ISSN 2816-573X

ORIGINAL ARTICLE

Unveiling Advanced Computational Applications in Quantum Computing: A Comprehensive Review

J H Markna[1], T P Palatia[2], Smeetraj Gohel[3], Bharat R Kataria[1*]

Markna JH, Palatia TP, Gohel S, et.al. Unveiling Advanced Computational Applications in Quantum Computing: A Comprehensive Review. Int J Adv Nano Comput Anal. 2023;2(2):81-92.

Abstract

The field of advanced computing applications could experience a significant impact from quantum computing, which is a rapidly developing field with the potential to revolutionize numerous areas of science and technology. In this review, we explore into the various ways in which complex computational problems could be tackled by utilizing quantum computers, including machine learning, optimization, and simulation. One potential application of quantum computers is in machine learning, where they could be used to improve the accuracy and efficiency of algorithms. Complex optimization problems, such as those encountered in logistics and finance, can be addressed using quantum computers as well. Furthermore, the utilization of quantum computers could enable the simulation of intricate systems, such as molecules and materials, leading to significant applications in fields like Physics and Material Technology. Although quantum computers are currently in the early stages of development, they possess the potential to propel numerous areas of science and technology forward in a significant manner. Further research and development are needed to fully realize the potential of quantum computing in the field of advanced computing applications.

Key Words: *Quantum computing; Quantum approximate; Optimization algorithm; Quantum key distribution*

Introduction

The history of quantum computing dates to the early 1980s, when physicist Paul Benioff proposed the idea of using quantum-mechanical phenomena, such as superposition and entanglement, to perform computation. In 1985, David Deutsch, a physicist at the University of Oxford, published a seminal paper introducing the concept of a quantum Turing machine, which is a theoretical model of a quantum computer. One of the key milestones in the early development of quantum computing was the discovery of Shor's algorithm in 1994, which is a quantum algorithm for efficiently factoring large integers. Shor's algorithm represents a quantum-based method devised to identify the prime factors of a given integer.

[1]Department of Nanoscience and Advanced Materials, Saurashtra University, Rajkot, India

[2]Department of Computer Engineering, VVP Engineering College, Rajkot, India

[3]Lambton College, Sarnia, ON N7S 6K4, Canada

[*]Corresponding author: Bharat R Kataria, Department of Nanoscience and Advanced Materials, Saurashtra University, Rajkot, India, Tel: +91-9428015023; E-mail: brkataria22@rediffmail.com

Received: December 11, 2023, Accepted: December 26, 2023, Published: December 29, 2023

This algorithm demonstrated the potential for quantum computers to solve certain problems much faster than classical computers [1-3].

In the late 1990s and early 2000s, several researchers, including Isaac Chuang, Michael Nielsen, and John Preskill, made significant contributions to the field by developing experimental techniques for implementing quantum algorithms on small-scale quantum devices. Since then, there have been many significant developments in the field of quantum computing, including the construction of larger and more complex quantum systems, the development of new algorithms and applications, and the creation of specialized quantum hardware and software. Today, quantum computing is an active area of research and development, with the potential to revolutionize fields such as cryptography, drug discovery, and materials science.

Quantum computing is a type of computing that harnesses the principles of quantum mechanics to perform calculations that are beyond the capabilities of classical computers. Quantum computers use quantum bits, or qubits, which can represent both a 0 and a 1 simultaneously, unlike classical bits which can only represent a 0 or a 1. This allows quantum computers to perform certain types of calculations much faster than classical computers [1-4]. The number of qubits available in quantum computers is also related to the complexity of the tasks that quantum computers can perform. As the number of qubits increases, the complexity of the tasks that quantum computers can perform also increases, which leads to an increase in the market size of the quantum computer business. This is because more complex tasks require more powerful quantum computers, which leads to an increase in demand for quantum computers. As the demand for quantum computers increases so does the market size of the quantum which was represented in Figure 1 [1-4].

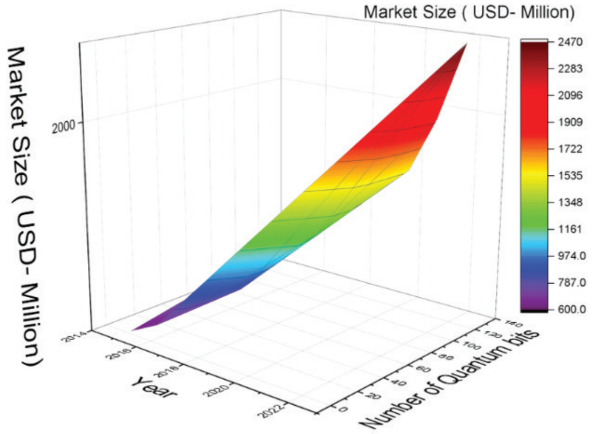

Figure 1) *Scenario of market size and Number of Qubits associated with Quantum Computer.*

Advance Applications of Quantum Computing

Quantum computing has the potential to solve certain problems that are currently intractable for classical computers, such as factoring large numbers, optimizing complex systems, and simulating quantum systems. It has the potential to revolutionize industries such as pharmaceuticals, finance, and cybersecurity, and could lead to the development of new materials, drugs, and technologies. Quantum computing has the potential to solve certain problems that are currently intractable for classical computers, such as factoring large numbers, optimizing complex systems, and simulating quantum systems. It has the potential to revolutionize a wide range of industries, including cyber security, Pharmaceuticals, Artificial interagency, Machine Learning, Material technology, Supply chain, Finance, etc. In this review paper few, out of large number of industrial applications of quantum computing are shown to shows future of quantum computing [5-10].

Cybersecurity

Quantum computers have the potential to significantly advance many fields, including cybersecurity. One of the main ways they could do this is by being able to solve certain mathematical problems much faster than classical computers. For example, certain encryption methods that are currently considered secure could be easily broken by a large-scale quantum computer. On the other hand, quantum computers could also be used to develop new and more secure encryption methods.

In addition to their potential impact on encryption, quantum computers could also have other implications for cybersecurity. For example, they could be used to simulate and test the security of complex systems, or to analyse and improve the security of machine learning models [11-15]. Overall, while quantum computers could have significant implications for cybersecurity, it is important to note that they are still in the early stages of development and it will likely be some time before they have a widespread impact on the field. One example of how quantum computers could potentially be used for cybersecurity is in the development of new, more secure encryption methods. One potential approach is to use quantum key distribution (QKD) to establish a shared secret key between two parties that can then be used to encrypt and decrypt messages [16]. In QKD, a sender (Alice) generates a random series of quantum states and sends them to a receiver (Bob). Bob then performs measurements on the states and sends the results back to Alice. By comparing their results, Alice and Bob can establish a shared secret key that can be used for encryption and decryption.

The security of QKD is based on the fundamental principles of quantum mechanics, which makes it resistant to certain types of attacks that are possible on classical systems. For example, an attacker (Eve) trying to intercept the quantum states sent by Alice would inevitably disturb them in some way, which Alice and Bob can detect through their measurements. This means that QKD could potentially provide a way to establish secure communication that is immune to certain types of cyber-attacks. However, it is important to note that QKD is still a relatively new field and there are many challenges that need to be overcome before it can be widely used in practice. For example, the distance over which QKD can be performed is currently limited, and there are also issues related to the cost and complexity of implementing QKD systems [16,17]. In addition to QKD, there are also other potential uses of quantum computers for cybersecurity. For example, quantum computers could potentially be used to simulate and test the security of complex systems, or to analyse and improve the security of machine learning models. However, these applications are still largely in the research and development stage, and it is not yet clear how they will be applied in practice.

Pharmaceuticals

Quantum computers could be used to design new drugs by simulating the behaviour of molecules and predicting their interactions with proteins. In the field of pharmaceuticals, quantum computers have the potential to revolutionize the process of drug discovery and development. One of the key challenges in drug discovery is understanding how molecules will interact with proteins in the body. This is a complex process that involves simulating the behaviour of molecules at the atomic and molecular level, which is currently beyond the capabilities of classical computers.

Quantum computers, have the potential to perform these simulations much more quickly and accurately. By using quantum algorithms, quantum computers can simulate the behaviour of molecules and predict their interactions with proteins with a high degree of accuracy as shown in Figure 2. This could allow researchers to design and test new drugs much more efficiently, potentially leading to the development of new treatments for a wide range of diseases. It is important to note that quantum computers are still in the early stages of development, and it will likely be some time before they are widely used in drug discovery. However, many researchers and companies are actively working on developing quantum computers and their applications in the pharmaceutical industry, and it is expected that quantum computers will play a significant role in drug discovery and development in the future.

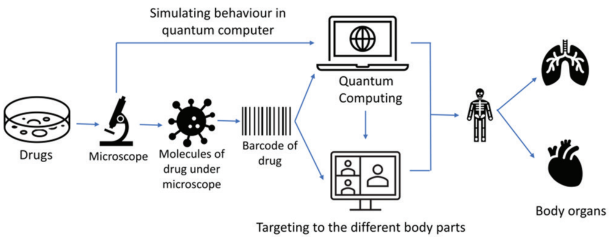

Figure 2) *Complex process for the targeting drug delivery in pharmaceutical sector.*

One example of a quantum algorithm that could be used to simulate the behaviour of molecules and predict their interactions with proteins is the quantum approximate optimization algorithm (QAOA). The QAOA is a heuristic quantum algorithm that can be used to find approximate solutions to optimization problems [17-19]. In the context of drug discovery, the QAOA could be used to find the lowest energy configuration of a molecule, which would correspond to its most stable state. This could be used to predict how a molecule will interact with a protein and whether it is likely to be an effective drug candidate. Innovative application of Quantum computing in the field of Drug Discovery shown in Table 1.

TABLE 1
Innovative Application of Quantum Computing in the Field of Drug Discovery

Quantum-Assisted Drug Discovery	Ref 20
Quantum-assisted drug discovery using the quantum approximate optimization algorithm	Ref 21
A quantum approximate optimization algorithm for protein-ligand binding	Ref 22
Quantum-assisted drug discovery using quantum machine learning	Ref 23
Quantum Machine Learning for Drug Discovery	Ref 24
Quantum computing for drug discovery	Ref 25
Quantum-Assisted Drug Discovery: A Quantum Computing Approach for Virtual High-Throughput Screening	Ref 26

There are many other quantum algorithms that could be used for this purpose, including quantum Monte Carlo algorithms, quantum-annealing algorithms, and quantum machine learning algorithms. These algorithms are still being developed and refined, but they have the potential to significantly improve the efficiency and accuracy of drug discovery and development.

Finance

Quantum computers could be used to perform risk analysis and optimize portfolios. In the field of finance, quantum computers have the potential to revolutionize risk analysis and portfolio optimization. These are complex tasks that involve analysing large amounts of data and making predictions about the performance of financial assets. Classical computers can perform these tasks, but they can be time-consuming and may not be able to fully capture the complexity of financial markets. Quantum computers, on the other hand, have the potential to perform risk analysis and portfolio optimization much more quickly and accurately. By using quantum algorithms, quantum computers can analyse large amounts of data and make more accurate predictions about the performance of financial assets. This could allow financial institutions to make more informed investment decisions and optimize their portfolios for maximum returns [27,28].

One example of a quantum algorithm that could be used for risk analysis and portfolio optimization is the quantum linear systems algorithm (QLSA) [29,30]. The QLSA is a quantum algorithm that can be used to solve systems of linear equations, which is a common task in risk analysis and portfolio optimization. By using the QLSA, quantum computers can quickly and accurately solve systems of linear equations, allowing financial institutions to make more informed investment decisions. There are many other quantum algorithms that could be used for risk analysis and portfolio optimization, including quantum Monte Carlo algorithms, quantum annealing algorithms, and quantum machine learning algorithms. Flow step for the QLSA algorithm in the general steps of the QLSA algorithm as follows:

- Encoding the coefficients: The coefficients of the linear system of equations are encoded into quantum states, which can be represented as unitary matrices.
- Preparation of the initial state: The initial state of the quantum system is prepared by applying quantum gates to the encoded coefficients.
- Iterative refinement: The quantum system undergoes a series of iterations, where quantum gates are applied to refine the solution. These iterations are designed to find the eigenvalues and eigenvectors of the matrix that represents the linear system of equations.
- Measurement: The final state of the quantum system is measured, and the results are used to estimate the solution of the linear system.
- Repetition: The measurement process is repeated multiple times to improve the accuracy of the solution.

These algorithms are still being developed and refined, but they have the potential to significantly improve the efficiency and accuracy of risk analysis and portfolio optimization in the financial industry.

Supply chain management

Quantum computers have the potential to significantly improve supply chain management by allowing for the optimization of complex logistics systems. Quantum computers can solve optimization problems much faster than classical computers, which makes them well-suited for tasks such as route optimization, inventory management, and demand forecasting. For example, quantum computers could be used to optimize the routing of goods in a supply chain, taking into account factors such as transportation costs, lead times, and capacity constraints. They could also be used to optimize inventory levels, helping companies to reduce excess inventory and improve their responsiveness to changing demand. In addition, quantum computers could be used to improve demand forecasting, helping companies to better predict customer demand and adjust their production and distribution accordingly.

One example is the Quantum-Assisted Supply Chain Optimization (QASCO) project, which is funded by the European Union. The project aims to develop a quantum-enhanced optimization platform for supply chain management that can be used to improve the efficiency and resilience of logistics systems. The platform will be based on a hybrid quantum-classical approach, which combines the strengths of both quantum and classical computers [31-33]. Another example is the startup Quantum Base, which is developing quantum algorithms for supply chain optimization. The company is working on a number of applications, including route optimization and demand forecasting, and is collaborating with industry partners to test and validate its algorithms. While these are just a couple of examples, they illustrate the potential for quantum computers to have a significant impact on supply chain management in the future. As quantum computers become more mature and widely available, it is likely that we will see more and more real-world examples of their use in this field. Quantum computers could have a significant impact on supply chain management by enabling more efficient and effective decision-making in complex logistics systems.

Energy

Quantum computers could be used to optimize the design of catalysts and batteries, leading to more efficient energy usage. Quantum computers have the potential to significantly advance many fields, including energy. One way they could do this is by enabling more efficient and accurate simulation and modelling of complex systems, such as materials and chemical reactions. This could be used to design more efficient energy systems and materials, as well as to optimize processes such as oil and gas exploration and production. In addition, quantum computers could potentially be used to optimize the operation of energy systems, such as power grids. For example, they could be used to optimize the scheduling of power generation and transmission in order to minimize costs and maximize the use of renewable energy sources. Quantum computers could also have other implications for the energy sector. For example, they could be used to improve the security of critical infrastructure, such as power grids and oil and gas pipelines, which are often targeted by cyber-attacks.

There are currently no widely publicized examples of the use of quantum computers to design batteries. However, there are several research projects and start-ups that are exploring the potential use of quantum computers for materials design and optimization, which could potentially include the design of batteries [33,34].

One example is the start-up QuantumScape, which is using quantum computers to design and optimize solid-state lithium-ion batteries. The company claims that its quantum-inspired algorithms can significantly improve the performance and durability of these batteries, and it is currently working on prototypes for use in electric vehicles. Another example is the Quantum-Enabled Materials Design (QEMD) project, which is funded by the European Union [34-36]. The project aims to develop a quantum-inspired platform for materials design that can be used to optimize the properties of a wide range of materials, including those used in batteries. Here, Figure 3 represents the schematic idea of quantum-inspired algorithms for the energy sector. While these are just a couple of examples, they illustrate the potential for quantum computers to have a significant impact on the design of batteries and other energy-related materials in the future. As quantum computers become more mature and widely available, it is likely that we will see more and more real-world examples of their use in this field. Generally, quantum computers have the potential to have a significant impact on the energy sector, they are still in the early stages of development, and it will likely be some time before their full potential is realized in this field.

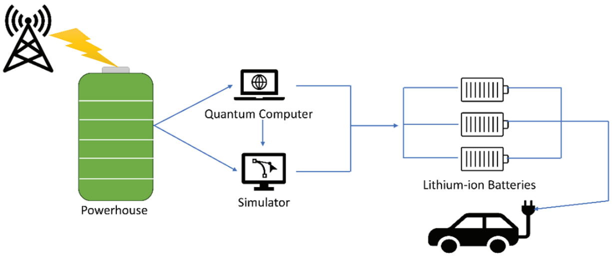

Figure 3) *Schematic idea of algorithm for energy.*

Machine learning

Quantum computers could be used to improve the accuracy and speed of machine learning algorithms. Quantum computers have the potential to significantly advance the field of machine learning by allowing for the more efficient and accurate solution of certain types of problems. One area where quantum computers could have a particularly significant impact is in the training of large machine learning models. Training such models requires a large amount of data and computational resources, and quantum computers could potentially be used to speed up this process. In addition, quantum computers could potentially be used to improve the accuracy of certain types of machine-learning algorithms, such as those used for image or speech recognition. They could also be used to develop new types of machine learning algorithms that are not possible on classical computers.

One example of a research project in this area is the Quantum-Assisted Neural Network (QANN) project, which is funded by the European Union [37]. The project aims to develop a quantum-inspired neural network architecture that can be used to improve the performance of machine learning algorithms as shown in Figure 4. The project is exploring the use of quantum-inspired algorithms to improve the training and inference of neural networks and is working on prototypes that can be tested on near-term quantum computers. Table 2 represent the new initiative of quantum computer in the field of machine learning.

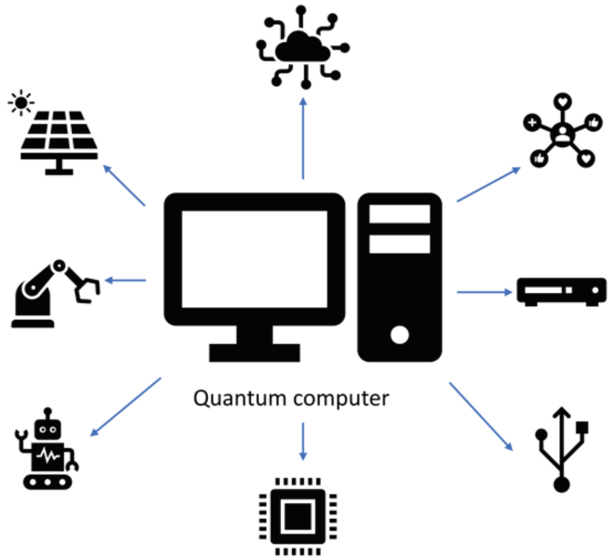

Figure 4) *Schematic idea for machine learning by using quantum computer.*

TABLE 2
New initiative of Quantum Computer in the field of Machine Learning

Quantum-Assisted Neural Networks	Ref 38
Quantum-Assisted Neural Network Training:	Ref 39
A quantum algorithm for neural network training	Ref 40
Quantum-assisted neural networks with the quantum approximate optimization algorithm	Ref 41
Quantum Machine Learning for Neural Networks	Ref 42
Quantum-Assisted Deep Learning	Ref 43
Quantum-assisted deep neural networks	Ref 44
Quantum-Assisted Neural Networks for Image Recognition	Ref 45
Quantum-Assisted Neural Networks for Speech Recognition	Ref 46
Quantum-Assisted Neural Networks for Natural Language Processing	Ref 47

Another example is the startup Zapata Computing, which is developing algorithms and software tools for machine learning on quantum computers [48]. The company is working on a range of applications, including natural language processing and image recognition, and is collaborating with industry partners to test and validate its algorithms. While these are just a couple of examples, they illustrate the potential for quantum computers to have a significant impact on the field of machine learning in the future. Overall, while quantum computers have the potential to significantly advance the field of machine learning, they are still in the early stages of development, and it will likely be some time before their full potential is realized in this field.

Climate modelling

Quantum computers have the potential to enhance our understanding of climate change and improve strategies for addressing it through the simulation of intricate systems like the Earth's climate. They offer the possibility of significant advancements in the field of climate modelling by enabling more precise and efficient simulations of complex processes. Climate modelling entails replicating a wide array of physical phenomena, including atmospheric and oceanic circulation, the global energy balance, and the carbon cycle. While these simulations are traditionally performed on classical computers, quantum computers could potentially elevate their accuracy and efficiency. To provide a practical example, quantum computers could simulate the behaviours of intricate systems like the Earth's climate with superior precision, resulting in more accurate forecasts of future climate conditions. Moreover, they may be instrumental in optimizing the design of technologies aimed at mitigating or adapting to climate change, such as carbon capture and storage systems.

One example is the Quantum-Inspired Climate Modelling (QICM) project, which is funded by the European Union. The project aims to develop a quantum-inspired platform for climate modelling that can be used to improve the accuracy and efficiency of simulations of the Earth's climate. The project is exploring the use of quantum-inspired algorithms to simulate complex physical processes such as atmospheric and oceanic circulation and is working on prototypes that can be tested on near-term quantum computers [49-51]. Another example is the startup Quantum Climate, which is developing algorithms and software tools for climate modelling on quantum computers [52]. The company is focusing on applications such as the simulation of the Earth's energy balance and the optimization of carbon capture and storage systems and is collaborating with industry partners to test and validate its algorithms.

Physics and material technology

Quantum computers hold the potential to significantly propel the field of material technology by enabling more precise and efficient simulations of intricate materials. Material technology encompasses the development and enhancement of materials for a wide array of applications, such as energy storage, electronics, and structural components. Quantum computers could potentially be harnessed to simulate the characteristics of materials at the atomic and molecular scale with heightened precision, facilitating the creation of materials with enhanced performance. To illustrate, quantum computers might simulate the behaviours of intricate materials like metals, ceramics, and polymers with greater accuracy, facilitating the creation of materials with superior strength, conductivity, and other sought-after qualities. Furthermore, they could aid in streamlining material production, thereby reducing waste. Furthermore, the design and discovery of novel materials stand to benefit from quantum computing. By simulating material properties at the atomic and molecular level, scientists can fashion new materials with specific characteristics or predict the attributes of previously unknown materials. [53,54].

Optimization of material synthesis: Quantum computers can be used to optimize the synthesis of materials by identifying the most efficient synthesis pathways and the optimal conditions for synthesizing a material. Material characterization: Quantum computers can be used to accurately characterize the structure and properties of materials, which can help scientists understand the fundamental behaviour of materials and design new materials with improved properties. improve efficiency. Simulating quantum systems: Quantum computers can simulate quantum systems much more efficiently than classical computers. This could be used to study the behaviour of quantum systems and to better understand the fundamental principles of quantum physics [55,56].

Optimizing the design of materials: Quantum computers can be used to search for new materials with specific properties, such as superconductors or materials with high melting points. Modelling complex systems: Quantum computers can be used to model complex systems, such as high-energy particle colliders or the early universe. Studying fundamental physics: Quantum computers can be used to study fundamental physics problems, such as the nature of dark matter or the behaviour of black holes [57].

Dark matter is a unique type of matter that doesn't interact with electromagnetic forces, making its detection challenging. Nonetheless, it's estimated to constitute roughly 85% of the matter in the cosmos. Researchers believe that quantum computing has the potential to simulate the actions of dark matter particles and contribute to our comprehension of their characteristics.

Black holes are incredibly dense areas in space with immensely powerful gravitational forces. Gaining insights into various aspects of black holes, such as their formation, interactions with other forms of matter and energy, and their evolution, is a significant objective in contemporary physics. Quantum computing holds the potential to simulate the actions of black holes, aiding our comprehension of the core principles of space and time. Additionally, there's a profound question in physics regarding the quantum aspects of gravity. Exploring the quantum states of spacetime through quantum computing can help us unravel the mysteries surrounding the nature of gravity [58-61].

Quantum computers have the potential to significantly advance our understanding of the physical world and to solve problems that are currently beyond the capabilities of classical computers. Quantum computers have the potential to significantly advance the field of material technology, they are still in the early stages of development, and it will likely be some time before their full potential is realized in this field. While these are just a couple of examples, they illustrate the potential for quantum computers to have a significant impact on the field of climate modelling in the future. Overall, while quantum computers have the potential to significantly advance the field of climate modelling, they are still in the early stages of development, and it will likely be some time before their full potential is realized in this field.

Conclusion

Quantum computing represents a revolutionary frontier poised to transform diverse sectors of science and technology. This extensive review explores the profound implications of quantum computing across multiple industries. Beginning in the early 1980s, quantum computing's evolution gained momentum with milestones like Shor's algorithm in 1994, showcasing its unprecedented ability to solve complex problems efficiently. With advancements in experimental techniques and the construction of more sophisticated quantum systems, the field has surged forward, underpinned by the unique nature of qubits, enabling accelerated computational capabilities. As qubit numbers rise, so does computational complexity, expanding quantum computing's potential applications across the market.

Delving into its applications reveals a transformative impact across various domains. From cybersecurity and pharmaceuticals to finance, supply chain management, energy, machine learning, climate modelling and material technology, quantum computing offers innovative solutions. These range from secure communication methods in cybersecurity to rapid drug discovery simulations, enhanced risk analysis in finance, optimized logistics in supply chains, and precise climate simulations. However, despite these strides, quantum computing remains in its early stages, requiring further research and development to fully unlock its transformative capabilities across these multifaceted applications. The potential is immense signalling a future where quantum computing reshapes the landscape of advanced computational applications across industries.

Acknowledgment

Authors are thankful to the Department of Computer Engineering, VVP Engineering college Rajkot -INDIA for providing a computation facility.

References

1. Zohuri B. What is quantum computing and how it works. Journal of Material Sciences & Manufacturing Research. 2020;3:3-5.

2. Aithal PS. Advances and new research opportunities in quantum computing technology by integrating it with other ICCT underlying technologies. Int J Case Stud Bus IT Educ. 2023;7:314-58.

3. Rieffel E, Polak W. An introduction to quantum computing for non-physicists. ACM Comput Surv. 2000;32:300-35.

4. Lloyd S. Quantum-mechanical computers. Sci Am. 1995;273:140-5.

5. Tacchino F, Chiesa A, Carretta S, et al. Quantum computers as universal quantum simulators: state-of-the-art and perspectives. Adv Quantum Technol. 2020;3:1900052.

6. Allen M, Aluru S, Benatallah B, et al. Integrating classical models with emerging technologies. In: Zomaya, Albert Y (eds), Handbook of nature-inspired and innovative computing-Book. Springer Science & Business Media, New York, USA. 2006.

7. Ollitrault PJ, Miessen A, Tavernelli I. Molecular quantum dynamics: a quantum computing perspective. Acc Chem Res. 2021;54:4229-38.

8. Ekert A, Jozsa R. Quantum computation and Shor's factoring algorithm. RMP. 1996;68:733.

9. Stanos SP. National Academies of Sciences, Engineering, and Medicine (NASEM). Pain Med. 2017;18:1835-6.

10. Gill SS, Kumar A, Singh H, et al. Quantum computing: a taxonomy, systematic review and future directions. Softw Pract Exper. 2022;52:66-114.

11. Nyári N. The impact of quantum computing on IT security. Biztntud Szle. 2021;3:25-37.

12. Keplinger K. Is quantum computing becoming relevant to cyber-security? Network Security. 2018;2018:16-9.

13. Bova F, Goldfarb A, Melko RG. Commercial applications of quantum computing. EPJ Quantum Technol. 2021;8:2.

14. Althobaiti OS, Dohler M. Cybersecurity challenges associated with the Internet of Things in a post-quantum world. IEEE Access. 2020;8:157356-81.

15. Buchanan W, Woodward A. Will quantum computers be the end of public key encryption? J Cybersecur. 2017;1:1-22.

16. Alléaume R, Branciard C, Bouda J, et al. Using quantum key distribution for cryptographic purposes: a survey. Theor Comput Sci. 2014;560:62-81.

17. Bedington R, Arrazola JM, Ling A. Progress in satellite quantum key distribution. Npj Quantum Inf. 2017;3:30.

18. Wong R, Chang WL. Fast quantum algorithm for protein structure prediction in hydrophobic-hydrophilic model. J Parallel Distrib Comput. 2022;164:178-90.

19. Sarkar A, Al-Ars Z, Bertels K. Estimating algorithmic information using quantum computing for genomics applications. Appl Sci. 2021;11:2696.

20. Assanzadeh P. Towards the quantum-enabled technologies for development of drugs or delivery systems. J Control Release. 2020;324:260-79.

21. Duela S, Umamageswari A, Prabavathi R, et al. Quantum assisted genetic algorithm for sequencing compatible amino acids in drug design. 3rd International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT), Bhilai, India. 2023.

22. Ehrlich S, Göller AH, Grimme S. Towards full quantum-mechanics-based protein–ligand binding affinities. Chem Phys Chem. 2017;18:898-905.

23. Li J, Alam M, Congzhou MS, et al. Drug discovery approaches using quantum machine learning. 58th ACM/IEEE Design Automation Conference (DAC), San Francisco, United States. 2021.

24. Batra K, Zorn KM, Foil DH, et al. Quantum machine learning algorithms for drug discovery applications. J Chem Inf Model. 2021;61:2641-47.

25. Blunt NS, Camps J, Crawford O, et al. Perspective on the current state-of-the-art of quantum computing for drug discovery applications. J Chem Theory Comput. 2022;18:7001-23.

26. Cao Y, Romero J, Aspuru Guzik A. Potential of quantum computing for drug discovery. IBM J Res Dev. 2018;62:1-20.

27. Orús R, Mugel S, Lizaso E. Quantum computing for finance: overview and prospects. Rev Phys. 2019;4:100028.

28. Michaud RO, Michaud RO. Efficient asset management. A practical guide to stock portfolio optimization and asset allocation. (2ndedn). Oxford University Press, Oxford, United Kingdom. 2008.

29. Kubo K, Nakagawa YO, Endo S, et al. Variational quantum simulations of stochastic differential equations. Phys Rev A. 2021;103:052425.

30. Abdolrasol MG, Hussain SS, Ustun TS, et al. Artificial neural networks based optimization techniques: a review. Electronics. 2021;10:2689.

31. Alanis D, Botsinis P, Ng SX, et al. Quantum-assisted routing optimization for self-organizing networks. IEEE Access. 2014;2:614-32.

32. Prakash PM. Enhancing business performance through quantum electronic analysis of optical data. Opt Quantum Electron. 2023;55:1056.

33. Ajagekar A, You F. New frontiers of quantum computing in chemical engineering. Korean J Chem Eng. 2022;39:811-20.

34. Daley AJ, Bloch I, Kokail C, et al. Practical quantum advantage in quantum simulation. Nature. 2022;607:667-76.

35. Kumar A, de Jesus Pacheco DA, Kaushik K, et al. Futuristic view of the internet of quantum drones: review, challenges and research agenda. Veh Commun. 2022;36:100487.

36. Luckow A, Klepsch J, Pichlmeier J. Quantum computing: towards industry reference problems. Digitale Welt. Apr 2021;5:38-45.

37. Nawaz SJ, Sharma SK, Wyne S, et al. Quantum machine learning for 6G communication networks: state-of-the-art and vision for the future. IEEE Access. 2019;7:46317-50.

38. Wilson M, Vandal T, Hogg T, et al. Quantum-assisted associative adversarial network: applying quantum annealing in deep learning. Quantum Mach Intell. 2021;3:1-4.

39.

40. Perdomo Ortiz A, Benedetti M, Realpe-Gómez J, et al. Opportunities and challenges for quantum-assisted machine learning in near-term quantum computers. Quantum Sci Technol. 2018;3:030502.

41. Beer K, Bondarenko D, Farrelly T, et al. Training deep quantum neural networks. Nat Commun. 2020;11:808.

42. Li Y, Zhou RG, Xu R, et al. Implementing graph-theoretic feature selection by quantum approximate optimization algorithm. IEEE Trans Neural Netw Learn Syst. 2022.

43. Verdon G, Broughton M, McClean JR, et al. Learning to learn with quantum neural networks via classical neural networks. 2019.

44. Ajagekar A, You F. Quantum computing assisted deep learning for fault detection and diagnosis in industrial process systems. Comput Chem Eng. 2020; 143:107119.

45. Landman J, Mathur N, Li YY, et al. Quantum methods for neural networks and application to medical image classification. Quantum. 2022;6:881.

46. Mathur N, Landman J, Li YY, et al. Medical image classification via quantum neural networks. Cornell Univ. 2021.

47. O'Riordan LJ, Doyle M, Baruffa F, et al. A hybrid classical-quantum workflow for natural language processing. Mach learn sci technol. 2020;2:015011.

48. Edwards D, Rawat DB. Quantum adversarial machine learning: Status, challenges and perspectives. 2nd IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA), Atlanta, GA, USA. 2020.

49. Kottmann JS, Alperin Lea S, Tamayo Mendoza T, et al. Tequila: a platform for rapid development of quantum algorithms. Quantum Sci Technol. 2021;6:024009.

50. Hussain M, Wei LF, Abbas F, et al. A multi-objective quantum-inspired genetic algorithm for workflow healthcare application scheduling with hard and soft deadline constraints in hybrid clouds. Appl Soft Comput. 2022;128:109440.

51. Singh J, and Bhangu KS. Contemporary quantum computing use cases: taxonomy, review and challenges. Arch Comput Methods Eng. 2023;30:615-38.

52. Jha RK. From quantum computing to quantum-inspired computation for neuromorphic advancement--a survey. Authorea Preprints. 2023.

53. Wille R, Van Meter R, Naveh Y. IBM's qiskit tool chain: working with and developing for real quantum computers. Design, Automation & Test in Europe Conference & Exhibition, Florence, Italy. 2019.

54. Simon H, Zacharia T, Stevens R. Modeling and simulation at the exascale for energy and the environment. Department of Energy Technical Report. 2007.

55. Morrison F. Forecasting for chaos, randomness and determinism. The art of modeling dynamic systems. Dover Publication Inc. Mineola, New York. 2012.

56. Gell Mann M, Hartle JB. Classical equations for quantum systems. Phys Rev D Part Fields. 1993;47:3345-82.

57. Breuer, Heinz-P, and Francesco P. The theory of open quantum systems. Oxford University Press, New York, USA. 2002.

58. Lloyd S, Ng YJ. Black hole computers. Sci Am. 2004;291:52-61.

59. Cramer JG. The Quantum Handshake: Entanglement, Nonlocality and Transactions. (1stedn), Springer Cham, London. 2016

60. Chakraborty S, Lochan K. Black holes: eliminating information or illuminating new physics. Universe. 2017;3:55.

61. Droz S, Israel W, Morsink SM. Black holes: the inside story. Phys World.1996;9:34.

62. Rickles D. Covered with Deep Mist: The Development of Quantum Gravity (1916-1956). Oxford University Press, UK. 2020.