computing, *i.e.*, qubits, superposition, entanglement, and quantum gates, and then proceeds to cover the essential principles of Quantum Machine Learning (QML) algorithms like Quantum Support Vector Machines (QSVM), Quantum Neural Networks (QNN), and Quantum Principal Component Analysis (QPCA). The chapter further gives some more details about Quantum-Driven AI and where its applications could be (in the medical sector, in finance, in cyber security, and in optimization problems). The advantages of Quantum AI have been discussed earlier, but it has some disadvantages as well, such as a lack of hardware, algorithmic complexities, and even issues regarding the morality of the technology. Lastly, the possibility of Quantum AI and the evolutionary strategy to bring this technology are emphasized. Now, with greater advancements in the physical substrates and new quantum peripherals in the quantum computer, more advanced construction of hybrid quantum-classical models, and more engagement of artificial intelligence in quantum research. People in all fields anticipate quantum mechanics and artificial intelligence to innovate and rejuvenate the industries and sectors they have adopted. This groundbreaking chapter will summarize the nature of Quantum AI to the researchers, experts, and anybody who wishes to venture into the world's next big thing.

* **Corresponding author Pardeep Tiwana:** Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India; E-mail: tiwana07763@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

Keywords: Artificial neural networks (ANNs), Boltzmann machines, Clustering algorithms, Deep learning, Grover's algorithm, Hybrid quantum-classical models, Noisy intermediate-scale quantum (NISQ), Quantum approximate optimization algorithm (QAOA), Quantum boltzmann machines, Quantum data processing, Quantum feature mapping, Quantum linear regression, Quantum principal component analysis (QPCA), Quantum reinforcement learning (QRL).

INTRODUCTION

AI and ML [1] are some of the most prominent technological trends that have affected almost all sectors, including healthcare, finance, robotics, and cybersecurity, among others [1]. There are various drawbacks related to the classical computing structures, specifically in the fields of optimization and high-dimensional problems with AI models. Quantum Computing (QC)—as the next generation computing technology that performs concurrent computations—has the potential to enhance the computation of AI algorithms, refine algorithms, and solve new problems practically impossible for classic computers [2]. This chapter aims to focus on the combination of quantum computing with conventional Machine Learning, known as Quantum Machine Learning (QML) [3], which is also referred to as Quantum-Driven Artificial Intelligence. This section gives a brief introduction about AI and quantum computing, why there is a requirement for quantum computing in AI, and examines the difficulties that quantum-enabled AI seeks to overcome that are present in classical machine learning.

Overview of AI and Machine Learning

AI is a branch of computer science that deals with the enlargement of intelligent systems that are special in the sense that they are able to do tasks that usually require the intervention of human intelligence. They are as follows: Speech recognition, image processing, decision-making, and lastly, predictive model mapping. There exist various branches of AI; however, Machine Learning (ML) stands out as the most prominent.

Key Components of Machine Learning

Machine learning is categorized into supervised learning, unsupervised learning, and reinforcement learning. Supervised learning involves algorithms that train on labeled datasets for the purpose of making predictions or decisions. A few examples are E-mail spam control, the functionality of which is to classify an E-mail as spam or not, or control, which forecasts sustained values, like stock prices, based on past data achieved, or not. Conversely, in the case of unsupervised learning, the algorithm operates based on unlabelled data, and the goal is to search for some pattern or structure in the data. Some of the ubiquitous practices include customer-related clustering, which can be utilized to group customers who have analogous behavior, and dimensionality reduction methods that can be utilized to minimize the diversity of input features, like PCA [4]. Finally, reinforcement learning relies on models training themselves to respond in order to learn the optimal cumulative rewards in an environment. This is very popular in Robotics, Autonomous systems, and games; some famous applications are AlphaGo and OpenAI Gym [5].

Quantum Computing Introduction

Quantum computing is a novel way to execute the calculations that are challenging or even impossible for traditional computers to carry out. As compared to classical computing depends on bits that can be 0 or 1, quantum computing is based on the utilize of qubits and the superposition ability, which allows the qubit to be both 0 and 1 at the same time. In computation, quantum computing uses qubits, whereas classical computing employs bits. In contrast, qubits can be 0, 1, or a value between 0 and 1, or any other value simultaneously, because of superposition. Another phenomenon is the coupling whereby two or more qubits are inescapably coupled in a manner that they get affected when the other one is, irrespective of the distance between them. This is due to the fact that it provides huge amounts of parallelism through parallel computation and data transfer. Also, in contrast to classical computers, quantum computers utilize quantum gates, which are unitary operators unlike AND, OR, NOT-type gates found in classical computers [6].

Need for Quantum Computing in AI

As AI models grow in complexity, they demand higher computational power, faster optimization techniques, and improved accuracy. Quantum Computing offers several advantages that make it a potential game-changer in AI:

Speeding Up Computation

Grover's search algorithm and Shor's factorization algorithm are two paradigmatic examples to describe how quantum computers may be significantly more powerful than classical computers [7]. This acceleration is crucial for training, deep learning models, and tackling difficult combinatorial optimization problems.

Enhancing Data Processing in High-Dimensional Spaces

Contemporary quantum systems are capable of handling data in an exponential number of dimensions in the Hilbert space over traditional systems, which is computationally more efficient in solving high-dimensional problems in ML.

CHAPTER 7

Comparative Analysis for Human Protein Function Prediction through Machine Learning Techniques and Performance Enhancement Using Quantum Machine Learning (QML)

Sunny Sharma[1,*], **Sandeep Sood**[2], **Palwinder Singh**[3] and **Anil Kumar**[4]

[1] *Department of Computer Science And Applications, Hindu College, Affiliated to Guru Nanak Dev University, Amritsar, Punjab, India*

[2] *Department Computer Science & Engineering, Guru Nanak Dev University, Amritsar, Punjab, India*

[3] *Department of Computer Science and Applications, BBK DAV College for Women, Amritsar, Punjab, India*

[4] *Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India*

Abstract: The technology is evolving quickly, and the immense and complex protein sequence databases are growing every day. To extract information from these huge masses of data, we require sophisticated computational approaches, such as Quantum Machine Learning (QML), which could be rapidly applied for the benefit of humanity. The HPFP (Human-Protein-Function-Prediction) is a crucial study used for the discovery of disease diagnosis, medicines, and crop hybridization. These days, lots of computational approaches are available for HPFP, yet many do not deliver reliable findings rapidly. This research study performed the experiment for HPFP by extracting the dataset from the HPRD (Human-Protein-Reference-Database), the SDFs (Sequence-Derived-Features) from protein sequence are extracted through the proposed HP-SDFES, as well as from some other web-servers. This study utilizes an RF (Random Forest) Machine Learning (ML) classifier for HPFP by extracting SDFs from HPF (Human-Protein-Sequence) and achieved 74.91% accuracy for individual protein class prediction. With improved SDF extractions and in conjunction with input configurations, the prediction accuracy enhances and ranges from 98% to 100% under ideal conditions. This study identifies that RF is the better classifier for HPFP rather than any other ML classifier, and this methodology can be applied similarly to other allied studies for the advancement of humanity, which is also the key finding of this research study. Further, to increase the prediction process speed, the QML approach has been used on RF. Quantum computing improves RF by accelerating feature

* **Corresponding author Sunny Sharma:** Department of Computer Science And Applications, Hindu College, Affiliated to Guru Nanak Dev University, Amritsar, Punjab, India;
E-mail: sunnyshrama05@yahoo.co.in

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

selection, entropy computations, and decision tree splits. The obtained final result has been compared with the existing benchmarks.

Keywords: Decision tree, Human protein function (HPF), HPRD, Hybrid quantum-classical models, Mutation prediction, Prediction accuracy, Protein function prediction (PFP), Protein-protein interaction (PPI), Random forest classifier, Quantum feature map, Quantum kernel, Quantum machine learning (QML), SDF, ZZFeatureMap.

INTRODUCTION

Although there is a lot of data accessible for research and analysis in the wide field of protein categorization, very little is known about how to interpret it accurately. However, recent studies indicate that one area in which ML faces major challenges is the prediction of protein activity. A thorough compilation of over 65 studies was used to determine that ML approaches are applicable to HPF prediction. Thus, the primary goal of this study is also to identify barriers and viable solutions. A study identifies that ML presents viable answers to a poorly defined field of study and useful tool for examining potential improvements to our current knowledge of proteins [1]. Literature shows that many techniques are available to predict protein functions, but very few efforts have been made to correctly predict the HPF. The researchers who predict the HPFs use some ML approaches, but their performance degraded when the dataset or input configurations increased. This research identifies a gap that necessitates the development of an ML classifier. This classifier must be capable of accurately predicting HPF or classifying the target protein with high speed and accuracy when utilizing huge datasets. It also identifies that for protein classification, the ML prediction approach based on decision trees—particularly RF—is a very transparent and reliable technique. RF makes the chain of computations involved at every level very clear because it employs a white-box technique. Because of this advantage, computational professionals can use it even if they are not very knowledgeable in the area. In a similar vein, it permits a domain expert to closely examine the protocols that a computational expert adheres to. It bridges the knowledge gap between technical proficiency and subject competence. In a Decision Tree (DT), nodes and edges stand for various functionalities at various computing levels. A DT provides the required outputs or results in an easy-t--understand manner among the potential outcomes. It provides an understandable hierarchical presentation of the problem structure and its interpretations, because of the model's unique ability to accomplish a goal while taking into account a range of input factors. The QML processes have further flourished the working of the ML classifiers by increasing their speed, which plays an important role in the prediction. The upcoming sections comprehensively discuss the protein and its classes, the working principles of the Random Forest (RF) algorithm, and the proposed methodology. These sections also present the obtained results and compare them with existing benchmarks.

INTRODUCTION TO PROTEIN

All life on Earth is made up of large, complex building pieces called proteins. They play an imperative role in the organization, functionality, and regulation of the body's tissues and organs. The microscopic building blocks of proteins, called Amino Acids (AAs), are bonded to one another and perform a number of tasks in living cells. Based on the roles that they play, proteins can be divided into numerous groups. For every protein, there are the following groups: transport proteins, structural proteins, hormones, enzymes, storage proteins, immunoglobulin or antibodies, and motor proteins. The twenty various types of tiny units, commonly known as AA's, are aspartic acid, arginine, alanine, asparagine, glutamic acid, cysteine, glycine, phenylalanine, histidine, glutamine, leucine, methionine, isoleucine, serine, lysine, proline, tyrosine, tryptophan, threonine, and valine. The primary form of the protein sequence is created by chaining together 20 different amino acids, which make up a protein [2]. When the amino group (-NH2) of one AA and the carboxylic group (-COOH) of another AA are joined, the Peptide Bond (PB) is formed (Fig. **1**).

$-NH_2$	+	$-COOH$	=	$=-CONH$
Amino group (Amino acid 1)		Carboxylic group (Amino acid 2)		Peptide bond

Fig. (1). Peptide bond detail.

To put it simply, an AA forms a PB with another AA to build the long chain of AAs. These peptide linkages are collectively referred to as polypeptides. The AA chain of each protein defines its unique 3D structure and specific function [3].

FEATURES EXTRACTION FROM PROTEIN SEQUENCE

The class of the protein can be predicted using a number of features of the protein sequence. The development of classifiers that predict human protein classes depends on these properties [5]. These crucial traits can be obtained from a particular AA protein sequence using web-based bioinformatics tools. Even though there are numerous feature extraction technologies accessible, none of them are able to extract features from a single platform; instead, different characteristics are extracted utilizing different methods. To ease the laborious process of feature extraction utilizing web-based technologies [9], "Sequence-

CHAPTER 8

Quantum AI for Natural Language Processing and Computer Vision

Pummy Dhiman[1,*], **Pratibha**[1], **Sudha**[2] and **Noor Adnan**[3]

[1] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[2] *Department of Computer Applications, Gian Jyoti institute of management and technology, Chandigarh, Punjab, India*

[3] *Department of Computer Science, College of Science for Women, University of Baghdad, Baghdad, Iraq*

Abstract: Quantum AI is the integration of quantum computing and artificial intelligence, an interaction with the expected impact to be quite positive for the two. For example, QNLP and QCV have the potential to provide radical enhancements to the present methodologies that are used to program machines to comprehend textual as well as image data by harnessing the concept of superposition, entanglement, and quantum parallelism. In this chapter, the application of Quantum AI in NLP and Computer Vision is discussed through quantum language models, quantum image representation, as well as a hybrid approach. However, the tools presented here, together with the theory, have shown the ability to possibly achieve speedup and better efficiency; however, the current NISQ hardware limits the implementation of the tools presented herein. This chapter also discusses difficulties, further study prospects, and prospects for Quantum AI in the domains of NLP and Computer Vision.

Keywords: Artificial neural networks, Computer vision, Data encoding, Deep learning, Feature extraction, Grover's algorithm, Image classification, Natural language processing (NLP), Pattern recognition, Quantum algorithms, Quantum neural networks (QNNs), Quantum-enhanced computer vision, Support vector machines (SVMs).

INTRODUCTION

Artificial Intelligence (AI) technology has garnered prominence in recent years, having found use in numerous sectors such as intelligent assistants and self-automated systems, as well as in improving the healthcare sector [1]. Today, AI is implemented in many spheres and industries, and it proves to be efficient in imp-

* **Corresponding author Pummy Dhiman:** Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India; E-mail: pummydhiman192@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

roving work, automating processes, and supporting the decision-making process. As one may note, data stands at the center of AI; it is commonly referred to as "the new oil" of the digital world. The advancements of deep learning, not only to handle large-scale datasets, but also to analyze data and find hidden patterns, have extended its application to the Natural Language Processing (NLP) [2], financial, health care, cybersecurity, and the smart automation domain. Nevertheless, the conventional machine learning algorithm is becoming less adequate in tackling large data.

Deep learning, a subfield of AI, has responded to some of these by using artificial neural networks, which are able to handle large-scale data. Despite this, even in deep learning models, there are constraints when it comes to complexity, dimensionality, and algorithms involving high computational power in combining large dimensions to make correct estimates and patterns. With time, datasets grow in size and the nature of the analyzed problems, so there is a growing demand for nontraditional paradigms. Quantum computing comes out as an innovative solution to these computation bottlenecks. Unlike classical computers that deal with 0 and 1 as basic units, quantum computers work using quantum bits or qubits [3]. The principles of superposition and entanglement, known in quantum mechanics, enable quantum computers to perform a number of calculations much faster than conventional computers can. This aspect makes it possible to solve a class of problems that is intractable with the current machines used in classical computers, for instance, optimization, cryptography [4], and simulation. Quantum computing is an interdisciplinary field that borrows its techniques from computer science, physics, and mathematics. It is a field that also deals with the development of complex equipment or hardware and the improvement of software to adequately solve computational issues. Practical applications involving quantum computing algorithms in AI include ways of speeding up model training or the performance of search algorithms, pattern recognition, and more. With the breakthrough of the connection between quantum computing and AI, a novel area has emerged as Quantum AI. This area aims to extend the machine learning and deep learning phase by utilizing the quantum possibility.

Consequently, one of the most revolutionary use cases of Quantum AI includes Natural Language Processing (NLP) and Computer Vision—two subdomains of AI. NLP helps machines to comprehend, translate, and even generate natural language for applications like sentiment analysis, speech, real-time translation, and the development of chatbots. NLP enables AI systems to understand textual data, while Computer Vision enables the interpretation of visual data such as facial recognition, medical image interpretation, self-driving cars, and object detection, among others. Quantum AI, in conjunction with NLP and Computer Vision, holds great promise. Quantum-aided NLP is beneficial for language modeling, meaning retrieval, and contextual analysis since such NLP often faces certain difficulties, for instance, when dealing with ambiguous data or separators with long-range interactions. Quantum AI in Computer Vision can help reduce time and increase the accuracy of image classification, systematize feature extraction, and optimize object recognition, making the AI vision systems noteworthy [5]. For the more recent domain of Quantum AI, the future is yet to be written as the researchers and key players in the field think about the future developments in the area. While quantum hardware is currently quite young, there are advancements in quantum algorithms and models, as well as in AI and the combination of both quantum and classical computing, which offer promising prospects. The integration of Quantum Computing with AI will result in the reimagination of the paradigms of NLP and Computer Vision with profound impacts ranging from automation, prognostics of early health diagnosis, security solutions, and developing smarter interfaces to interact with computers [5].

Contribution

This chapter delves into the fundamental concepts of Quantum AI, its role in advancing NLP and Computer Vision, and the potential challenges and opportunities in this emerging field. By understanding how quantum computing can augment AI capabilities, we can pave the way for next-generation AI systems that operate beyond the limits of classical computation.

Study Organization

The rest of this article is organized as the following picture shown below (Fig. **1**).

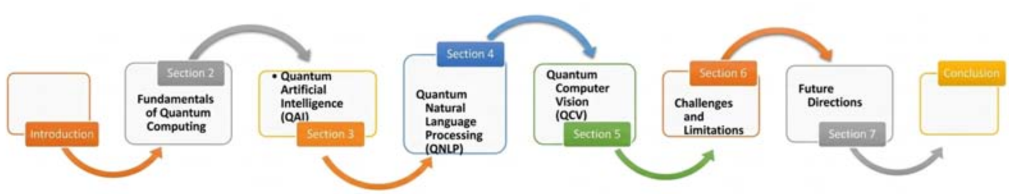

Fig. (1). The structure of the study.

Section 2 covers the fundamentals of Quantum Computing (QC). Section 3 explains the interrelation of Quantum Computing and Artificial Intelligence. Section 4 sheds light on the use of QC in NLP, whereas Section 5 covers the integration of QC and CV. Section 6 outlines the key challenges, while Section 7 shows the future trends. In the last part of the article, which is Section 8, the author presents a closing note and a conclusion.

CHAPTER 9

Edge Computing and Real-time Decision Making with Quantum AI

Aditi Dutta[1,*], **Kunjana Mittal**[2], **Akshit Patyal**[1], **Indu Bharti Jain**[2], **Pardeep Tiwana**[1] and **Sayed Abid Hussain**[3]

[1] *Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India*

[2] *Department of Law, Maharishi Markandeshwar University (deemed to be University), Mullana, Ambala, Haryana, India*

[3] *Department of Computer Science and Engineering, Bakhtar University, Kabul, Afghanistan*

Abstract: The recent intersection between Quantitative Artificial Intelligence (Quantum AI) and edge computing is providing real-time decision-making. This is achieved by combining the distributed processing power of edge computing with the optimization capabilities of quantum computation. Edge computing that allows analyzing data anywhere from the source resulting in lower latency, less utilization of bandwidth and higher security when compared to mainstream computing systems and Quantum AI that is based on quantum mechanics and is a much powerful version of Classical AI as they are much faster in their problem-solving techniques. This directly aids to discretionary fields such as autonomous systems, smart cities, predictable maintenance, fraud detection, and healthcare industry that requires pushing intelligence decision for real-time. Nonetheless, this fusion is promising; however, it has several issues, such as limitations of quantum hardware, computational noise, security issues, and compatibility issues. The current strategies involve the development of quantum-classical computers and hybrid systems, as well as quantum-safe programming and energy-efficient quantum computing for augmenting the applicability of Quantum AI in the Edge domain. Advancements in quantum computing as well as development of edge intelligence are being set to transform industries by creating high levels of efficiency, security, and automation in real-time operations.

Keywords: Cloud integration, Data processing, Decision making, Edge devices, Edge intelligence, Edge networks, Quantum algorithms, Quantum artificial intelligence (QAI), Quantum machine learning (QML), Quantum security, Real-time analytics, Internet of things (IoT), Machine learning models, Real-time data processing, Smart devices.

* **Corresponding author Aditi Dutta:** Department of Computer Science and Engineering, CGC - College of Engineering, Mohali, Punjab, India; E-mail: dutta.aditi20@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

Smart computing takes processing to new levels as data is processed close to its origin rather than relying on appendices on online servers [1]. It also enhances the psychology of quick processing and enhances security by minimizing the exposure of the compound to possibly attack by hackers during the transfer of the data. Local data processing and dispensing involves sending only useful data to centralized systems, hence using less bandwidth and costs [2]. This capacity is most helpful in sectors such as healthcare and transport, where monitoring of equipment and making split decisions is very sensitive. Likewise, in a manufacturing plant setting, the paradigm is used for maintenance of machinery in order to avoid extended downtimes and to have increased production. The use of artificial intelligence at the edge now goes one step further by enhancing the automation as well as its decision-making processes [3]. The architecture of edge computing, where data processing occurs closer to the source, minimizing latency and optimizing bandwidth usage, is depicted below (Fig. **1**).

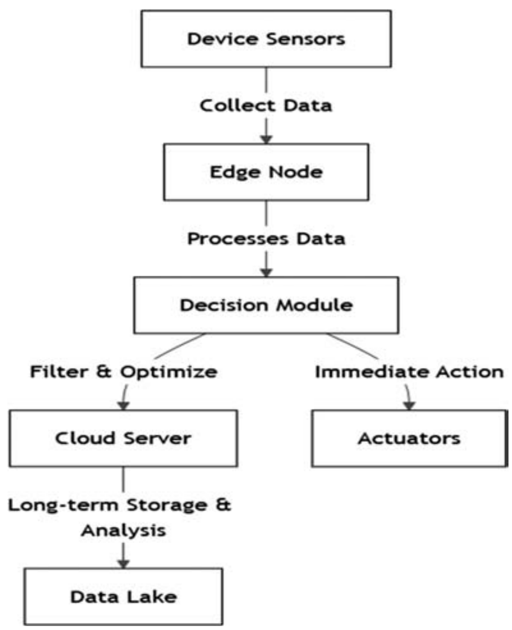

Fig. (1). Overview of edge computing.

The Role of Real-Time Decision Making

Real-time decision-making is a critical factor in modern digital ecosystems, enabling instantaneous responses based on continuously evolving data [4]. This capability is essential in industries where rapid analysis and immediate action can significantly impact efficiency, safety, and user experience. AI technologies are being widely adopted across industries to improve operational efficiency, decision-making, and customer satisfaction (Table **1**). The integration of AI enables organizations to achieve measurable benefits such as cost savings, safety improvements, and enhanced service delivery.

Table 1. Applications of AI across key industries and their primary benefits.

Industry	Application	Key Benefits
Healthcare	Patient monitoring, emergency alerts	Faster response times, improved outcomes
Autonomous Vehicles	Navigation, collision avoidance	Enhanced safety, reduced accidents
Finance	Fraud detection, automated trading	Risk mitigation, financial security
Industrial Automation	Predictive maintenance, process optimization	Reduced downtime, increased efficiency
Retail and E-Commerce	Dynamic pricing, personalized recommendations	Better customer experience, higher sales
Smart Cities	Traffic management, public safety monitoring	Reduced congestion, enhanced security
Cybersecurity	Threat detection, real-time response	Stronger data protection, fewer breaches
Supply Chain and Logistics	Route optimization, inventory management	Cost savings, faster deliveries
Telecommunications	Network traffic control, service optimization	Better connectivity, reduced latency

Quantum AI: A New Frontier

Quantum AI is an amalgam of quantum computing and artificial intelligence that has the potential to transform problem-solving techniques far beyond the capacities of conventional computing architectures [5]. In this way, quantum computers use principles related to superposition and entanglement to analyze the loss of data and carry out calculations much faster than conventional devices. This is especially significant in applications such as drug design, finance, and all problems that use machine learning and artificial intelligence in decision-making, which require large computational power. Also, the interaction of machine learning and quantum computation will lead to higher pattern recognition, cryptography, and data security, which would positively advance cybersecurity and cryptology. While this research is still ongoing, the inclusion of Q-AI integration may pave the way to future innovations in science, operations, and robotics—as well as in decision-making processes. Nonetheless, this field of AI is still in the development phase and has a dynamic hardware nature, which raises

CHAPTER 10

A Comparative Study on Unsupervised Machine Learning Techniques for Agricultural Data Analysis

Bhawandeep Kaur[1], **Gurpreet Singh**[1,*], **Satinder Kaur**[1] and **Piyush Samant**[2]

[1] *Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India*

[2] *Department of Data Science, Mirxes Labs Pte Ltd., Kuala Lumpur, Malaysia*

Abstract: Precision agriculture is a transformative field aimed at maximizing crop yield while optimizing resource efficiency and sustainability. This study compares unsupervised learning techniques—Principal Component Analysis (PCA), K-Means, DBSCAN, and Hierarchical Clustering—for clustering crop data and generating actionable insights. Using a dataset of 1,000 records with soil properties such as pH, organic matter, and nutrient concentrations, PCA was applied for dimensionality reduction to retain variance while improving clustering efficiency. Clustering performance was evaluated using the Silhouette Score, Calinski-Harabasz Index, and Davies–Bouldin Index. K-Means performed superior with spherical clusters, DBSCAN identified outliers and non-globular structures efficiently, and Hierarchical Clustering showed hierarchical relations of clusters. Using t-SNE improved the visualization and interpretability. This study assesses the potential of unsupervised learning methods in precision agriculture to help optimize resources, sustain the environment, and increase crop yields *via* soil nutrient information and hotspot cluster monitoring to further plans to optimize nitrogen applied in the environment. Emerging paradigms like quantum computing can further accelerate unsupervised learning techniques by enabling faster and more complex clustering on large-scale agricultural datasets. In the future, adaptations can include larger datasets, time-series analysis, and raw data diving with advanced clustering, self-organizing maps, and deep learning models to create scalable, data-driven decision-making tools for precision agriculture.

Keywords: Agricultural data, Clustering algorithms, Dimensionality reduction, K-means clustering, Machine learning models, Principal component analysis (PCA), Self-organizing maps (SOM), Support vector machines (SVM), SVM for clustering, Time-series analysis, Unsupervised classification, Unsupervised learning, Variable selection.

* **Corresponding author Gurpreet Singh:** Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India; E-mail: gurpreetsinghgndu@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

.

INTRODUCTION

This is because the global population is expected to rise in the future, especially in Asia and sub-Saharan Africa, where in the next 33 years it will be projected to reach 9.7 billion. That is why sustainable, efficient agriculture for people needs to be developed. In such circumstances, precision agriculture has been identified as the main way of increasing efficiency in the use of resources, increasing population productivity, and reducing the negative effects on the environment of the arrangements that are used in the system, with the use of Internet of Things (IoT), UAVs, and ML. Nitrogen is certainly one of the important issues of precision agriculture since nitrogen application remains the critical factor to increase food production while preserving the environment. Excessive nitrogen use leads to environmental problems, including soil degradation, water pollution, and increased greenhouse gas emissions. Conversely, insufficient nitrogen limits the crop's growth and yield potential. Striking the right balance relies on high-resolution data analysis and real-time decision-making frameworks, which established nitrogen application methods simply cannot achieve in an effective manner. Proposals using UAV technology are quite recent and enable high spatiotemporal, multi-source data fusion, providing excellent resolution spectral imaging and superior decision-making for large-scale agricultural monitoring [1].

Standard nitrogen management techniques depend on advanced proximal sensors or small UAVs that do not provide the coverage and biological resolution needed for effective farm-scale operation. To overcome these limitations, this research presents a nitrogen recommendation model based on a fixed-wing UAV that combines spectral indices, weather patterns, and field management data using machine learning algorithms, particularly Random Forest for estimating important crop parameters such as Plant Dry Matter (PDM) and Plant Nitrogen Accumulation (PNA). This innovative method enables in-season nitrogen topdressing adjustments based on actual crop requirements, greatly increasing efficiency and minimizing the risk of nitrogen over-application. In addition, the study contributes to the existing body of knowledge by proposing the Nitrogen Nutrition Index Optimized Algorithm (NNIOA) for accurate recommendations on nitrogen input, aiming at minimizing environmental stressors and enhancing crop health. Unlike conventional nitrogen application methods, which are fixed in nutrient availability and timing, NNIOA addresses this variability in nutrient availability to ensure that crops receive optimal nutrition as field conditions change. Along with yield optimization, this study assessed energy consumption and carbon footprint for the different nitrogen treatments, thus providing critical insights into the environmental and energy aspects of nitrogen management. The integration of UAV-based spectral imaging with unsupervised machine learning techniques for crop data clustering has been identified as a significant research gap in current precision agriculture studies [2]. Traditional clustering methods are typically not scalable and do not adapt to large agricultural datasets. To address this gap, this work uses comparative unsupervised machine learning methods and reports the results of PCA, K-Means, DBSCAN, and Hierarchical Clustering applied to find hidden trends on crop data, optimise nitrogen application, and improve large-scale farming decision-making. These clustering approaches help in detecting soil nutrient variability and in optimizing fertilizer distribution, leading to a more data-driven, sustainable agricultural framework. This work then proposes a novel, tractable, and high-resolution nitrogen management system for large-scale agricultural settings by integrating UAV and machine learning capabilities. Unsupervised learning methods enable more efficient clustering of crop data, maximizing nitrogen utilization to minimize environmental repercussions. Notably, this study not only helps to broaden applications of UAVs in precision agriculture but also adds to the evolution towards sustainable high-throughput agricultural systems [3].

Literature Review

One study focused on crop health and forestry using Unmanned Aerial Vehicles (UAVs) [4]. Separately, another was on hyperspectral imaging [5]. Two different studies highlighted UAV application prospects, such as field mapping, pest detection, yield prediction, and identified areas where AI technology can produce benefits when integrated into UAV perception systems. IoT has simplified the process of connecting and initiating automation in agriculture. The authors of a study describe recent trends and challenges in IoT for smart farming, and propose impactful and robust frameworks that can be adopted to overcome issues of data security as well as scalability. A study [6] proposes an intelligent WSN-UAV-based IoT framework for precision agriculture applications, but good data accuracy and operational efficiency are discovered using WSN-UAV-IoT modelling applications. The energy efficiency remains a major challenge in IoT-based agriculture systems. The authors [7] of a study proposed a duty cycling algorithm that can optimally distribute a minimal amount of overall energy consumption by minimizing data transmission. Another study [8] highlighted the data analytics and machine learning techniques related to IoT, so optimization of the use of these resources and minimization of costs in operation. AI and Machine Learning, along with their inception in Precision Agriculture [9, 10], have been discussed, which illustrate the concept of implementing AI in remote sensing and control strategies that could improve the resilience of agricultural production systems. According to another study, machine learning entails the use of algorithms to learn from data and make predictions regarding unseen events, even in large datasets that may present high-dimensional representations. This is another sector with potential to incorporate renewable energy into agriculture. As

CHAPTER 11

The Transformative Applications of Quantum Artificial Intelligence in Healthcare, Finance, and Cybersecurity

Pratibha[1,*], **Pummy Dhiman**[1], **Sudha**[2] and **Mustafa Ali Khan**[3]

[1] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[2] *Department of Computer Applications, Gian Jyoti institute of management and technology, Chandigarh, Punjab, India*

[3] *Compunnel Software Group Inc, Phoenix, Arizona, USA*

Abstract: Quantum Artificial Intelligence (Quantum AI) is a popular and new computational field that incorporates the use of quantum computing in enhancing Artificial Intelligence (AI). This chapter addresses the use of Quantum AI in three sectors, namely healthcare, finance, and cybersecurity, with a view that the deployment of AI integrated with Quantum computing shall take the respective industry to another level. Quantum AI enhances diagnosis and medical imaging, pattern recognition, and diagnostics, which increases the rate of accuracy or detection and diagnosis of diseases and illnesses. Moreover, Quantum AI optimizes portfolio management, risk evaluation, and prediction, and fraud detection in the financial industry, as well as enhances the computational rate in comparison to current rates. Quantum is used to enhance investment solutions and approaches to assess large amounts of big data as soon as possible, resulting in more potent risk management tools. Also, they improve the detection of fraud in financial transactions by providing a means of detecting the variation in such transactions, making security in online/mobile banking and other facets of electronic payment firmer. On the same level, they defend computer networks and systems from cyber-attacks through massive and complicated structures of analyzing large data sets in an incredibly short period. Technology has certain drawbacks, which include issues in quantum computer hardware, errors that could be present in quantum structures, and moral issues relating to the safety of data and information. A solution to these challenges could only be good if Quantum AI becomes widely implemented across the numerous domains of industry today. This Chapter gives an elaborate overview of the relevance of Quantum AI in healthcare, finance, and cybersecurity, which defines the trend of intelligent and secure computing systems.

[*] **Corresponding author Pratibha:** Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India; E-mail: pratibha@chitkara.edu.in

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

Keywords: Artificial intelligence (AI), Big data analytics, Cybersecurity, disease prediction, Quantum-enhanced AI, Quantum finance, Quantum healthcare, Quantum simulation, Quantum-supported healthcare diagnostics, Quantum-driven fraud detection, Healthcare AI, Quantum algorithms, Quantum cryptography, Quantum data.

INTRODUCTION

Quantum computing is rooted in the quantum mechanics concept and can be explained by means of Quantum Mechanical concepts like superposition, Interference, entanglement, and so on. Unlike the classical binary bits, the qubits can be in multiple values at once owing to quantum mechanical behaviour. This specific quality makes quantum computers capable of processing a large array of data and calculating with precision in record time. Quantum computers utilize quantum mechanical characteristics such as the superposition and entanglement of quantum bits or “qubits” as opposed to “bits” [1 - 4]. This makes them advantageous in that several alternatives can be tested at one time, making them effective in solving intensive computation problems. Quantum computing roots itself in quantum physics, and it has a promising future in the field of computing by providing opportunities for real-time processing of big data. Due to the emerging limitations of Moore’s law, there has been a realized need for quantum computing among researchers with the aim of extending the limits of computation. Nevertheless, besides the benefits offered by quantum computing, one must consider that this field has its peculiarities and potential risks, which have to be examined more thoroughly [5].

Strengths of Quantum Computing Over Classical Computing

Enhanced Computational Speed

Quantum computing also incorporates the principles of quantum superposition and parallelism, which makes it possible for it to work simultaneously on the different calculations required. This significantly improves problem-solving in fields that include extensive computations or algorithms, such as encryption and decryption, nanotechnology, and finance.

Efficient Optimization

Many problems encountered in the natural world, including logistics, supply chain management, and scheduling, are fundamentally optimization problems that require efficient solutions. Quantum computing, quantum annealing, and superior algorithms can find the best solutions within the shortest time and with fewer resources than a classical computing system [6].

Superior Data Processing

Quantum computing also has the capability of processing massive data structures since it is exactly suited for processing and analyzing big data. This characteristic is particularly useful in such areas as weather prediction, genome interpretation, as well as real-time analysis since they involve large quantities of data that require analysis within a short duration.

Advanced Simulation Capabilities

Quantum simulations are exceptionally good in the approximation of complex phenomena, chemical reactions, efficiency of materials, and climate change. These simulations are of much use to the scientists as classical compute cannot provide them at such a level of depth.

Robust Security and Encryption

Quantum cryptography provides safe forms of communication like Quantum Key Distribution (QKD), which protects data from cyber threats. As compared to the traditional technique of encryption, quantum encryption has certain phenomenal differences with the underlying fundamental principle based on quantum techniques, which makes it more secure than the normal-type encryption.

Potential for Scalable Computing

It has the potential to bring radical improvements in computational scalability as quantum technology progresses. This can result in revolutionizing industries and solving problems that are presently out of reach in regular system computing [7, 8].

Revolutionizing Scientific Discoveries

Quantum computing also proves beneficial in answering some of the scientific theories in the fields of physics, chemistry, and biology. From bringing new materials to designing chemical formulas and predicting some chemical phenomena, it is considered one of the key technologies that define innovation and discovery [9]. Quantum AI stands out from other types of machine learning, which include convolutional and deep, as they cannot handle computations appropriately or need a lot of computation power [10, 11].

CHAPTER 12

Shielding IoT-Driven Healthcare: A Secure and Lightweight Authentication Protocol for Patient Data Protection

Parwinder Kaur Dhillon[1], **Jyoti**[2] and **Sheetal Kalra**[2,*]

[1] *Department of Computer Science, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India*

[2] *Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India*

Abstract: The rapid assimilation of the Internet of Things (IoT), Cloud computing, and Artificial Intelligence (AI) into healthcare has revolutionized patient monitoring and remote medical assistance. The distinctive attributes of IoT networks (open and heterogeneous) pose significant security concerns due to possible threats, such as man-in-the-middle, replay, and denial-of-service attacks, compromising sensitive patient information. In the proposed framework, an authentication protocol is designed that is secure, lightweight, and efficient to establish a session key between the users and the healthcare provider, and also ensures confidentiality and prevention of illegitimate access to IoT sensor nodes. We prove, using the AVISPA tool, that the proposed protocol is secure against common security attacks. They include an improved resilience against the known attacks, computational validity to consider the execution cost of the resource-constrained medical IoT devices, and diminished communication overhead. Moreover, the protocol is designed to be scalable and cloud-compatible, paving the way for secure integration with quantum-enhanced cloud AI healthcare systems.

Keywords: Authentication protocols, Data encryption, Healthcare IoT, Lightweight cryptography, Medical data protection, Patient data security, Public key infrastructure (PKI), Secure communication, Smart devices Authentication, Two-factor authentication (2FA), User authentication, Zero trust architecture..

INTRODUCTION

The medical industry is undergoing a massive shift, with the arrival of the Internet of Things (IoT). The integration of IoT technology into healthcare systems is

[*] **Corresponding Author Sheetal Kalra:** Department of Engineering and Technology, Guru Nanak Dev University, Regional Campus Jalandhar, Jalandhar, Punjab, India; E-mail: sheetal.kalra@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

transforming patient care, treatment processes, and medical research. IoT constitutes a network of interconnected physical entities, such as buildings, vehicles, and various objects, equipped with sensors, software, and network connectivity to facilitate data gathering and dissemination.

IoT integration in the healthcare industry has made it possible to gather and analyze a variety of patient data, encourage remote patient monitoring, and improve the effectiveness of medical institutions [1]. Secure data analytics is now possible because of IoT, which also delivers effective, top-notch healthcare service to patients' doors. Without requiring patients to attend hospitals, IoT has made it possible for healthcare professionals to remotely monitor patients with long-term medical conditions. In order to record vital body parameters, track patient activity levels, and measure other health metrics, patients are required to wear wearable technology, such as smart watches and sensors, on their bodies. Over an unsecure wireless channel, this data is sent to medical professionals, who can utilize it to keep an eye on their patients as needed, provide prompt care, and avoid readmissions to the hospital. Healthcare professionals can act quickly when health metrics depart from normal ranges thanks to remote monitoring and real-time data analysis. Better chronic condition management, fewer readmissions to the hospital, and better patient outcomes result from this. Remote or underserved locations can now obtain healthcare thanks to telemedicine and remote monitoring [2]. Healthcare is more accessible since patients can consult with professionals without having to travel far. The IoT ecosystem includes wireless sensors, smart wearable technology, hospital equipment and robotics, patients and medical staff, and all of these entities have the ability to share and exchange critical data across an insecure channel.

Fig. (**1**) depicts the four-stage process of an IoT-enabled healthcare system carried out by the medical IoT companies. Each stage is further tightly integrated in terms of data capture and processing.

Fig. (1). Four stages of IoT-enabled healthcare process.

Stage 1: Implementation of Networked Devices: This includes data-collecting equipment like actuators, sensors, monitors, detection devices, and surveillance systems.

Stage 2: Data Digitization: It involves combining and transforming the analog data obtained from sensors and other devices into a digital format.

Stage 3: Cloud Migration: The data is transferred to a cloud data center after the pre-processing and standardization process.

Stage 4: Insight Extraction: Advanced analytics are applied to this processed data after management and analysis, producing actionable insights.

For healthcare applications that provide higher-quality patient care without sacrificing comfort or health, sensors are a crucial component [3, 4]. Strict privacy restrictions apply to sensitive healthcare data. Maintaining patient trust and regulatory compliance requires the safe transfer and storage of patient data. The most significant barrier to IoT-enabled healthcare is data security and privacy. Both the patient and the physician could be harmed by the vast amounts of data that are routinely exchanged and kept. Hackers can fabricate IDs in order to purchase medications and substances, which they can then abuse [5]. Critical information is shared in healthcare applications; an adversary's slightest act of malice might risk a patient's life. The primary concern that needs to be addressed is the security of the data that is communicated *via* open public networks [6].

The research has been set up as follows: Applications of AI based on Quantum cryptography have been summarised in section 2. Section 3 depicts the motivation of the research work. The associated work is explained in Section 4. Preliminaries have been explained in Section 5. The proposed robust authentication protocol has been elaborated in Section 6. The informal security exploration is covered in Section 7. Simulation Results have been shown in Section 8. The chapter ends by highlighting the findings of the proposed protocol in Section 9 and outlining its future scope.

APPLICATIONS OF AI BASED ON QUANTUM CRYPTOGRAPHY AND ELLIPTIC CURVE CRYPTOGRAPHY IN IOT-DRIVEN HEALTHCARE

As the healthcare industry grows to rely increasingly on interconnected systems of IoT devices, securing communications and ensuring patient privacy amid rapidly changing technologies is a pressing priority. Emerging fields centered at the intersection of quantum cryptography and machine learning can offer potential solutions to safeguard protected health information in this complex environment.

CHAPTER 13

Exploring the Role of Quantum AI in Enhancing the Web Accessibility Evaluation Techniques

Suman Devi[1,*], Jasjit Singh Samagh[1], Satinder Kaur[2], Gurpreet Singh[2] and **Kumari Sarita[3]**

[1] *Department of Computer Science and Engineering, Chaudhary Devi Lal University, Sirsa, Haryana, India*

[2] *Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India*

[3] *Department of Computer Science, Guru Nanak Dev University, Amritsar, Punjab, India*

Abstract: In ensuring an inclusive digital environment, web accessibility plays an important role. The existing AI-based techniques face challenges in handling the dynamism of modern web structures. This chapter presents a comparative analysis of Quantum AI and classical AI techniques used for web accessibility evaluation. A comparative analysis approach is applied to examine the key accessibility parameters using a real-world dataset, efficiency, accuracy, and computational overheads of both approaches. The findings indicate that in the structured evaluation tasks, the classical AI performed well. By leveraging the computational advantages of QAI, processing time can be reduced, and the precision can be enhanced. QAI demonstrates superior efficiency in processing complex and large-scale accessibility assessments.

The present research provides important perspectives on the evolving role of QAI in web accessibility evaluation, offering a foundation for future advancements in automated assessment techniques.

Keywords: Accessibility testing, Artificial Intelligence (AI), Automated evaluation, Decoherence, Entanglement, Fidelity, Human-Computer Interaction (HCI), Interference, Machine learning models, Quantum Machine Learning (QML), Quantum optimization, Quantum-enhanced accessibility, Quantum AI, Quantum computing, Qubit, Quantum circuit, Sensor integration, Superposition, User Experience (UX), Web accessibility standards.

[*] **Corresponding author Suman Devi:** Department of Computer Science and Engineering, Chaudhary Devi Lal University, Sirsa, Haryana, India; E-mail: sumankasnia@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

To create an inclusive digital environment, it is essential to ensure web accessibility for individuals with disabilities. They can interact with the digital content seamlessly. The existing evaluation techniques face significant challenges in assessing accessibility compliance against the Web Content Accessibility Guidelines (WCAG) framework. WCAG provides guidelines for making digital platforms more accessible. The complex issues, such as semantic ambiguities and dynamic content rendering, are not often detected by the traditional evolution automated and manual methods. The existing evaluation techniques face challenges in adaptation to assistive technologies. These limitations hinder the effectiveness of current accessibility assessment tools, necessitating more advanced solutions.

QAI offers a promising approach for solving these difficulties. The combination of quantum computing technology with AI features produces enhanced processing power alongside improved dataset recognition capabilities. QAI utilizes improved machine learning capabilities and optimization techniques that boost both performance and accuracy, as well as data scale evaluation. Through enhanced accessibility barrier detection, QAI achieves better automation of compliance checks that deliver immediate user experience enhancements.

This document investigates the part QAI plays in changing techniques that evaluate web accessibility. QAI technologies manage to bypass standard procedure restrictions. The enhanced detection accuracy leads to better digital content accessibility through this approach. The evaluation of QAI aims to serve three principal functions beyond its initial purposes. Development of advanced methodologies for accessibility assessment leads to enhanced digital inclusivity and equity [1].

The Current State of Web Accessibility Evaluation

The evaluation is carried out to understand whether the digital content can be used by individuals with disabilities in accordance with the established WCAG guidelines. Current evaluation approaches rely on automated tools that can identify issues such as low color contrast, missing alt text, and improper heading structures. However, despite their potential, these tools have several limitations:

- **Lack of Semantic Understanding:** Traditional tools struggle to interpret the context and meaning of web content, leading to missed issues that require human judgment [2].

- **Dynamic Content Accessibility:** Traditional static evaluation methods face difficulty in addressing accessibility issues. But on the other hand, modern web applications often feature dynamic content that is generated in real-time [3].
- **Real-Time Feedback and Adaptation:** Existing tools often fail to provide real-time feedback and adaptations, limiting the tools' ability to enhance real-time user experience [4].

The Potential of Quantum AI in Web Accessibility

Quantum AI creates solutions through combining quantum computing capabilities with AI strategies to handle problems more efficiently compared to traditional computers. Quantum AI provides several solutions through its synergistic power to overcome existing issues in web accessibility evaluation.

- **Enhanced Semantic Analysis:** Quantum AI utilizes advanced Natural Language Processing (NLP) together with machine learning algorithms to perform semantic content evaluation that detects complex accessibility problems.
- **Real-Time Processing:** Quantum Computing simultaneously processes data so it executes real-time web content evaluation, which enables immediately accessible content resolution after discovery of emerging problems [5].
- **Improved Accuracy:** Quantum AI can analyze large datasets and complex patterns more efficiently, leading to more accurate detection of accessibility violations and reducing false positives and negatives [6].

Key Applications of Quantum AI in Web Accessibility

Automated Accessibility Testing

QAI plays an important role in improving the accuracy and comprehensiveness of automated accessibility testing. For example, quantum-powered machine learning models can analyze web content to detect improper heading structure, inadequate alt text, color contrast, etc. Such kinds of violations can be detected in an adequate way. Evaluation of the entire website rather than just evaluating a single page (case with traditional tools): QAI can process a large volume of data quickly and more efficiently.

Real-Time Accessibility Enhancement

Real-time accessibility enhancement is one of the most promising applications of QAI. By integrating QAI into a content management system or into web browsers, a developer can detect and rectify accessibility issues dynamically. For example, QAI has the potential to adjust color contrast, generate alt text for

CHAPTER 14

A Quantum Intelligence AI-Driven Secure Framework for IoV: QI-CAI Clustering Architecture with FDS-QI Deep Learning Security Model

Sumit Kumar[1,*], **Ishpreet Singh Virk**[2], **Anupam Bonkra**[1], **Ritu**[3], **Sunil Kumar Chawla**[4] and **Omar Mbrouk**[5]

[1] *Department of Computer Science and Engineering, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India*

[2] *Department of Computer Science & Engineering, Chandigarh Engineering College (CEC) Landran, Mohali, Punjab, India*

[3] *Department of Computer Science & Engineering, Chandigarh College of Engineering- CGC Jhanjeri, Mohali, Punjab, India*

[4] *Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India*

[5] *Department of Nano-Chemistry and its Environmental Applications, Environmental Studies and Research Institute, University of Sadat City, Sadat City, Menofia, Egypt*

Abstract: This chapter proposes a novel Quantum Intelligence (QI)-based optimized, secure, and intelligent architectures for the IoT-based VANETs, known as Internet of Vehicles (IoV). Such technologies range from general Quantum Intelligence, AI, ML, and DL, through to the specific architectures upon which these solutions may be based, including ANN and the Levenberg Neural Engine as examples. The first proposed architecture, known as Quantum Intelligence-Driven Cluster-Based Adaptive Intelligence (QI-CAI), represents a core contribution in enhancing IoV communication by enabling dynamic and efficient clustering through the integration of Internet of Things (IoT) enabled intelligent services within the combined framework. In continuity, the second proposed architecture, Fine-Tuned Deep Learning Security with Quantum Intelligence (FDS-QI) Model, for improve security and avoid cyber-attacks. Together, these two architectures form a unified framework that addresses both communication efficiency and security in next-generation IoV systems.

[*] **Corresponding author: Sumit Kumar:** Department of Computer Science and Engineering, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India; E-mail: kumarsumit.cse@gmail.com

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

Keywords: AI-driven security, Clustering architecture, Deep learning models, Internet of vehicles (IoV), Quantum computing, Quantum-enhanced security, Quantum intelligence (QI), Quantum optimization, Real-time security, Secure communication, Security frameworks, Vehicle networks, Vehicle security systems.

INTRODUCTION

The urban transport systems are years ahead in connectivity and intelligence. In this chapter, a secure integrated architecture is proposed by incorporating Quantum Intelligence (QI) supported AI, ML, and DL to improve the traffic efficiency and security in the area of the Internet of Vehicles (IoV). The framework supports the use of IoT sensors to facilitate interoperable data sharing, and QI-enhanced ML methods automate decision-making and communication processes. The solution itself consists of two core architectures. A novel large-scale quantum-enhanced multiple vehicle-routing model called Quantum Intelligence-Driven adaptive clustered-based intelligent (QI-CAI) model to alleviate traffic congestion through a quantum intelligence dynamic programming approach was proposed as the first, and in the second, a large-scale quantum-enhanced multi-vehicle routing algorithm with different features but optimized around better using quantum processing, avoiding congestion source avoidance scheme to prevent such congestion. The limitation of human intelligence procedures by machines particularly includes self-correction mechanisms, reasoning by applying rules to form conclusions, and learning, where machines acquire data and rules for their use. This chapter explores the integration of Artificial Intelligence (AI) and Quantum Intelligence (QI) as a transformative paradigm for enhancing cybersecurity [1]. Specific applications of AI include the development of expert systems that exhibit specialized knowledge, speech recognition enabling machines to understand and interpret human speech, and machine vision allowing systems to interpret visual information similarly to human perception [2]. The objective of Artificial intelligence is to develop intelligent machines that can execute tasks typically requiring human intelligence [3].

- **Quantum Intelligence (QI):** Quantum intelligence uses quantum computing to improve data processing and problem-solving, enabling faster and more efficient analysis of complex tasks [4].
- **Artificial Intelligence (AI):** The Capability to acquire and apply knowledge or simulation of intelligent behaviour. Learn how to solve problems and make intelligent decisions.
- **Machine Learning (ML):** A subclass of AI that uses computer algorithms. It can learn from examples on its own without being explicitly programmed and can be trained with a large set of data.

- **Deep Learning (DL):** A subclass of ML that uses basic layered Artificial Neural Networks (ANN) to simulate human decision-making.
- **Artificial Neural Network (ANN):** The inspiration for Artificial Neural Networks (ANNs) is derived from Biological Neural Networks (BNNs), which are designed to address intricate processes observed in biological systems by employing chemically connected neurons.

Types of Machine Learning (ML)

AI training is required when the learning system has to adapt to and develop precise responses to inputs, particularly when the input's information is restricted or uncertain. The training phase entails exposing the AI system to a variety of instances and settings, allowing it to learn and increase its capacity to handle a wide range of inputs. This adaptive learning is especially useful when dealing with uncertainties or gaps in knowledge, allowing the AI system to make educated judgments and respond accurately even in complicated or new circumstances. Fig. (**1**) depicts the categorization of Machine Learning (ML) methodologies.

Fig. (1). Classification of machine learning (ML) [5].

Supervised or Task-driven Learning

It makes predictions about the next value based on tagged data. The essential assumption in this model is that the system consistently generates the intended response when the input is applied. The system works by predicting outcomes for known cases and then comparing its predictions to the recognized results. This

CHAPTER 15

Wireless Sensor Networks in the Age of AI and Quantum Computing

Kirandeep Kaur[1,*], **Satinder Kaur**[1], **Satveer Kour**[1] and **Gurpreet Singh**[1]

[1] *Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India*

Abstract: Wireless Sensor Networks (WSNs) are essential components of modern information systems because they promote efficient gathering and sharing of information across a variety of domains, such as smart cities, healthcare, and environmental monitoring [1]. Yet, the sensor node's resource limitations, such as energy and storage, largely inhibit real-time accuracy, safety, and scalability. To resolve these challenges, this study examines how existing mechanisms of computing, namely, Artificial Intelligence (AI) and Quantum Computing (QC), may be integrated in wireless networks. The present chapter tries to present a detailed analysis of how QC and AI technologies can enhance WSN performance, security, and efficiency. Predictive maintenance and energy-efficient data transmission have all been investigated through Artificial Intelligence (AI) methods such as Machine Learning (ML) and Deep Learning (DL). Through the help of post-quantum cryptography and quantum algorithms in order to achieve resource optimisation and routing, the work also considers how QC can be employed for security issues. The key findings indicate that although AI provides intelligent, low-latency processing, QC gives strong cryptographic frameworks and optimisation facilities. Notwithstanding these improvements, there are still issues of implementation complexity, scalability, and hardware constraints. Besides outlining future areas of research, including Intelligence-based optimisation models, scalable quantum-secure communication protocols, and the design of intelligent, autonomous sensor networks, the current research highlights the revolutionary possibility of combining AI and QC in WSNs. This review focuses on the revolutionary potential of integrating AI and QC in WSNs and proposes future research areas, such as AI-based optimisation models, scalable quantum-secure communication protocols.

Keywords: AI-enhanced sensor networks, Big data analytics, Data privacy, Edge computing, Energy efficiency, Internet of things (IoT), Quantum algorithms, Quantum computing, Quantum machine learning (QML), Real-time data Processing, Sensor nodes, Sensor networks, Smart cities, Wireless communication, Wireless sensor network security.

* **Corresponding author Kirandeep Kaur:** Department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab, India; E-mail: kirandeepcet.rsh@gndu.ac.in

Satveer Kour, Harvinder Singh, Anupam Bonkra & Rupinder Singh (Eds.)

INTRODUCTION

WSNs are widely employed in smart cities, healthcare, industrial automation, farming, military use, and environmental monitoring. Energy challenges, computing power limitations, network security flaws, and inefficient data processing are some of the difficulties that conventional WSNs must overcome [2 - 5]. Emergence of QC and AI offers radical AI-driven methods, including machine learning, deep learning, and reinforcement learning show potential in increasing network security, facilitating autonomous decision-making, building data accuracy, and optimizing resource management [6]. In the meantime, QC offers to solve important problems, including data security, node localisation, and energy-efficient routing by providing exponential computational speedups, innovative encryption techniques, and improved optimisation capabilities [7, 8]. Considering the impact, benefits, and challenges of WSNs becomes crucial when they proceed to develop in the era of AI and QC. This comprehensive review investigates the integration of WSNs, AI, and QCM, focusing more on the developments, the present study's (tm)s gaps, and future advances [9, 10]. WSNs have evolved tremendously over the past years, moreover to continuous advances in data handling, energy efficiency, network protocols, and security factors [1, 3, 5]. Nevertheless, various challenges increase the scalability and real-time processing abilities of conventional WSNs. Merging Artificial Intelligence (AI) and QC could make WSNs more effective and adaptive, providing innovative approaches to these challenges [11]. The background study not only determines existing limitations in traditional WSN architectures but also presents a historical overview of WSN advances and considers how AI and quantum computing would assist in order to overcome significant constraints.

Background Study

WSNs have experienced a huge range of growth over the recent past because of constant advances in information processing, energy utility, protocol designs, and safety measures [1, 3, 5]. Nonetheless, the scalability and real-time operating attributes presented by conventional wireless communications have been affected due to multiple constraints. Incorporating AI with QC provides innovative approaches to these limitations, generating WSNs even more efficient, secured, and reliable [11]. The background research highlights an overview of the historical events of WSNs, recognizes existing constraints of traditional WSN architectures, and outlines how AI and QC could assist in resolving the major limitations.

First-Generation WSNs

Wireless network communications and information gathering have been the primary motivations of prior networks. These networks had very limited opportunities in terms of data retention, processing capacity, and energy efficiency, and depended upon fundamental communication protocols. Sensor nodes were mostly located in a static configuration with constraint ability to adapt towards environmental changes [2, 4, 5]. The industrial automation, environmental monitoring, and military intelligence surveillance also contributed to the majority of applications, where complete information was compiled and transmitted further to a central base station for processing [6, 7]. In addition to having complications alongside network congestion, energy limitations, and inadequate data processing, these WSNs proved to be scalable [8, 9].

Second-generation WSNs

In the second generation, WSNs had imposed sensor nodes, spontaneous mechanisms, and energy-efficient routing protocols as a consequence of the huge growth in wireless communication and integrated structures. These enhancements boosted the fault tolerance capacity, flexibility, and increased the lifespan of the network. Since topology and environmental conditions have certain modifications, nodes were also able to interact dynamically [8, 11]. Furthermore, applying data gathering, clustering, and hierarchical routing strategies enhanced scaling and reduced energy consumption. WSN applications have been strengthened by this generation to encompass smart transport systems, precision agriculture, industrial automation, and healthcare systems [9, 10].

Third-Generation WSNs

The most recent advancement in WSNs employs artificial intelligence (AI), cloud-based services, and edge computing for enabling efficient data processing, automated modelling, and real-time decision-making. In order to recognize patterns, observe discontinuity, and provide automated response messages, such neural networks are associated with machine learning algorithms [12, 13]. As cloud integration offers extensible storage and processing capacity for complicated analytics, edge computing reduces latency while processing data distantly at sensor nodes. Since applications that are available for autonomous systems, smart cities, precision healthcare, and industrial IoT, third-generation WSNs provide boosted dependability, confidentiality, and efficiency. In order to regularly optimise data privacy and integrity in the current times, WSN deployments, distributed neural networks, and the blockchain have also been under consideration.

Fig. (**1**) presents a timeline that shows key turning points in the early 20th century to 2025 in the development of Wireless Sensor Networks (WSNs), Artificial Intelligence (AI), and quantum computing. It focuses on significant advances, originating with the emergence of the "ouniversal machine" in the 1930s and Max

SUBJECT INDEX

A

B

C

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Satveer Kour

Dr. Satveer Kour has received her Bachelor of Technology degree in Information Technology from Technological Institute of Textile & Science, Bhiwani, Haryana, India in 2006. She completed her Master of Technology degree in Computer Science and Engineering from Chaudhary Devi Lal University, Sirsa, Haryana, India in 2009. She completed her PHD from SLIET, Longowal (India) in 2022. She is currently working as an Assistant Professor in CET Department of Guru Nanak Dev University, Amritsar. Her research interests include Wireless Networks, Mobile Ad-Hoc Networks, Vehicular Ad-Hoc Networks, Flying Ad-Hoc Networks, Wireless Sensor Networks, Mobility Models, and Quantum Computing. She is also a life member of IAENG. She is holding 12+ years of work experience at national level. She holds 4 Indian Patents.

Harvinder Singh

Dr. Harvinder Singh is an accomplished academician and researcher with over 13 years of experience in technical education and research. He currently serves as an Associate Professor at Chandigarh Engineering College, Landran (Mohali), Punjab. Dr. Singh holds a Ph.D. in Mechanical Engineering from Chandigarh University, Mohali, and specializes in Additive Manufacturing, Production Engineering, and surface modification techniques such as thermal spray coatings. He has published over 48 research papers in SCI and Scopus-indexed journals and authored several technical books. His contributions to innovation are reflected in 17 patent filings across diverse engineering applications. A committed mentor, he supervises M.Tech., B.Tech. Projects, and actively engages in national and international conferences, workshops, and accreditation processes. Dr. Singh is a member of various professional bodies, including ASME, SAE, and IAENG.

Anupam Bonkra

Dr. Anupam Bonkra is a faculty member at Maharishi Markandeshwar (Deemed to be) University, Mullana, and an assistant professor with an experience of more than a decade in teaching profession. She is currently a Ph.D. scholar in the same field of Computer Science in Amity University Jaipur. Therefore, she possesses an M.Tech and B.Tech in computer science, alongside a relevant diploma. Dr. Bonkra has written 26 research papers out of which some of the important titles include machine learning, deep learning, AI and its use in agriculture and health. She is a writer with 8 patents to his name, an author of a book with copyright. Using proficient Python, MATLAB skills, she also serves as a proctor to the faculty development programs, conference, and other matters of academics.

Rupinder Singh

Dr. Rupinder Singh is a vigorous and result oriented academician researcher having more than sixteen years of teaching and administration experience in computer science. He is at present working as an Assistant Professor at Chitkara University, Punjab; Ph.D., in Computer Applications. He is the author of more than 10 books in the domains of Programming, Web Technologies, Computer Networks and Artificial Intelligence. Specifically, he has authored over 40+ papers and has published in reputed SCI/Scopus and UGC journal listing domains such as Wireless Networks, Network Security, and Machine Learning. Dr. Singh possesses roughly 10 granted and filed patents and has IIT Bombay, Elsever, and Palo Alto Networks certifications.