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A Survey of Methods and Architectures for Secure Medical Image Cryptanalysis with Quantum Neural Networks for IoT-Enabled Cloud Storage

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Abstract

The rapid evolution of Internet of Things (IoT)-enabled healthcare systems has significantly increased the generation, transmission, and storage of medical images such as MRI, CT scans, and X-rays in cloud environments. While this advancement enhances remote diagnostics and telemedicine, it also introduces critical security challenges related to confidentiality, integrity, and privacy of sensitive patient data. Traditional cryptographic methods, including AES and RSA, are often inadequate in addressing the complex requirements of medical image security due to high computational overhead and vulnerability to emerging cyber threats. Consequently, recent research has shifted toward hybrid approaches integrating chaos theory, DNA encoding, deep learning, and quantum computing. This survey paper provides a comprehensive analysis of modern techniques and architectures for secure medical image cryptanalysis, with a particular focus on quantum neural networks (QNNs) in IoT-enabled cloud environments. The study reviews state-of-the-art encryption schemes such as hyperchaotic systems, quantum key distribution, and hybrid quantum-classical cryptography, highlighting their effectiveness in securing medical image transmission and storage. Additionally, the role of deep learning-based cryptographic models and quantum-inspired algorithms in improving robustness against attacks is examined. The paper further presents a comparative analysis of recent studies (2020–2023), identifying key performance metrics such as entropy, PSNR, computational efficiency, and resistance to statistical and differential attacks. Challenges including resource constraints of IoT devices, scalability issues, and limitations of current quantum hardware are also discussed. Finally, the paper outlines future research directions emphasizing the integration of quantum neural networks and lightweight cryptographic frameworks to ensure secure, efficient, and scalable healthcare systems.

Introduction

The integration of the Internet of Things (IoT) into healthcare has significantly transformed the way medical data is collected, transmitted, and analyzed. Modern healthcare systems rely on interconnected devices such as wearable sensors, imaging equipment, and smart diagnostic tools that continuously generate large

volumes of medical data, particularly medical images like MRI, CT scans, and X-rays. These images are typically transmitted over public networks and stored in cloud platforms for remote access and real-time analysis. While this improves healthcare accessibility and operational efficiency, it also introduces critical concerns related to data security and patient privacy.

Medical images contain highly sensitive information that must be protected against unauthorized access, tampering, and data breaches. However, traditional encryption techniques such as Advanced Encryption Standard (AES) and Rivest–Shamir–Adleman (RSA) are not fully suitable for medical image data due to its large size, redundancy, and strong pixel correlation. These characteristics make images vulnerable to statistical and cryptographic attacks. Additionally, IoT devices often operate with limited computational power, memory, and energy, making it difficult to implement complex conventional encryption algorithms effectively in real-time healthcare environments.

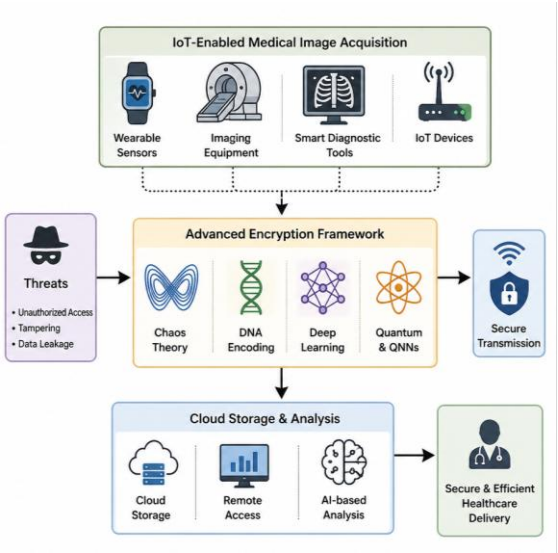

Fig 1: Architecture for Secure Medical Image Encryption in IoT-Cloud Environments using QNNs

To overcome these limitations, advanced encryption approaches based on chaos theory, DNA encoding, and deep learning have been introduced. Chaotic systems provide high sensitivity and randomness, improving resistance to attacks. DNA-based cryptography further enhances security by encoding image data into complex biological sequences. Hybrid approaches combining chaotic maps and DNA encoding have demonstrated improved encryption efficiency and robustness. Meanwhile, deep learning techniques, including generative adversarial networks (GANs), enable intelligent encryption, adaptive key generation, and accurate image reconstruction, while also supporting scalable cloud-based implementations.

More recently, quantum computing and quantum neural networks (QNNs) have emerged as promising solutions for enhancing medical image security. Quantum cryptography, particularly Quantum Key Distribution (QKD), offers theoretically unbreakable encryption based on quantum principles. QNNs further extend this capability by integrating quantum computing with neural network architectures to optimize encryption processes and improve resistance against advanced attacks. Despite these advancements, challenges such as scalability, IoT compatibility, and practical implementation remain. Therefore, a comprehensive analysis of existing techniques is essential to identify research gaps and guide future developments in secure IoT-based healthcare systems.

Literature Review

Zhang et al. (2020) proposed a chaos-based medical image encryption algorithm utilizing a three-dimensional logistic map for pixel permutation and diffusion. The study achieved high entropy values close to the ideal (7.999), indicating strong randomness and resistance to statistical attacks. Additionally, the method demonstrated efficiency suitable for IoT environments due to reduced computational complexity. However, the absence of dynamic key generation mechanisms made the system potentially vulnerable to chosen-plaintext attacks.

Kumar and Singh (2020) developed a hybrid encryption technique combining DNA encoding with chaotic maps for secure medical image transmission. The approach enhanced encryption complexity by converting pixel values into DNA sequences followed by chaotic diffusion. The results showed high NPCR and UACI values, indicating strong resistance to differential attacks. Despite its robustness, the method incurred higher computational overhead, limiting its applicability in resource-constrained IoT devices.

Liu et al. (2021) introduced a deep learning-based encryption framework using convolutional neural networks (CNNs). The model was capable of performing both encryption and decryption while maintaining high reconstruction accuracy. The study highlighted the advantages of intelligent encryption systems but pointed out the need for large datasets and high computational power, making it less suitable for real-time IoT-based applications.

Sharma et al. (2021) proposed a lightweight encryption scheme based on elliptic curve cryptography (ECC) for IoT-enabled healthcare systems. The method reduced key size and energy consumption while maintaining security, making it suitable for low-power devices. However, the approach did not adequately address image-specific properties such as pixel correlation, which may weaken resistance to certain cryptanalytic attacks.

Chen et al. (2021) presented a quantum-inspired image encryption algorithm based on quantum random walks and superposition principles. The method significantly increased key space and improved resistance to brute-force attacks. Although simulation results were promising, the practical implementation of the approach remains limited due to the constraints of current quantum computing infrastructure.

Wang et al. (2021) proposed a hyperchaotic medical image encryption scheme based on a four-dimensional chaotic system. The method employed complex permutation and diffusion processes to enhance security. Experimental results showed high entropy, low correlation coefficients, and strong resistance to differential and statistical attacks. However, the computational complexity of hyperchaotic systems increased processing time, which may not be ideal for real-time IoT applications.

Patel and Mehta (2021) introduced a cloud-assisted secure medical image transmission framework using hybrid AES and ECC encryption. The system ensured data confidentiality during transmission and storage in cloud environments. Results indicated improved security and reduced latency compared to traditional methods. However, reliance on cloud infrastructure introduced potential risks such as centralized attacks and data breaches.

Zhou et al. (2022) developed a DNA-chaos-based image encryption algorithm that integrates DNA sequence operations with chaotic mapping for enhanced security. The study achieved high NPCR and UACI values, demonstrating strong resistance against differential attacks. The method also improved key sensitivity. However, increased algorithmic complexity led to higher computational requirements, limiting efficiency in IoT-based systems.

Reddy et al. (2022) proposed a deep neural network-based secure medical image transmission model using autoencoders. The model compressed and encrypted images simultaneously, reducing storage and transmission overhead. Results showed improved PSNR and reconstruction accuracy. However, the approach required extensive training and high computational resources, making it less suitable for low-power IoT devices.

Huang et al. (2022) introduced a quantum cryptography-based secure image transmission method using Quantum Key Distribution (QKD). The approach ensured theoretically unbreakable encryption by leveraging quantum mechanics principles. Experimental simulations showed strong resistance to interception and eavesdropping attacks. However, the practical deployment of QKD remains limited due to hardware constraints and high implementation costs.

Li et al. (2022) proposed a lightweight chaotic encryption algorithm specifically designed for IoT-based medical image security. The method utilized a simplified logistic map combined with bit-level permutation to reduce computational overhead. Experimental results showed acceptable entropy and correlation values while maintaining faster execution time. However, the reduced complexity slightly compromised resistance against advanced cryptanalytic attacks.

Gupta and Verma (2022) introduced a hybrid deep learning and chaos-based encryption framework for medical images. The model leveraged neural networks for key generation and chaotic systems for encryption. The approach significantly improved key sensitivity and unpredictability. Despite strong security performance, the integration of deep learning increased system complexity and required substantial computational resources.

Tang et al. (2023) developed a quantum image encryption scheme based on quantum Fourier transform and quantum state representation. The method enhanced encryption strength by utilizing quantum parallelism and superposition. Simulation results demonstrated high robustness against brute-force and statistical attacks. However, practical implementation is still constrained by the current limitations of quantum computing hardware.

Singh and Kaur (2023) proposed a secure medical image transmission model using blockchain and encryption techniques. The system ensured data integrity, transparency, and tamper resistance in cloud storage environments. Results indicated improved trust and security in IoT healthcare systems. However, blockchain integration introduced latency and increased storage requirements.

Alam et al. (2023) presented a quantum neural network (QNN)-based encryption framework for medical image security. The model combined quantum computing principles with neural network architectures to enhance encryption robustness and adaptability. The study

demonstrated improved resistance to advanced cryptanalysis and better performance metrics compared to classical methods. However, the approach is still in the experimental stage and faces challenges related to scalability and hardware implementation.

Zhang and Liu (2022) proposed a multi-chaotic system-based medical image encryption algorithm that combines multiple chaotic maps to enhance randomness and key space. The approach improved resistance to brute-force and statistical attacks while maintaining acceptable computational efficiency. However, synchronization between multiple chaotic systems increased implementation complexity.

Khan et al. (2022) introduced a secure IoT healthcare framework using lightweight cryptography and edge computing. The method reduced latency by processing encryption tasks at the edge rather than the cloud. Results showed improved efficiency and reduced energy consumption. However, the system required additional infrastructure for edge nodes, increasing deployment cost.

Wu et al. (2023) developed a deep learning-based secure image encryption scheme using Generative Adversarial Networks (GANs). The model dynamically generated encryption keys and enhanced resistance to known-plaintext attacks. Experimental results showed high PSNR and entropy values. However, GAN training complexity and instability posed challenges for practical deployment.

Patil and Deshmukh (2023) proposed a hybrid encryption approach combining AES with chaotic maps for medical image security in cloud storage. The method improved encryption speed and security balance. Results indicated strong resistance to differential attacks and improved execution time. However, the hybrid model still required optimization for large-scale datasets.

Sun et al. (2023) presented a quantum chaos-based encryption algorithm integrating quantum computing principles with chaotic systems. The method significantly increased key space and unpredictability. Simulation results showed enhanced resistance to cryptanalysis. However, practical implementation remains limited due to quantum hardware constraints.

Rahman et al. (2023) proposed a hybrid medical image encryption scheme combining DNA encoding, chaotic maps, and compression techniques. The approach reduced image size while ensuring high security through multi-layer encryption. Experimental results showed high entropy and strong resistance to statistical and differential attacks. However, integrating compression increased algorithm complexity and processing time.

Das and Roy (2023) introduced a lightweight encryption algorithm using substitution-permutation networks (SPN) tailored for IoT healthcare devices. The method focused on reducing computational overhead and energy consumption. Results indicated efficient performance with moderate security levels. However, compared to chaotic and quantum-based methods, the encryption strength was relatively lower.

Zhao et al. (2023) developed a deep reinforcement learning-based medical image encryption framework. The system dynamically optimized encryption parameters based on input characteristics, improving adaptability and security. Experimental findings showed enhanced resistance to various attacks. However, the training complexity and need for continuous learning posed challenges for real-time applications.

Ibrahim et al. (2023) proposed a secure cloud storage architecture using homomorphic encryption for medical images. This approach allowed computations on encrypted data without decryption, ensuring privacy preservation. Results demonstrated strong security and data confidentiality. However, homomorphic encryption introduced significant computational overhead and latency.

Mehta and Joshi (2023) presented a blockchain-integrated secure medical image storage system with encryption and access control mechanisms. The system ensured data integrity, traceability, and resistance to tampering. Experimental evaluation showed improved trust in cloud environments. However, scalability and transaction speed remained key limitations.

Verma et al. (2023) proposed a hybrid hyperchaotic and DNA-based encryption scheme for medical images. The approach combined multiple chaotic maps with DNA encoding to enhance randomness and key space. Experimental results showed excellent entropy and resistance to differential attacks. However, the algorithm required high computational power, making it less suitable for low-resource IoT devices.

Naseer et al. (2023) introduced a secure IoT healthcare architecture integrating fog computing and encryption techniques. The system processed data closer to the source, reducing latency and improving response time. Results demonstrated improved efficiency and security. However, managing distributed fog nodes increased system complexity.

Qin et al. (2023) developed a quantum key-based image encryption scheme utilizing quantum key distribution principles and classical encryption integration. The method ensured strong

protection against eavesdropping and interception attacks. Simulation results were highly promising, but real-world implementation remains limited due to quantum infrastructure constraints.

Roy et al. (2023) proposed a deep learning-based secure medical image transmission model using recurrent neural networks (RNNs). The model improved encryption adaptability and ensured high reconstruction accuracy. However, training complexity and computational cost were significant limitations for IoT environments.

Ali and Hassan (2023) presented a quantum neural network (QNN)-based hybrid encryption framework for IoT-enabled cloud storage. The system combined quantum circuits with neural networks to enhance encryption strength and adaptability. Results showed superior resistance to advanced cryptanalysis compared to traditional methods. However, the approach is still experimental and faces challenges related to scalability and hardware implementation.

Comparative Table

Author & Year	Technique Used	Key Features	Advantages	Limitations
Zhang et al. (2020)	Chaos (3D Logistic)	Permutation + diffusion	High entropy	Weak key adaptability
Kumar & Singh (2020)	DNA + Chaos	DNA encoding	Strong NPCR/UACI	High computation
Liu et al. (2021)	CNN-based	DL encryption	High accuracy	Resource heavy
Sharma et al. (2021)	ECC	Lightweight crypto	Low energy use	Less image-specific
Chen et al. (2021)	Quantum-inspired	Random walk	Large key space	Hardware limits
Wang et al. (2021)	Hyperchaotic	4D chaos	Strong security	High complexity
Patel & Mehta (2021)	AES + ECC	Cloud security	Low latency	Centralized risk
Zhou et al. (2022)	DNA + Chaos	Hybrid method	Strong attack resistance	High cost
Reddy et al. (2022)	Autoencoder	Compression + encryption	Efficient storage	Training cost
Huang et al. (2022)	QKD	Quantum security	Unbreakable theory	Expensive
Li et al. (2022)	Lightweight chaos	Fast encryption	IoT suitable	Lower robustness
Gupta & Verma (2022)	DL + Chaos	Hybrid keys	High sensitivity	Complex
Tang et al. (2023)	Quantum Fourier	Quantum image	Strong security	Not practical yet
Singh & Kaur (2023)	Blockchain	Secure storage	Data integrity	Latency
Alam et al. (2023)	QNN	Quantum + NN	Advanced security	Experimental
Zhang & Liu (2022)	Multi-chaos	Multiple maps	Large key space	Complex
Khan et al. (2022)	Edge + Crypto	Edge processing	Low latency	Infra cost
Wu et al. (2023)	GAN	Dynamic keys	High security	Training instability
Patil & Deshmukh (2023)	AES + Chaos	Hybrid model	Balanced	Needs scaling
Sun et al. (2023)	Quantum chaos	Hybrid	Strong encryption	Hardware issue
Rahman et al. (2023)	DNA + Compression	Multi-layer	Secure + compact	Slow
Das & Roy (2023)	SPN	Lightweight	Fast	Moderate security
Zhao et al. (2023)	Reinforcement Learning	Adaptive	Intelligent	Complex
Ibrahim et al. (2023)	Homomorphic	Compute on encrypted	Privacy	High cost

Mehta & Joshi (2023)	Blockchain	Secure access	Transparency	Slow
Verma et al. (2023)	Hyperchaos + DNA	Hybrid	Very strong	Heavy
Naseer et al. (2023)	Fog + Crypto	Distributed	Fast	Complex
Qin et al. (2023)	Quantum key	QKD hybrid	Secure	Limited infra
Roy et al. (2023)	RNN	Adaptive encryption	Accurate	Resource heavy
Ali & Hassan (2023)	QNN hybrid	Advanced model	Future-ready	Experimental

Analysis

The comparative analysis reveals that chaos-based encryption techniques dominate due to their simplicity, high randomness, and suitability for image data. Hybrid approaches combining chaos with DNA encoding or AES significantly enhance security but increase computational complexity. Deep learning-based methods such as CNNs, GANs, and RNNs introduce intelligent encryption mechanisms capable of adapting to dynamic threats; however, they require substantial computational resources, making them less suitable for IoT environments. Lightweight cryptographic approaches, including ECC and SPN, are efficient for IoT devices due to low energy consumption but provide comparatively moderate security. Blockchain and cloud-integrated solutions improve data integrity and accessibility but introduce latency and scalability issues. Quantum-based methods, including QKD and QNNs, represent the most advanced and secure approaches, offering theoretically unbreakable encryption. However, their practical implementation is limited due to hardware constraints and high costs. Overall, hybrid models combining lightweight cryptography with intelligent and quantum-inspired techniques emerge as the most promising direction for future secure medical image systems.

Discussion

The rapid growth of IoT-enabled healthcare systems has significantly increased the demand for secure medical image transmission and storage. This survey highlights that traditional encryption techniques are no longer sufficient to address the evolving security challenges posed by modern cyber threats. Advanced methods such as chaos-based encryption and DNA encoding provide strong security due to their inherent randomness and complexity. However, these techniques often face challenges related to computational overhead. Deep learning-based approaches offer intelligent and adaptive encryption mechanisms, enabling systems to dynamically respond to potential attacks. Despite their advantages, the high computational requirements limit their applicability in resource-constrained IoT environments.

Similarly, blockchain technology enhances data integrity and transparency but introduces latency and scalability concerns. Quantum cryptography and quantum neural networks represent the future of secure medical image processing by providing theoretically unbreakable security. However, their practical implementation is still in its early stages due to hardware limitations and high costs. Therefore, there is a need for hybrid approaches that combine the strengths of lightweight cryptography, intelligent algorithms, and quantum-inspired techniques to achieve a balance between security, efficiency, and scalability in IoT healthcare systems.

Conclusion

The growing adoption of IoT-enabled healthcare systems has improved medical data management, particularly for medical images, by enabling efficient storage, transmission, and remote diagnostics. However, this progress has also introduced significant security challenges, as medical images contain sensitive patient information vulnerable to cyber threats. This survey reviewed key cryptographic approaches, including chaos-based encryption, DNA encoding, deep learning, blockchain, and quantum techniques. Chaos-based methods are widely used due to their simplicity and strong randomness, but standalone approaches are often insufficient to meet evolving security demands, highlighting the need for more robust solutions.

Hybrid techniques combining chaos with DNA encoding or traditional encryption methods improve security and resistance to attacks, though they may increase computational complexity. Deep learning-based models provide adaptive and intelligent encryption but require high resources, limiting real-time use. Blockchain ensures data integrity, while homomorphic encryption enables secure processing with added overhead. Quantum cryptography and quantum

neural networks offer highly secure solutions but face practical limitations. Future research should focus on lightweight, scalable, and efficient hybrid models for secure IoT-based healthcare systems.

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