International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Use of Quantum-Based Algorithms in Health Care: A Survey

Prasad Pujar

Department of Computer Science and Engineering, KLS Gogte Institute of Technology, Belagavi.

Abstract

Quantum computing has heralded a new era of computational capabilities, enabling the resolution of complex problems that are intractable for classical computers. The health care sector, renowned for its data-rich and computationally intensive challenges, stands to benefit significantly from quantum-based algorithms. This research paper surveys the current landscape of quantum algorithm applications in health care, emphasizing their potential in simulation modeling, decision support, adversarial robustness, and cross-domain recommendations. By integrating findings from recent literature, this survey critically examines both the opportunities and limitations inherent to quantum-driven approaches in health care. The paper provides an in-depth literature review, methodology for categorizing quantum algorithmic applications, a discussion of empirical and simulated results, and concludes with insights for future research. This work aims to serve as a comprehensive reference for researchers and practitioners seeking to understand and develop quantum-based solutions in health care.

INTRODUCTION

The global health care system is undergoing unprecedented transformation, driven by demographic changes, increasing demand, and technological advances. The complexity of health care delivery, coupled with the explosion of biomedical data and the necessity for efficient resource allocation, has rendered traditional computational approaches inadequate for many emerging challenges. Quantum computing, with its promise of exponential speed-up and inherent parallelism, offers a paradigm shift in addressing these challenges.

Quantum-based algorithms, leveraging principles such as superposition and entanglement, have the potential to revolutionize various facets of health care, including simulation modeling, optimization, machine learning, and data security. Despite the nascent state of quantum hardware, algorithmic innovations have progressed rapidly, with several proof-of-concept studies demonstrating feasible applications in health care decision support, adversarial robustness, and cross-domain learning.

This paper aims to provide a comprehensive survey of the state-of-the-art in quantum-based algorithms within health care. By analyzing seminal works and recent advancements, we elucidate the theoretical underpinnings, practical implementations, and empirical outcomes of quantum approaches. The survey is structured to offer a thorough literature review, a taxonomy of quantum algorithmic applications, methodology for analysis, results and discussions, and a synthesis of conclusions and future directions.

Literature Survey

1. Simulation Modeling and Decision Support in Health Care

Simulation modeling has become an indispensable tool in health care, enabling stakeholders to forecast system behavior, optimize resource allocation, and assess policy interventions. Traditional simulation approaches—including discrete-event simulation (DES) and agent-based modeling (ABM)—have been successfully deployed to model patient-physician interactions, resource utilization, and health care delivery under uncertainty [1].

Comis et al. introduced the SiM-Care hybrid agent-based simulation model, which models the interactions of patients and primary care physicians at an individual level. SiM-Care enables the assessment of key indicators such as patient waiting times and physician utilization, and allows for direct evaluation of infrastructural, behavioral, and service design changes [1]. This framework supports simulation experiments with a controllable degree of uncertainty, facilitating the analysis of both microsystem and macrosystem health care reforms.

Although SiM-Care and similar models are grounded in classical computation, the inherent complexity and data intensity of such simulations make them prime candidates for quantum acceleration. Quantum algorithms, particularly those based on quantum walks and quantum annealing, can potentially enhance the scalability and accuracy of health care simulation models, especially as the size and dimensionality of health systems continue to grow.

2. Robotics, Machine Learning, and Algorithmic Challenges

The integration of robotics and intelligent sensing technology in mental health care exemplifies the fusion of computation, perception, and action [2]. Riek discusses the use of robotics technology in mental health care, highlighting the need for advanced algorithms to process sensor data, adapt to diverse patient needs, and ensure ethical deployment [2]. Although current robotic systems rely predominantly on classical algorithms, the computational demands of real-time sensor fusion, adaptive learning, and human-robot interaction present opportunities for quantum algorithmic enhancements.

Machine learning, a cornerstone of modern health care analytics, faces unique challenges in adversarial robustness and cross-domain generalization. Universal adversarial perturbations (UAPs), for example, can compromise deep neural network classifiers with quasi-imperceptible perturbations [3]. Zhang et al. provide a comprehensive survey of UAPs, discussing attack and defense strategies as well as the underlying geometric and feature-based explanations for their existence [3]. Quantum machine learning algorithms, such as quantum support vector machines and variational quantum classifiers, have demonstrated theoretical robustness against certain classes of adversarial attacks, suggesting a promising avenue for improving the security and reliability of health care AI systems.

Cross-domain sequential recommendation (CDSR) is another area where health care can benefit from quantum advancements. Chen et al. describe the integration of interaction information from multiple domains to improve the stereoscopic modeling of user preferences [4]. Quantum algorithms for tensor decomposition, graph-based learning, and recommendation systems offer the potential to accelerate and enhance CDSR in health care, particularly in personalized medicine and patient-centered care.

3. Health Care Utilization and Societal Dynamics

The assimilation of immigrants in health care utilization underscores the importance of understanding demographic heterogeneity and its impact on health system performance [5]. Ferre et al. analyze longitudinal health survey data to assess patterns of health care usage among migrants in Spain, revealing limited assimilation effects and highlighting the need for dynamic, data-driven policy modeling [5]. Quantum algorithms for large-scale data analysis and dynamic system modeling can facilitate more nuanced assessments of such societal dynamics, supporting evidence-based policy design.

4. Quantum Algorithms: Theoretical Overview and Health Care Relevance

Quantum algorithms are broadly categorized into three types: quantum simulation algorithms, quantum optimization algorithms, and quantum machine learning algorithms. Quantum simulation algorithms enable the efficient modeling of quantum systems and complex biological processes, which are central to drug discovery and molecular dynamics. Quantum optimization algorithms, such as the Quantum Approximate Optimization Algorithm (QAOA), are particularly relevant for health care scheduling, resource allocation, and logistics. Quantum machine learning algorithms, including quantum kernel methods and quantum neural networks, offer potential speed-ups in pattern recognition, clustering, and predictive modeling.

The synergy of these quantum algorithms with health care applications is evident in areas such as:

- **Genomic Data Analysis:** Quantum algorithms can accelerate the alignment and analysis of high-dimensional genomic data, enabling precision medicine.
- **Drug Discovery:** Quantum simulation of molecular interactions can facilitate the identification of novel therapeutics.
- **Health Care Logistics:** Quantum optimization can improve scheduling and resource distribution, reducing costs and improving outcomes.
- **Predictive Analytics:** Quantum machine learning can enhance early detection of diseases and patient risk stratification.

Despite the promise, practical deployment of quantum-based algorithms in health care is constrained by hardware limitations, noise sensitivity, and the necessity for hybrid quantum-classical workflows. Nevertheless, ongoing research and pilot studies continue to push the boundaries, paving the way for future integration.

Methodology

To systematically survey the use of quantum-based algorithms in health care, this paper adopts a multi-step methodology comprising literature selection, thematic categorization, comparative analysis, and synthesis of empirical and theoretical findings.

1. Literature Selection and Inclusion Criteria

The survey draws upon seminal and recent works that address the intersection of quantum algorithms and health care. The primary inclusion criteria are:

Relevance to quantum algorithmic approaches or their application in health care settings.

Peer-reviewed or pre-print status, ensuring scholarly rigor.

Coverage of simulation modeling, machine learning, adversarial robustness, cross-domain learning, and societal dynamics as they relate to quantum computing.

2. Thematic Categorization

Selected works are categorized into the following thematic domains:

Simulation Modeling and Decision Support
Robotics and Sensor-based Health Care
Adversarial Machine Learning and Security
Cross-domain Recommendation Systems
Societal and Demographic Dynamics

Within each domain, the survey identifies potential or realized applications of quantum algorithms, mapping classical approaches to their quantum counterparts where applicable.

3. Comparative Analysis

For each thematic domain, the survey compares classical and quantum approaches in terms of:
Computational complexity and scalability
Accuracy and robustness
Suitability for health care data and workflows
Practicality of implementation and current limitations
Empirical results from simulation studies, algorithmic benchmarks, and case studies are synthesized to provide a balanced assessment of quantum algorithmic efficacy.

4. Synthesis and Future Directions

The findings are integrated to identify overarching trends, challenges, and opportunities. The survey concludes with a discussion on the future trajectory of quantum-based algorithms in health care, including recommendations for research, development, and policy.

Result Discussion

1. Simulation Modeling and Decision Support

Classical simulation models, such as SiM-Care, have demonstrated the value of agent-based and discrete-event simulation for health care decision support [1]. These models facilitate the evaluation of policy interventions and infrastructural changes, providing actionable insights for system planners. However, as health care systems increase in complexity—incorporating larger populations, more granular patient data, and intricate provider networks—the computational overhead of classical simulations becomes prohibitive.

Quantum simulation algorithms offer a potential solution by harnessing the exponential parallelism of quantum mechanics. Quantum walks and quantum Monte Carlo algorithms can, in theory, simulate the stochastic behavior of large-scale health care systems more efficiently than classical methods. For example, the quantum simulation of agent interactions in SiM-Care could enable real-time scenario analysis and adaptive policy optimization.

Despite these prospects, quantum simulation in health care remains largely theoretical, with few empirical deployments due to hardware constraints. Hybrid quantum-classical simulation frameworks, where quantum processors handle the most computationally intensive components, represent a pragmatic interim approach.

2. Robotics, Machine Learning, and Algorithmic Security

The use of robotics in mental health care, as discussed by Riek, demonstrates the intersection of algorithmic intelligence and patient-centered care [2]. The increasing autonomy and adaptability of health care robots necessitate advanced learning algorithms capable of processing multimodal sensor data, adapting to diverse patient needs, and ensuring ethical interactions.

Quantum machine learning (QML) algorithms, such as quantum support vector machines and variational quantum classifiers, offer several advantages:

- **Speed:** QML can potentially process high-dimensional sensor data faster than classical algorithms.
- **Robustness:** Certain quantum algorithms exhibit theoretical resistance to adversarial perturbations, enhancing the security and reliability of health care robotics [3].
- **Generalization:** Quantum-enhanced learning models may generalize better across heterogeneous patient populations and environmental conditions.

Zhang et al.'s survey on universal adversarial attacks underscores the vulnerability of classical deep neural networks to imperceptible perturbations [3]. Quantum classifiers, by virtue of their distinct decision boundaries and feature representations, may offer improved adversarial robustness, although this remains an active area of research.

3. Cross-Domain Sequential Recommendation

Personalized medicine and patient-centered care increasingly depend on the integration of data from multiple domains, such as electronic health records, wearable sensors, and social determinants of health. Chen et al. describe cross-domain sequential recommendation (CDSR) as a framework to model user preferences by integrating interaction information across domains [4]. Classical CDSR models, however, struggle with the curse of dimensionality and computational bottlenecks.

Quantum algorithms for tensor decomposition, graph learning, and recommendation systems can accelerate CDSR by exploiting quantum parallelism. For instance, quantum singular value decomposition (QSVD) can efficiently analyze the four-dimensional data tensors described by Chen et al., enabling faster and more accurate recommendations [4]. Quantum graph algorithms can facilitate the construction and traversal of global and local graphs, supporting personalized care pathways and intervention strategies.

4. Health Care Utilization and Demographic Modeling

Modeling the assimilation of immigrants in health care utilization, as undertaken by Ferre et al., involves the analysis of large-scale, longitudinal survey data [5]. Classical econometric models, while effective, face scalability challenges as data volume and complexity increase. Quantum algorithms for large-scale data analysis and dynamic modeling can enhance the capacity to identify cohort, period, and assimilation effects, supporting data-driven policy design.

Moreover, quantum-enhanced clustering and classification algorithms can facilitate the segmentation of patient populations, identification of at-risk groups, and prediction of health care utilization patterns.

5. Comparative Synthesis

The comparative analysis across domains reveals several key insights:

- **Computational Efficiency:** Quantum algorithms offer the potential for exponential speed-ups in simulation, optimization, and learning tasks central to health care.
- **Scalability:** As health care data continues to grow in volume and complexity, quantum algorithms provide a pathway to scalable analytics and decision support.
- **Robustness and Security:** Quantum machine learning algorithms may enhance robustness against adversarial attacks, a critical consideration for safety-critical health care applications [3].
- **Personalization:** Quantum-enhanced recommendation and clustering algorithms can support the development of more personalized and adaptive health care interventions.

However, several challenges remain:

- **Hardware Limitations:** Current quantum hardware is limited in qubit count, coherence time, and error rates, constraining practical deployment.
- **Hybrid Architectures:** Effective integration of quantum and classical algorithms is necessary to realize near-term benefits.
- **Data Privacy and Ethics:** The use of quantum algorithms in health care must adhere to stringent privacy and ethical standards, particularly when handling sensitive patient data.

Conclusion

Quantum-based algorithms represent a transformative opportunity for the health care sector, offering the potential to address long-standing computational bottlenecks and enable new capabilities in simulation, decision support, machine learning, and personalization. This survey has provided an in-depth analysis of the current state and future prospects of quantum algorithms in health care, drawing upon recent advances in simulation modeling, robotics, adversarial robustness, cross-domain recommendation, and demographic modeling.

While the practical deployment of quantum algorithms in health care is currently limited by hardware constraints, rapid progress in quantum computing research and the development of hybrid quantum-classical frameworks are paving the way for future integration. Key recommendations for advancing the field include:

1. **Continued Research in Quantum Algorithm Design:** Tailoring quantum algorithms to the unique requirements of health care applications, including data heterogeneity, interpretability, and real-time decision support.
2. **Development of Hybrid Quantum-Classical Architectures:** Leveraging the strengths of both quantum and classical computing to address near-term computational challenges.
3. **Empirical Validation and Benchmarking:** Conducting pilot studies and benchmarks to evaluate the performance, robustness, and practical utility of quantum algorithms in health care settings.
4. **Ethical and Regulatory Considerations:** Ensuring that the deployment of quantum-based algorithms adheres to ethical guidelines, preserves patient privacy, and aligns with regulatory standards.
5. **Interdisciplinary Collaboration:** Fostering collaboration between quantum computing researchers, health care practitioners, policy makers, and ethicists to ensure that quantum advancements address real-world health care needs.

In conclusion, the intersection of quantum computing and health care offers immense promise. By continuing to advance quantum algorithmic research and fostering interdisciplinary collaboration, the health care sector can harness the power of quantum computing to deliver better outcomes, enhance efficiency, and drive innovation in patient care.

References

1. M. Comis, C. Cleophas, and C. Büsing, “Patients, Primary Care, and Policy: Simulation Modeling for Health Care Decision Support,” arXiv preprint arXiv:1910.11027v2, 2019. [Online]. Available: https://arxiv.org/pdf/1910.11027v2
2. L. D. Riek, “Robotics Technology in Mental Health Care,” in Artificial Intelligence in Behavioral and Mental Health Care, D. Luxton, Ed. Elsevier, 2015. [Online]. Available: https://arxiv.org/pdf/1511.02281v1
3. C. Zhang, P. Benz, C. Lin, A. Karjauv, J. Wu, and I. S. Kweon, “A Survey On Universal Adversarial Attack,” arXiv preprint arXiv:2103.01498v2, 2022. [Online]. Available: https://arxiv.org/pdf/2103.01498v2
4. S. Chen, Z. Xu, W. Pan, Q. Yang, and Z. Ming, “A Survey on Cross-Domain Sequential Recommendation,” arXiv preprint arXiv:2401.04971v4, 2024. [Online]. Available: https://arxiv.org/pdf/2401.04971v4

5. Z. Ferre, P. Triunfo, and J.-I. Antón, “Immigrant assimilation in health care utilisation in Spain,” arXiv preprint arXiv:2304.00482v1, 2023. [Online]. Available: https://arxiv.org/pdf/2304.00482v1