Secure Odyssey: Advancing the Frontiers of Data Security in Smart Healthcare

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Abstract

Smart healthcare, driven by the Internet of Medical Things (IoMT), is transforming contemporary medical practice by enabling continuous monitoring, intelligent diagnostics, and data driven clinical decision making. This paradigm shift has led to an unprecedented explosion of healthcare data, with medical images constituting a dominant and diagnostically critical component. The pervasive generation, transmission, and storage of such sensitive visual data across distributed healthcare infrastructures introduce concomitant security and privacy risks, typically including (a) unauthorized access, disclosure or modification; (b) substitution; and (c) forgery; thereby undermining trust in clinical outcomes. Consequently, ensuring comprehensive medical image security across the data lifecycle has therefore emerged as a foundational requirement for trustworthy and resilient smart healthcare ecosystems.

To address these risks, medical image security has traditionally relied on encryption techniques for confidentiality and watermarking techniques for integrity and authenticity. However, existing encryption techniques are often constrained by suboptimal key scheduling, weak permutation-diffusion architectures, and vulnerability to cryptanalytic attacks, while watermarking approaches suffer from insufficient robustness, elevated computational cost, authentication ambiguity, inadequate diagnostic utility assurance, and limited practical suitability for IoMT enabled healthcare. Motivated by these limitations, this thesis investigates principled security mechanisms for medical images, structured around two complementary objectives: achieving data confidentiality during transmission and storage, and addressing data integrity and authenticity during medical data utilization.

From a data confidentiality perspective, the thesis proposes a series of novel image encryption frameworks grounded in key scheduling mechanisms and permutation-diffusion architectures. These contributions include robust key scheduling strategies through the design of mathematically enhanced chaotic maps, structured permutation and diffusion mechanisms tailored to the statistical characteristics of medical images. The first contribution presents a lightweight synchronized chaos driven encryption framework that combines structured spiral scrambling with efficient diffusion to achieve effective security performance. The second introduces a hybrid encryption approach that integrates learned latent representations with fractal curve obfuscation and coupled chaos guided diffusion, providing robust confidentiality assurance. The third contribution introduces a novel nonlinear chaotic map and employs it within a encryption scheme harnessing a dual stage shuffling and feedback driven diffusion pipeline to enhance key sensitivity, propagate local changes globally, and to substantially improve attack resistance.

On the integrity and authenticity front, the thesis develops a robust watermarking framework that binds patient identity and biometric information to diagnostic

images. The framework employs adaptive embedding via singular value decomposition and quantization to ensure imperceptible yet resilient embedding, along with randomization enhanced secure data handling. Importantly, the framework is integrated with a clinically relevant kidney stone segmentation framework, ensuring that only verified medical images are admitted for automated analysis, thereby reinforcing trustworthy diagnostics.

Collectively, the contributions of this thesis realize reliable and secure handling of medical images in smart healthcare environments. The proposed frameworks guarantee core security aspects such as confidentiality, integrity, and authenticity across practical transmission, storage, and usage scenarios, while preserving diagnostic utility and computational efficiency. Extensive experimental evaluations demonstrate strong resistance to diverse attacks, confirming their suitability for medical image security. The thesis finally culminates by discussing potential future research directions.

Publications (forming part of this thesis)

1. **Parkala Vishnu Bharadwaj Bayari**, Nishtha Tomar, Gaurav Bhatnagar, and Chiranjoy Chattopadhyay. Watermarking Protocol Inspired Kidney Stone Segmentation in IoMT. *IEEE Journal of Biomedical and Health Informatics*, vol. 30, no. 2, pp. 828-838, 2026.

2. **Parkala Vishnu Bharadwaj Bayari**, Gaurav Bhatnagar, and Chiranjoy Chattopadhyay. SecureNet: A deep learning inspired security framework for healthcare data. *Computers and Electrical Engineering*, 128:110723, 2025.

3. **Parkala Vishnu Bharadwaj Bayari**, Yashmita Sangwan, Gaurav Bhatnagar, and Chiranjoy Chattopadhyay. A Novel Chaotic Map and Its Application to Secure Transmission of Multimodal Images. *IEEE Transactions on Computational Social Systems*, vol. 12, no. 5, pp. 3765-3777, 2025.

4. **Parkala Vishnu Bharadwaj Bayari**, Apoorva Lakshman, Gaurav Bhatnagar and Chiranjoy Chattopadhyay. A Novel Security Framework for Medical Data in IoT Ecosystems. *IEEE MultiMedia*, vol. 29, no. 2, pp. 34-44, 2022.

5. **Parkala Vishnu Bharadwaj Bayari**, Gaurav Bhatnagar, and Chiranjoy Chattopadhyay. A comprehensive study on the security of medical information using encryption. *Medical Information Processing and Security: Techniques and applications*, IET, pp. 229-260, 2022.

Publications (not part of this thesis)

6. Nishtha Tomar, **Parkala Vishnu Bharadwaj Bayari**, and Gaurav Bhatnagar. SBTD: Secured Brain Tumor Detection in IoMT Enabled Smart Healthcare. *IEEE Journal of Biomedical and Health Informatics*, vol. 30, no. 1, pp. 39-50, 2026.

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8. Apoorva Lakshman, **Parkala Vishnu Bharadwaj Bayari**, and Gaurav Bhatnagar. A Novel Logo-Inspired Chaotic Random Number Generator. *Proceedings of the Academia-Industry Consortium for Data Science*. Springer Nature Singapore, pp. 297–306, 2022.

9. Harimohan Sharma, **Parkala Vishnu Bharadwaj Bayari**, Munnu Sonkar, and Gaurav Bhatnagar. A Chaotic Image Encryption Algorithm for Industrial IoT Environments. (Submitted)

10. Yashmita Sangwan, **Parkala Vishnu Bharadwaj Bayari**, Gaurav Bhatnagar, and Vishakha Pareek. SecQR: A Visual Secret Sharing Scheme for QR Codes. (Under Preparation)