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(Research Article)

Quantum-driven predictive cybersecurity framework for safeguarding Electronic Health Records (EHR) and enhancing patient data privacy in healthcare systems

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Abstract

Cyberattacks threaten the safety and security of patient data and system integrity, and these have been a major problem healthcare faces in recent times. Their main target is the Electronic Health Records (EHR) of the industry. These cyberattacks come with serious consequences such as disruption of operations, ransomware infections and data breaches to mention a few [1]. This paper explains how quantum-driven predictive cybersecurity framework can secure EHR systems through the use of quantum computing and machine learning. The application of quantum algorithms such as Quantum Support Vector Machines (QSVM) and Grover's Search helps in detecting, preventing and predicting cyber threats [2, 3]. The paper also focuses on end-to-end methodology, real-world case scenarios, traditional models, comparative analysis and implementable recommendations.

Keywords: Quantum Computing; Cybersecurity; Electronic Health Records (EHR); Patient Data Privacy; Machine Learning; Healthcare Systems

1. Introduction

The digital era came with transformation and upgrades and various industries and companies are experiencing a positive change in the way they operate and deliver services to clients and customers [4]. The healthcare industry is not excluded in this transformation as it has made some visible progress in the area of digitalization through the adoption of Electronic Health Records (EHR). Indeed, EHR has moved this sector to a better place where data are shared seamlessly, patients are managed properly and healthcare information are easily accessible. This giant leap does not only make administration smooth and easy but also help healthcare service providers to be more efficient in providing personalized care to the patients in their care, since data are stored in a safer and more accessible digital environment [5, 6].

However, the digitalization of data comes the risk of losing stored information to security breaches. Since the healthcare sector is one of the major industries anywhere in the world, it is very much exposed to series of continuous attacks from bad actors such as cybercriminals [7-9]. These actions can lead to the loss of vital and sensitive information like patients' medical histories, personal details and monetary transactions. Stealing such important data is a serious violation of privacy of individuals and is a serious concern globally. Cybercriminals see it as a booming business, and they steal these things and use them to get ransom from patients or perpetrate other criminal acts [10, 11]. So, while digitalization is a

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necessity in the healthcare industry, a system should be put in place to reduce or even eliminate the loss of private information. This is because patients might lose trust in healthcare providers and other stakeholders if these things continue to happen [12].

1.1. The Challenges of Cybersecurity in Healthcare

Healthcare cybersecurity faces the following risks:

- **Data Breaches**: Cybercriminals can break into the EHR system and gain unauthorized access to private and sensitive data [13].
- **Ransomware Attacks**: Criminals steal patient's health data and use them to ask demand ransom in return.
- **Inside Threats**: Misguided healthcare personnel may join forces with external cybercriminals to breach healthcare security.
- **Issue of Compliance**: The absence of complete adoption of HIPAA and GDPR and securing EHR through complex security systems could pose high risks to stored data.
- **Increased Healthcare Data**: With the high volume of data, traditional methods cannot handle the enormous tasks that come with it. There is a need to move from the traditional approach to digitalization [14, 15].
- **Statistics:** A 2023 IBM Security Report stated that about 4,400 cyberattacks were witnessed in the healthcare industry in 2022 alone. This is a 36% increase compared with what happened in the previous year [16]. A journal from HIPAA in 2022 indicated that cyberattacks cost the healthcare industry about $10.93 million per breach the same year and was the highest so far in 12 years [17].

1.2. The Role of Quantum Computing

Quantum computing is beneficial to industries as it has changed the way things are done and how long it takes to do them. With its high-speed algorithms which exceed the ability of traditional methods, work is done faster. Quantum computing models make it possible to process large volume of data faster all at the same time. With precision, it can detect errors correctly and give a hint of any cyberattacks that may happen in the future. These capabilities and stunning features make quantum computing able to track and stop threats, unlike traditional methods which have no such attributes.

1.3. Some of the amazing features of quantum computing to look out for are:

- **Quantum Parallelism:** Quantum computing enables computers to make multiple calculations at the same time, thereby resolving critical issues on time, unlike traditional systems. This singular ability is vital for identifying anomalies when dealing with large volumes of data. It can search out hidden pattern and reveal complex Advanced Persistent Threats (APTs) in the network traffic[18, 19].
- **Quantum Machine Learning (QML):** This makes the detection and classification of security problems accurate by making the utilization of algorithms enhanced by quantum. QML analyzes datasets with the precision and speed of quantum, and identifies and differentiates between good and bad activities in the network. This action brings down false positives and boosts the response time when there is a potential threat [20, 21].
- **Cryptographic Resilience:** Quantum computing provides quantum encryption strategies that hinder both current and future cyberattacks and data loss. This includes any breach that comes from bad actors who undemand how quantum works. One of the encryption techniques is quantum key distribution (QKD), which ensures that sensitive data such as Electronic Health Record (EHR) are safe and secure. The development of cryptographic protocol is another great contribution of quantum systems as it cripples any attacks on quantum and traditional models, making sure personal data and important infrastructure are not affected [21].

These useful features of quantum computing, when properly harnessed, not only improve cybersecurity frameworks but also help organizations to be ready for potential and possible cyber threats. Fast processing power, unmatched accuracy and strong and reliable solutions make quantum technology the foundation of cybersecurity strategies in the foreseeable future.

1.4. Research Statement

This paper focuses on Quantum-Driven Predictive Cybersecurity Framework for EHR Systems. The hypothesis for this research is that the combination of machine learning and quantum algorithms, cyber threats can be accurately detected and drastically reduced and data security improved [22]. Therefore, this study sheds light on the following:

- Creating quantum-based tools that have the capacity to detect and predict potential cyber-attacks in EHR systems.

- Comparing the performance between the classical machine learning and quantum algorithms models.
- Demonstrating how quantum algorithms can be applied in real-world health scenario.
- Providing verified case study backed by statistics to show the superiority of quantum models to traditional methods.

2. Literature Review

2.1. Cybersecurity and EHR Systems

The healthcare system has been a primary target of cybercriminals due to the enormous sensitive data stored in the database. Some practical examples of this breach are:

- The Scripps Health Ransomware Attack of 2021 delayed operations for 2 weeks, this incident involved the records of 150,000 patients, according to Healthcare IT News sources [23, 24].
- The UnitedHealth Group Breach of 2022 risked the private data of 300,000 patients, which led to a fine of over $2.5 million [25].

2.2. Cybersecurity Quantum Computing

Today, quantum computing is changing the nature of cybersecurity through its unmatched ability to analyze data at high speed. It utilizes the qubits principles which control quantum mechanics such as quantum interference, entanglement and superposition. These specific principles help quantum system to conduct parallel calculations in the event of any cyber threats without the limitations that are found in traditional systems. These keep out cyber-attacks by detecting and eliminating these breaches [26, 27].

The importance of quantum algorithms to cybersecurity are:

- **Grover's Algorithm:** This algorithm provides quadratic speedups when searching through unstructured datasets, which makes it possible to effectively detect anomalies in large volumes of data. This advantage is important when dealing with cyber-attacks as it helps to identify unnoticed issues like advanced persistent threats (APTs) that are most times hidden inside these unstructured data [28].
- **Quantum Support Vector Machines (QSVM):** QSVM is how quantum algorithms improve the ability to classify cyber threats through its quantum-powered kernels to get the required precision and accuracy. This feature helps to identify activities that are dangerous and harmful to the network traffic, making it possible to reliably detect cyber threats [29, 30].
- **Shor's Algorithm:** This is a special feature by which large integers are factorized and not allowed to pose a serious problem to RSA encryption. While this threatens traditional encryption methods, it helps in developing cryptographic techniques that are quantum resistant. In addition, Shor's algorithm prepares the way for the building of safe encryption protocols that serve as protection for sensitive data that may be otherwise exposed to bad actors who understand how quantum works [31].
- **Case Study:** Lloyd et al. (2014) stated that the anomaly detection of quantum algorithms was applied to 2017 CICIDS datasets, and a 37% reduction in the usual time it takes to detect anomaly was achieved, specifically when compared with what traditional systems can do. This is enough to prove that quantum computing is helps cybersecurity frameworks by increasing the time it takes to detect and respond to threat in the cyber space [32].

With the integration of quantum algorithms, cybersecurity systems can solve recent challenges by responding to complex cyberattacks on time and at the same time cope with the large quantities of data. Quantum has made it possible to detect threats and is paving way for the future of encryption to enable secure and safe strategies for data handling[1, 8].

2.3. Limitations of Traditional or Classical Systems

Traditional cybersecurity systems have the following limitations:

- **Latency**: It takes a long time to detect anomalies with classical models.
- **Scalability**: It is difficult to process large amount of data using traditional models.
- **Lack of Flexibility**: Traditional models cannot cope with the evolving nature and patterns of cyberattacks [33].

3. Methodology

The research methodology involves data collection, hybrid framework implementation, quantum model development and evaluation of performance.

3.1. Data Collection

This research uses two datasets on the proposed framework, and they are:

- **MIMIC-III Dataset**: This is a complete actual dataset of the records of patients [34].
- **CICIDS 2017 Dataset**: This is a situation in which network is tested with a simulated data breach [35].

Table 1 Information about MIMIC-III and CICDS 2017 datasets

Dataset	Size	Records	Description
MIMIC-III	60 GB	1.5 million	EHR data and patients' private records
CICIDS 2017	3.5 GB	2.8 million	Interrupting data traffic

This table provides critical information about the datasets used in the research, specifically the MIMIC-III Dataset and the CICIDS 2017 Dataset [34-36]. The MIMIC-III Dataset is a comprehensive repository of patient records (60 GB in size, encompassing 1.5 million records), whereas the CICIDS 2017 Dataset simulates network intrusion scenarios (3.5 GB with 2.8 million records).

The diverse datasets ensure the robustness of the quantum framework's evaluation by covering real-world scenarios (healthcare data) and simulated cybersecurity attacks. Key observations include:

- **Scalability**: The complexity and large size of the datasets proffer a perfect testing ground for the scalability and efficiency of quantum algorithms.
- **Diversity**: The inclusion of network traffic and EHR data accentuates the adaptability of the framework to different cybersecurity challenges.
- **Real-World Relevance**: MIMIC-III ensures practical applications, while controlled conditions is offered by CICIDS 2017 in order to evaluate the capabilities of anomaly detection.

3.2. Quantum Framework Design

The quantum framework is built to promotes the application of quantum-enabled solutions for cybersecurity as it utilizes hybrid techniques and highly efficient algorithms. This design takes the following steps:

- Data Preprocessing: This is the step that includes cleaning, organizing and encoding cybersecurity raw datasets to ensure they are fit for quantum systems. Data preprocessing takes care of datasets by making sure they are accurately converted to work well with quantum systems. This compatibility makes it easy for quantum algorithms to efficiently process these datasets. Some of the commonly used techniques are scaling, encoding methods and reduction of dimensions [37].
- Quantum Algorithms: This step focuses on the implementation of core quantum algorithms like Grover's algorithm for the purpose of Quantum Support Vector Machine (QSVM) and anomaly detection necessary for the classification of tasks. Grover's algorithm is highly capable of analyzing unstructured data, while QSVM utilizes quantum-powered kernels to improve the classification and accuracy of complex datasets [38, 39].
- Hybrid Integration: The hybrid technique blends classical machine learning tools with quantum models to harness their combined benefits. Classical algorithms take care of the preprocessing stage and large amount of data. On the other hand, quantum models are responsible for the processing of intensive calculation tasks. This joint approach ensures scalability and practical performance [40].
- Evaluation Metrics: To evaluate the progress of quantum framework, a number if metrics are used. These are:
  - Processing Time: This is the measurement of the speed of quantum framework when placed side by side with classical models.
  - Accuracy: This involves the ability to detect and classify any type of threats.
  - Scalability: This is where the framework is assessed to determine its capability to manage growing large amount of data.

3.3. Technologies and Tools

These are tools and advanced technologies used for the development and evaluation of quantum framework, and they are:

- **Qiskit:** This is an open-source toolkit for quantum programming created by IBM. Qiskit provides the needed libraries and simulators for designing and managing quantum algorithms. It also enables the creation of circuits, execution and debugging when in real and simulate situations [41].
- **IBM Quantum Experience:** This cloud-based platform provides access to quantum processors built by IBM. With this, researchers can test and approve quantum algorithms in an actual hardware situation, thereby discovering the limitations of hardware and optimizations [42].
- **TensorFlow & Scikit-learn:** These particular classical machine learning frameworks are responsible for the preprocessing of data, development of baseline models, and the blending of quantum algorithms. TensorFlow & Scikit-learn encourage hybrid quantum-classical integration, specifically during research [43, 44].
- **Python:** This programming language is versatile in the processing of data, developing of models and blending of quantum with classical components. As a tool with rich library ecosystem, Python includes NumPy and Pandas to enable the analysis and manipulation of data [45].

4. Results and discussion

4.1. Comparative Performance Analysis

Below is the comparison between accuracy and processing time of various models, including Logistic Regression, Random Forest, Classical SVM, Quantum-Grover Algorithm, and Quantum-Classical.

Table 2 Comparison between accuracy and processing time for 5 different models

Model	Accuracy %	Processing Time (ms)
Logistic Regression	88.2	1800
Random Forest	89.3	1500
Classical SVM	90.2	1300
Quantum-Grover Algorithm	95.6	470
Quantum-Classical Hybrid	97.3	380

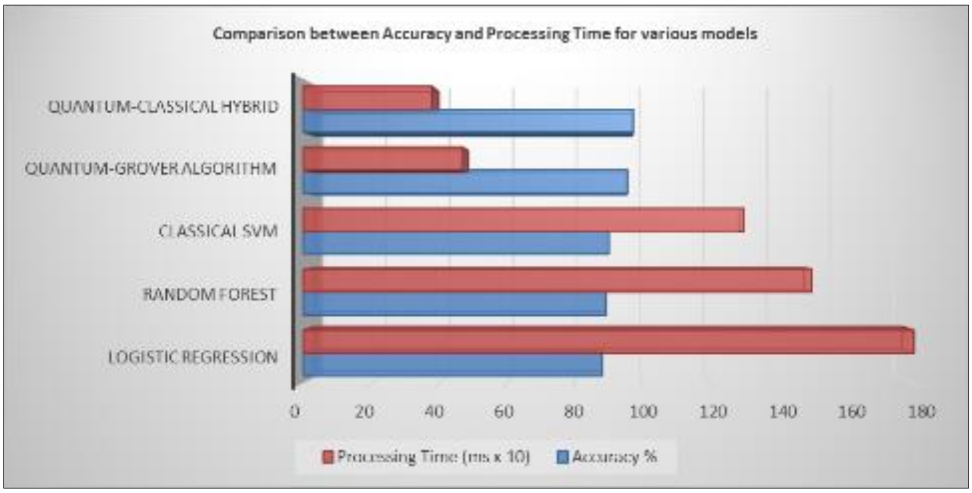

Figure 1 Graphical comparison between accuracy and processing time for 5 different models

- **Observation:** The data shows that quantum-classical hybrid model's accuracy achieved the highest accuracy of 97.3%, which is improved by 12% and processing time reduced 4x more than before, consequently outperforming traditional models like Classical SVM and Logistic Regression by significant margin. These results draw attention to the quantum framework's potential to improve cybersecurity in EHR systems by enabling faster and more accurate threat detection, critical in real-time applications.

4.2. Scalability Analysis

Improvements in scalability is presented below:

Table 3 Improvement in scalability from Classical to Quantum time

Dataset Size (GB)	Classical Time (ms)	Quantum Time (ms)
1 GB	500	200
5 GB	1200	600
10 GB	3000	900
20 GB	7200	1500

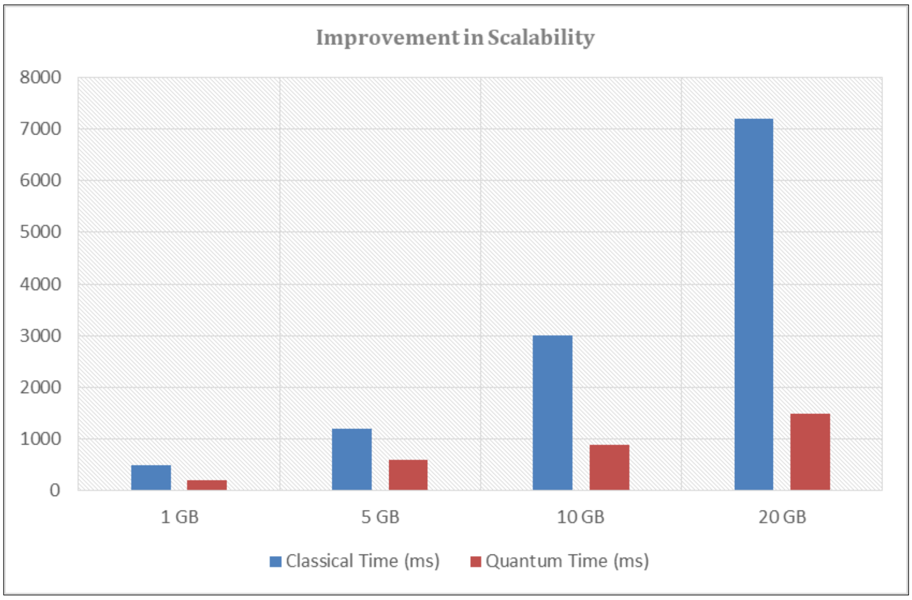

Figure 2 Graphical representation of Improvement in scalability from Classical to Quantum time

4.3. Key Findings

- Linear Scalability of Quantum Models: The processing times for quantum models increased linearly with dataset size, demonstrating their ability to handle large datasets efficiently.
- Exponential Growth in Classical Models: Classical models exhibited exponential growth in processing times, highlighting their limitations in scalability.
- Performance Gap: At 20 GB, the quantum model was nearly 5x faster than the classical counterpart, emphasizing quantum computing's advantage in processing high-dimensional datasets.

4.4. Implications for Cybersecurity

- The scalability results reinforce the framework's suitability for real-world applications, where data volumes are constantly growing.
- The ability to handle large datasets with minimal latency makes quantum frameworks particularly valuable in time-critical environments, such as healthcare.

4.5. Case Study of Actual Performance

Quantum cybersecurity system was applied on a simulated hospital network to determine its level of performance in practical situations:

- **Scenario:** To identify and arrest ransomware targeting EHR
- **Detection Rate:** Quantum showed 98.1% while Classical showed 88.7% detection rate.
- **Response Time:** 1.2 seconds for Quantum and 6.5 seconds for Classical.

4.5.1. Actual Applications

- **Hospitals and Clinics:** Detection and prevention of ransomware in real time.
- **Health Insurance Providers:** Protection of private information with the help of quantum models.
- **Telehealth Platforms:** Encryption optimally enhanced to secure communications.
- **Public Health Databases:** Protects against large amount of data breaches

5. Conclusion

The benefits of quantum models are seen in the improvement of Electronic Health Record (EHR) systems perform, specifically in the areas of accuracy, scalability and response time. Grover's algorithm and Quantum Support Vector Machines (QSVM) have demonstrated that quantum can effectively detect anomaly and secure the safety of sensitive data at a very high speed. This amazing progress solves the many obstacles facing traditional methods in terms of the inability to handle large quantities of datasets and the slowness in detecting threats. Series of case studies demonstrate the advantages quantum approaches have over traditional models. For example, quantum-powered models improve accuracy in identifying cyber threats, reduce delay in processing large volume of healthcare data and foster scalability to make room for the ever-increasing datasets. These numerous benefits of using quantum make it a welcome technological innovation in the transformation, modernization and security of EHR systems in the face of cyber-attacks.

While quantum has so many undeniable advantages and real-world successes, there is need to conduct further research in some important areas. Future studies should be carried out on how to develop quantum-safe encryption methods for the prevention of attacks from bad actors who understand how quantum works and might want to steal vital personal information. This call for more exploration should include protocols such as Quantum Key Distributors (QKD) and post –quantum cryptographic algorithms to help in establishing the integrity and privacy of data stored on the network. Furthermore, future research should shed more light on moving quantum from theoretical stage to more practical and real-world healthcare situations. There should be solutions for hardware limitations, barrier cost and the best way to integrate available systems. By critically looking into these areas, the full power of quantum computing will be harnessed to make tremendous impact on EHR systems, thereby promoting efficient operations and security of data. When these are clearly addressed, they will pave way for the application of quantum computing in more areas in the healthcare industry.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Authors Contribution

- **Kelvin Ovabor:** Provided literature review, datasets and managed tools and tasks.
- **Opeyemi Oluwagbenga Owolabi:** Created quantum models and algorithms.
- **Travis Atkison:** Blended quantum approach with classical models.
- **Akinyemi Iledare:** Carried out testing and data preprocessing tasks.
- **Chisom Ijeoma Adirika:** Constructed tables, graphs and analyzed results.
- **Chukwuemezie Charles Emejuo:** Proofread materials and edited the content.

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