Modern Journal of Health and Applied Sciences *(MJHAS)*

E-ISSN 3078-2791; P-ISSN 3078-2783

Journal homepage: https://mucjournals.muc.edu.ps

MRI Images Colorization and Encryption Using 2RGB and Chaotic Maps

Kawther H. Al-khafaji [1], Hanan A. Al-Haidari [2], and Zahraa Mohammed Mashkoor [3]*

[1] Kufa University, Faculty of Education for Girls, Kufa, Iraq.
[2] Islamic University of Najaf, College of Medical Technology, Department of Radiology.
[3] Al-Furat Al-Awsat Technical University, Najaf, Iraq.

ARTICLE INFO

Received:16th May 2025
Received in revised form: 09th August 2025
Accepted: 14th August 2025
Published: 15th March 2026

***Corresponding Author:**
Hanan A. Al-Haidari
E-mail :
hananahmed97@iunajaf.edu.iq

Citation : Al-khafaji , K. H, Al-Haidari, H. A, & Mashkoor, Z. M. (2026). MRI Images Colourisation and Encryption Using 2RGB and Chaotic Maps. *Modern Journal of Health and Applied Sciences*, 3(1), 18-28.

DOI: https://doi.org/10.70411/MJHAS.3.1.2026247

ABSTRACT

This research focuses on the encryption and decryption of MRI images, comparing greyscale and colorized versions to evaluate both security and visual quality. The study uses MATLAB for implementation and analyses encryption performance through metrics such as NPCR (Number of Pixels Change Rate), UACI (Unified Average Changing Intensity), PSNR (Peak Signal-to-Noise Ratio), and SNR (Signal-to-Noise Ratio).

Key findings include: high encryption effectiveness, with NPCR values near 0.97 indicating that almost all pixels were altered; uniform histogram distribution in encrypted images, ensuring security by removing identifiable patterns; low pixel correlation in encrypted images, demonstrating strong resistance to statistical attacks; successful decryption, with restored images closely matching the originals (high PSNR values); and the finding that colorization does not weaken encryption, maintaining security while improving visual interpretability.

The study confirms that the proposed encryption method is secure, efficient, and suitable for medical imaging, ensuring both data protection and recoverability.

Keywords: MRI images, Medical image, Color medical image, Encryption, Chaotic encryption algorithm, 2RGB.

1. Introduction

Magnetic Resonance Imaging (MRI) is a critical tool in modern medical diagnostics because it produces detailed images of internal body structures without ionizing radiation. However, with the growing use of digital transmission and storage, protecting the privacy and integrity of MRI images has become a major concern. Image encryption converts the image into an unreadable format, preventing unauthorized access. Furthermore, the colorization of greyscale MRI images has emerged as a promising technique to enhance visualization and interpretation, especially for training and educational purposes. Combining encryption and colorization techniques offers a dual advantage: securing sensitive medical data and improving the visual clarity of diagnostic images. This research explores recent methods and algorithms in MRI image encryption and colorization, highlighting their importance in secure medical imaging systems (Ahmed et al., 2023).

2. Background and Literature Review

Magnetic Resonance Imaging (MRI) provides high-resolution images that are essential for medical diagnosis. However, as these images are often transmitted over networks or stored in cloud systems, securing them against unauthorized access is critical. Image encryption is a key technique for ensuring the confidentiality and integrity of sensitive data. Several encryption methods have been developed specifically for medical images, including chaotic-based encryption, block-based scrambling, and hybrid cryptographic algorithms (Pankaj & Dua, 2024).

Chaotic systems, in particular, are well suited to image encryption due to their sensitivity to initial conditions and their random-like behaviour. For example, the use of logistic maps, Lorenz attractors, and Arnold transformations has shown promising results in securing medical images with minimal computational overhead. Furthermore, encryption schemes that combine compression and encryption have been proposed to enhance efficiency without compromising security (Odeh & Al-Haija, 2023).

On the other hand, MRI images are typically greyscale, which may limit their visual interpretation, especially for educational or illustrative purposes. colorization aims to enhance the visual perception of greyscale MRI images by assigning color values based on texture, intensity, or learnt patterns. Recently, deep learning models such as convolutional neural networks (CNNs) and generative adversarial networks (GANs) have been widely adopted for medical image colorization, achieving realistic and clinically useful results.

Integrating encryption and colorization remains challenging because the processes are mutually exclusive: encryption aims to obscure visual information, while colorization seeks to enhance it. Therefore, research continues to focus on optimizing the sequence and compatibility of these two operations to develop robust and secure medical imaging systems (Pavithra & Jeyamala, 2018).

3. Methods and Techniques

3. 1. Chaotic Encryption and Decryption for MRI Images

Chaotic encryption is a lightweight and efficient method for securing medical images such as MRI scans. Unlike traditional encryption algorithms, chaotic systems rely on nonlinear dynamic equations that produce pseudo-random behaviour, making them highly sensitive to initial conditions and control parameters. This sensitivity ensures that even a small change in the key or input image will result in a completely different encrypted output, enhancing security (Seeli & Thanammal, 2025).

One of the commonly used chaotic maps is the Logistic Map, defined by the equation:

$$X_{(n+1)} = r \cdot X_n \cdot (1-X_n) \quad \text{Eq.01}$$

where $0 < X(n) < 1$ and $3.57 < r \leq 4$. This map can generate a chaotic sequence used for pixel permutation and value substitution in the image. The encryption process typically involves the following steps (Mohanty, 2015).

- **Key Generation:** A chaotic sequence is generated using a chosen map and initial parameters.
- **Pixel Scrambling:** The image pixels are rearranged based on the chaotic sequence to break spatial relationships.
- **Pixel Modification:** The pixel values are altered using XOR or other operations involving the chaotic sequence.

3. 2. Chaotic Encryption Offers Several Advantages for Medical Imaging

- High sensitivity to keys (enhancing security).
- Fast execution and low computational load.
- Effective for greyscale and color images.

Due to its efficiency and strong security properties, chaotic encryption is particularly suitable for protecting MRI images during storage and transmission.

3. 3. Grey 2RGB Colorization Method

Medical images are typically acquired and displayed in greyscale, which represents the intensity of tissues. However, greyscale visualization may limit the ability to distinguish anatomical structures, especially for non-expert viewers. In the context of MRI images, color mapping (or false coloring) means taking the original greyscale image and assigning different colors to intensity levels (signal) rather than displaying it solely in shades of grey.

The 2RGB colorization method aims to enhance the visual perception of MRI images by converting the single-channel greyscale data into a three-channel RGB representation. Although it is possible to display the images in black and white, doing so will result in the loss of most of the diagnostic details, so doctors only use it for very specific purposes, such as computational image processing (Kaur et al., 2021; Pareek et al., 2006; Sokouti et al., 2016).

The core idea of 2RGB is to map the greyscale intensity values to red, green, and blue channels using a defined transformation function or lookup table. For example, lower intensity values may be mapped to cooler colors (e.g., blue), while higher intensities may shift toward warmer tones (e.g., red). This technique does not change the actual medical content of the image but improves contrast and interpretability for both educational and diagnostic support (Geetha et al., 2018; Kamal et al., 2021).

2RGB is considered a lightweight and efficient alternative to deep learning-based colorization, which requires large datasets and training. It is especially useful in contexts where real-time performance and simplicity are essential. Additionally, color-enhanced MRI images can help in visual analytics and pattern recognition, particularly in brain imaging (Gonzalez, 2009).

To convert a greyscale MRI image into a color image using the 2RGB method, each pixel's intensity value is first normalized to the range [0, 1]. The RGB values are then computed using the following equations (Al-Khafaji & Sahib, 2024).

$$\begin{cases} R = I * 255 \\ G = (1 - I) * 255 \\ B = |0.5 - I| * 510 \end{cases} \quad \text{Eq.02}$$

Where:

- R, G, B are the red, green, and blue components of the resulting color pixel.
- I is the normalized greyscale intensity of the original pixel.
- |0.5-I |* 510 centers the blue channel around mid-intensity values.

The red channel increases linearly with intensity, highlighting brighter regions. The green channel decreases with intensity, emphasizing darker areas. The blue channel peaks at medium intensity values, adding visual contrast in intermediate tones (Al-Haidari & Al-khafaji, 2024).

This mapping enhances visual perception by spreading greyscale intensity across color channels, thereby improving differentiation between anatomical features without altering diagnostic content. It is computationally light, does not require training data, and is well-suited for real-time visualization in medical applications (Albermani et al., 2022, 2023).

Chaotic Image Encryption with Lorenz Map + 2RGB Coloring :

- **Step 1 – Input and Setup:** Load the input greyscale image of fixed size 484 × 484 pixels and determine the total number of pixels.
- **Step 2 – Generate Chaotic Key Stream.**
- **Step 3 – Image Encryption:** Apply bitwise XOR between the greyscale image pixels and the chaotic key matrix. The result is the encrypted greyscale image.
- **Step 4 – 2RGB Coloring:** Create three color channels from the encrypted greyscale image:

  R channel: Encrypted greyscale image directly.
  G channel: Encrypted image shifted by 1 row (vertical shift).
  B channel: Pixel-wise inversion.

Merge the three channels into one RGB image and save the encrypted colored image.

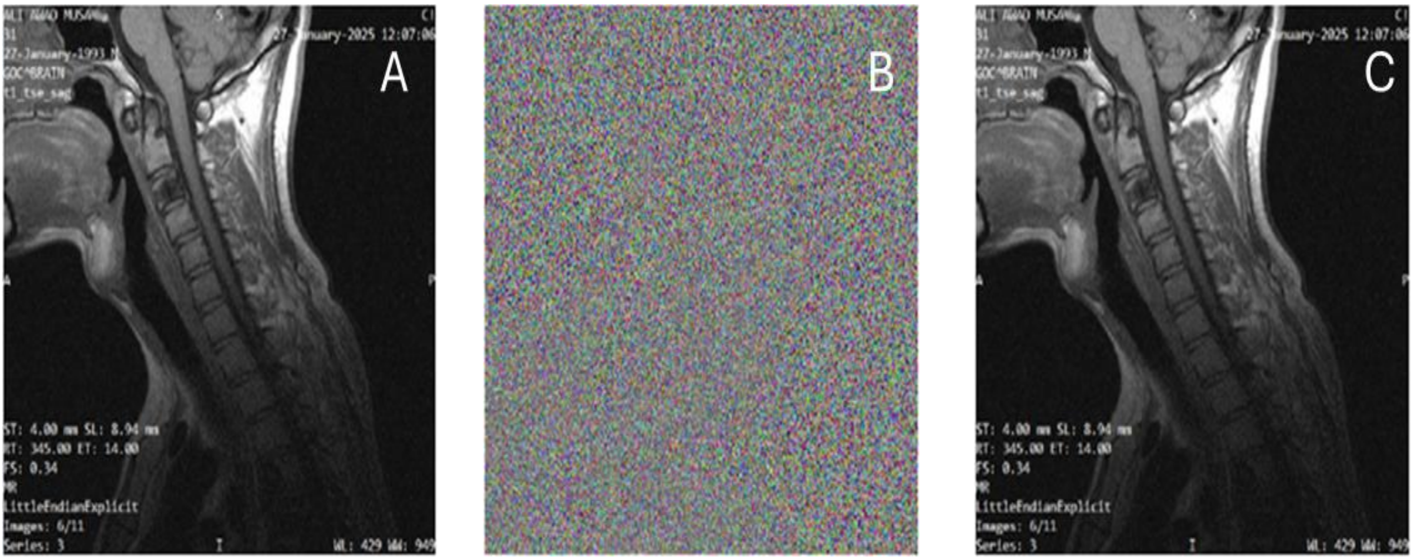
- **Step 5 – Decryption:** Load the encrypted RGB image, extract the R channel (which contains the encrypted greyscale), regenerate the same chaotic keystream using the exact same initial conditions and parameters, and then apply bitwise XOR between the R channel and the key matrix to recover the original greyscale image.

4. Implementation

The proposed implementation is designed to evaluate the impact of image colorization on the security and quality of encrypted MRI images. Two parallel workflows were conducted:

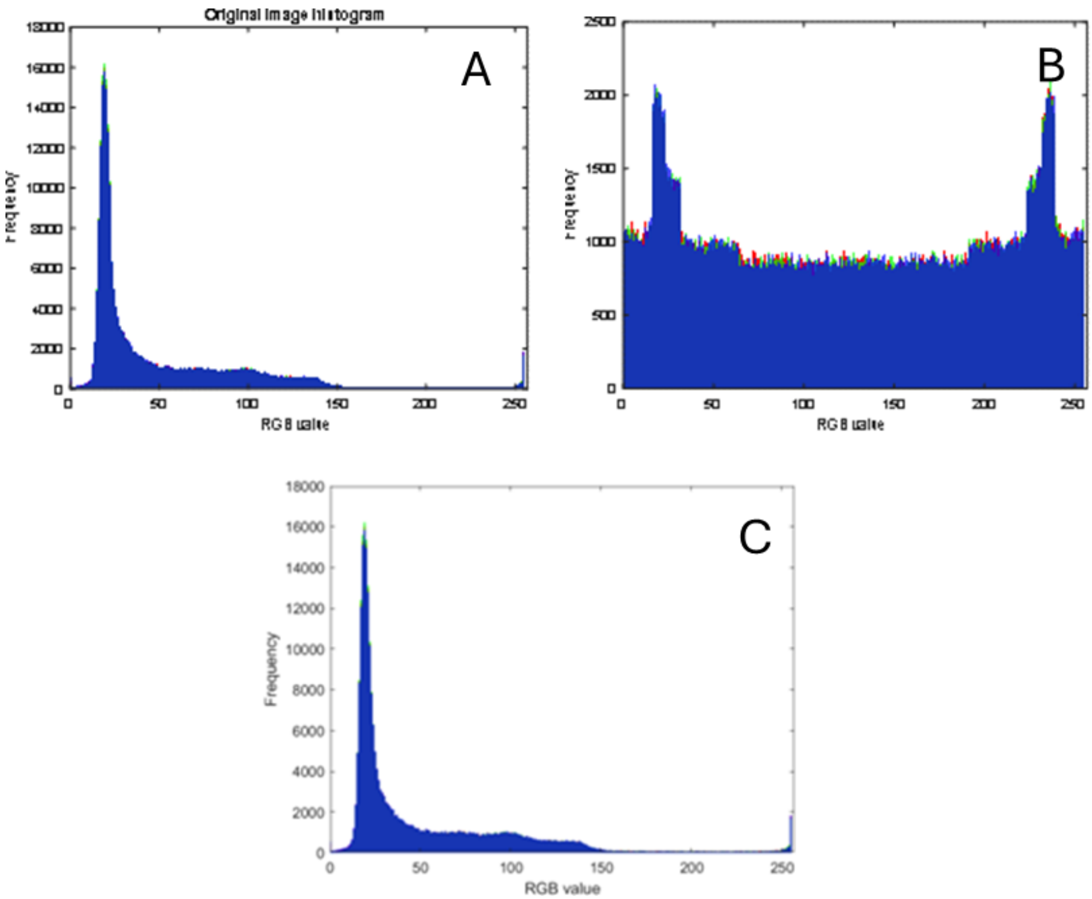
4. 1. Encryption Before Colorization

The greyscale MRI image was first encrypted using a chaotic logistic map-based algorithm. The image matrix was scrambled and diffused using chaotic sequences generated with a secret key.



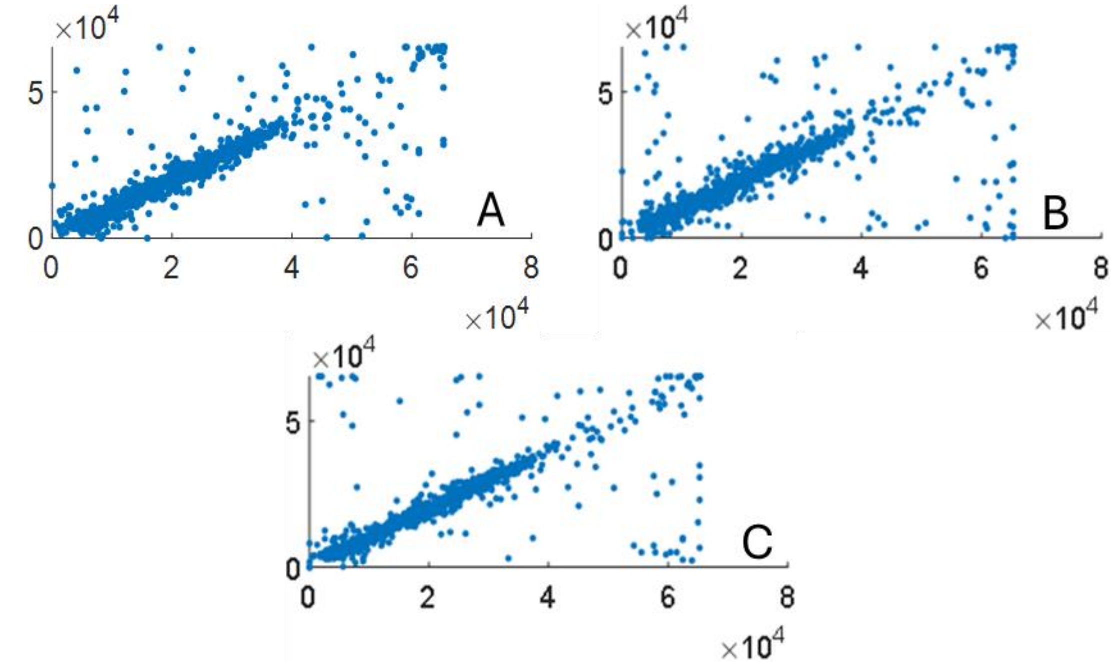
A. Organize MRI gray image B. Encryption MRI gray image C.Decryption MRI gray image

Figure 1. Encryption and Decryption MRI image before colorization



A. Organize the MRI image Histogram B. Encryption MRI image Histogram C. Decryption MRI image Histogram

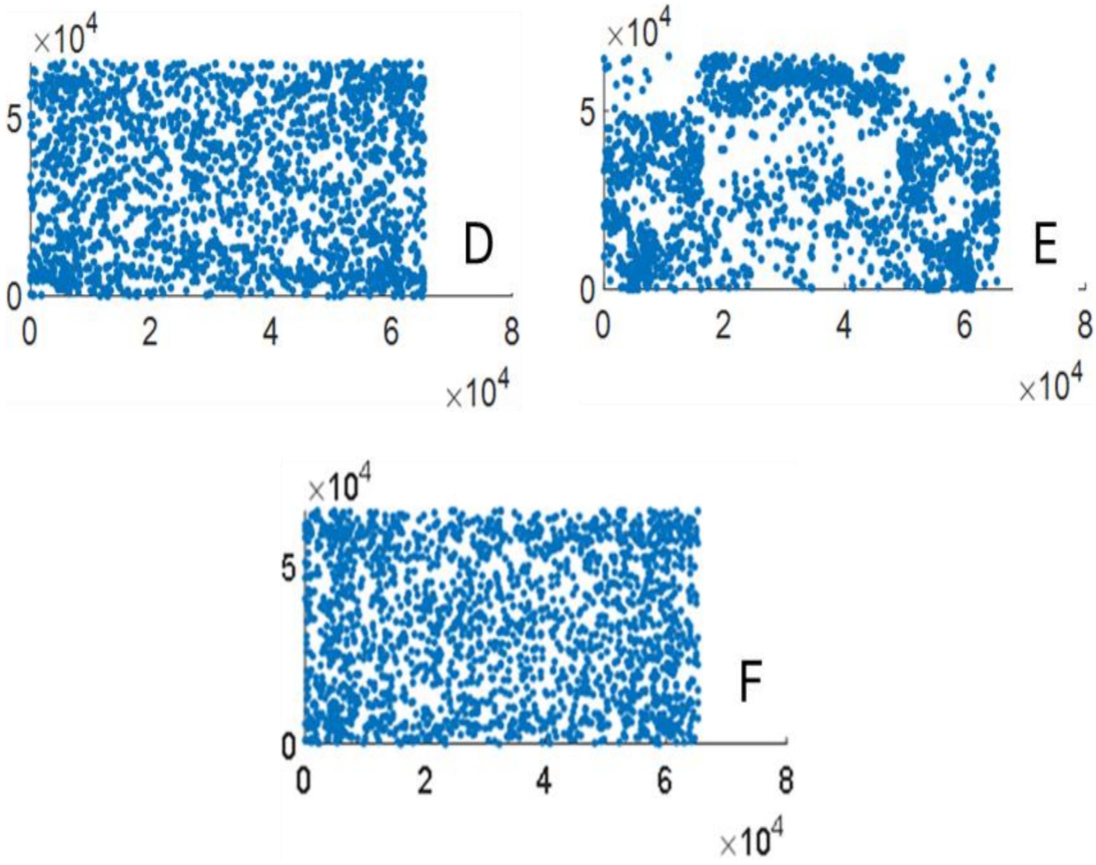
Figure 2. Encryption and Decryption MRI gray image Histogram before colorization



A. Correlation plot of two adjacent MRI Original image pixels in horizontal

B. Correlation plot of two adjacent MRI Original image pixels in Vertical

C. Correlation plot of two adjacent MRI Original image pixels in Diagonal



D. Correlation plot of two adjacent MRI encryption image pixels in horizontal

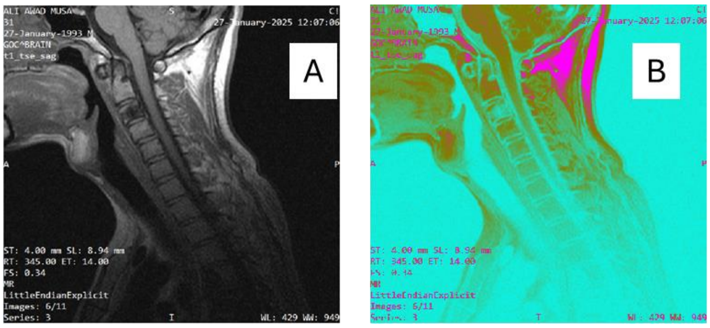
E. Correlation plot of two adjacent MRI encryption image pixels in Vertical

F. Correlation plot of two adjacent MRI encryption image pixels in Diagonal

Figure 3. Correlation plot of two adjacent MRI gray image pixels

Table 1. Show Some IQM Value in MRI Medical gray Image

IQM	The Value	IQM	The Value	IQM	The Value
UACI	0.362084	**MSNR1**	6.595512	**RMSE1**	6.173283
NPCR	0.971507	**MSNR2**	1.406830	**RMSE2**	13.154646
SNR1	38.736137	**WSNR1**	11.342383	**LMSE1**	44.334986
SNR2	38.736137	**WSNR2**	4.530051	**LMSE2**	1.023487
PSNR1	99.000000	**MSE1**	38.109421	**NMSE**	0.000000
PSNR2	32.320480	**MSE2**	0.000000	**NAE1**	0.170310

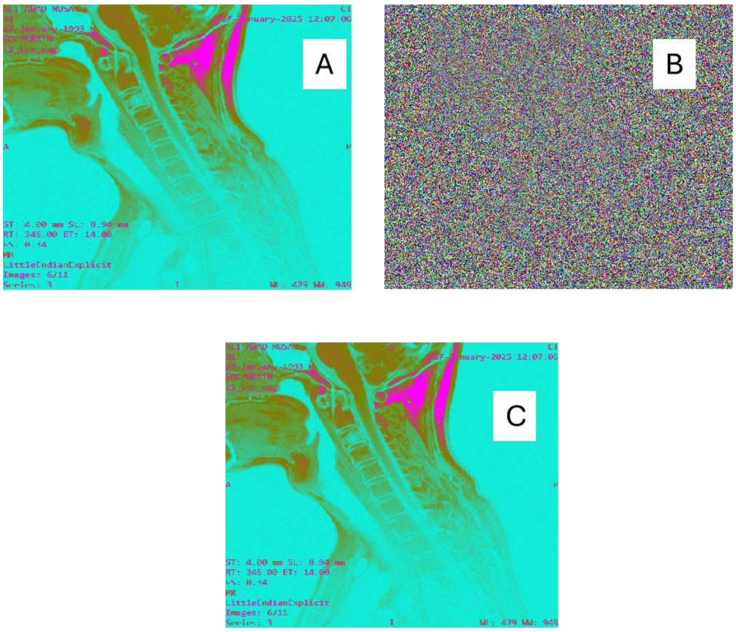


A. Organize MRI gray image B. Color MRI image

Figure 4. Gray 2RGB Colorization

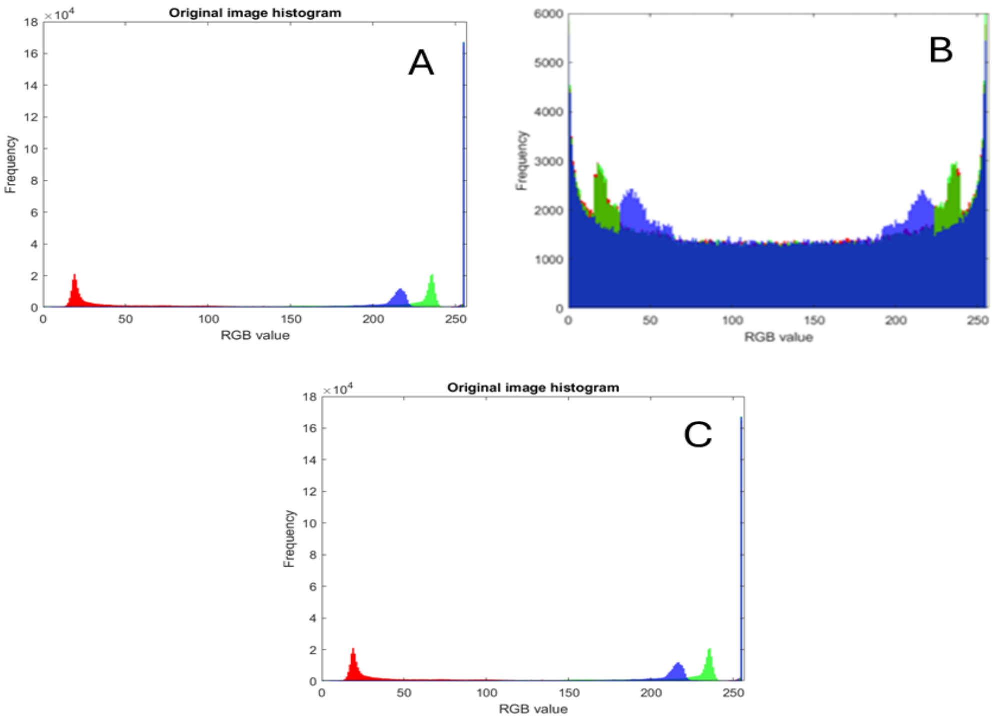
4.2. Encryption MRI image Colorization

In the second workflow, the original greyscale MRI image was first converted to a three-channel RGB image using the 2RGB method. Each color channel was then encrypted individually using the same chaotic encryption method.



A. Organize MRI Color image B. Encryption MRI Color image C. Decryption MRI Color image

Figure 5. Encryption and Decryption MRI image after colorization

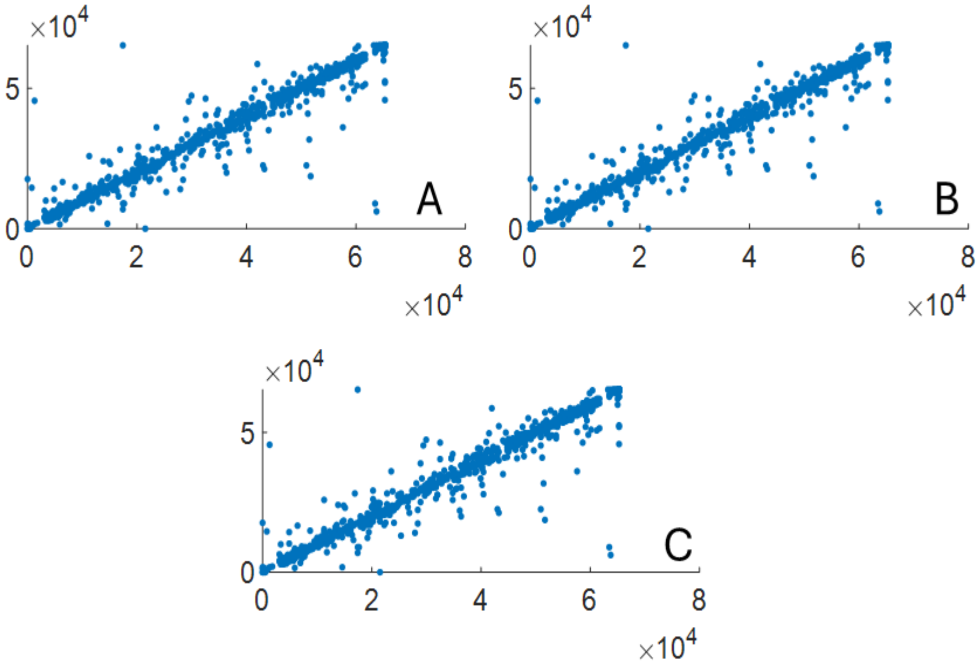


A. Organize MRI image Histogram

B. Encryption MRI image Histogram

C. Decryption MRI image Histogram

Figure 6. Encryption and Decryption MRI color image Histogram after colorization

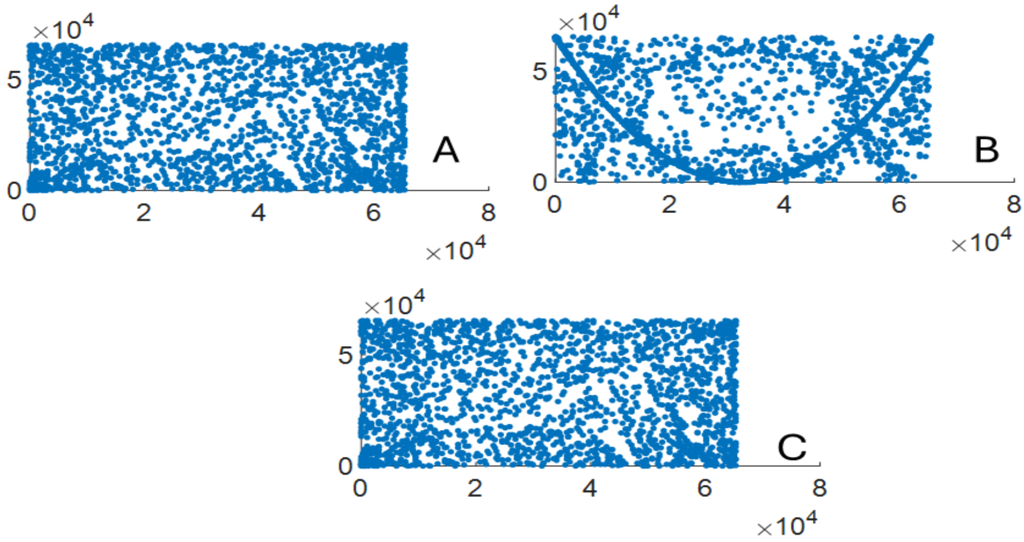


A. Correlation plot of two adjacent MRI Original color image pixels in horizontal

B. Correlation plot of two adjacent MRI Original color image pixels in Vertical

C. Correlation plot of two adjacent MRI Original color image pixels in Diagonal

Figure 7. Correlation plot of two adjacent MRI original color image pixels



A. Correlation plot of two adjacent MRI encrypted color image pixels in horizontal

B. Correlation plot of two adjacent MRI encrypted color image pixels in Vertical

C. Correlation plot of two adjacent MRI encrypted color image pixels in Diagonal

Figure 8. Correlation plot of two adjacent MRI encrypted color image pixels

Table 2. Show Some IQM Value in MRI Medical color Image

IQM	The Value	IQM	The Value	IQM	The Value
UACI	0.406147	**MSNR1**	2.299877	**RMSE1**	10.499305
NPCR	0.971936	**MSNR2**	2.239793	**RMSE2**	10.254181
SNR1	37.976404	**WSNR1**	6.478356	**LMSE1**	253.635786
SNR2	37.976404	**WSNR2**	6.942806	**LMSE2**	1.004126
PSNR1	99.000000	**MSE1**	110.235405	**NMSE**	0.000000
PSNR2	27.707593	**MSE2**	0.000000	**NAE1**	0.414586

The implementation was carried out in MATLAB. The visual quality and encryption performance of both methods were compared using metrics such as Histogram analysis, PSNR (Peak Signal-to-Noise Ratio), and NPCR (Number of Pixels Change Rate). This comparison aims to determine whether colorization affects encryption strength and to assess the visual interpretability of the final encrypted output.

In both workflows, a decryption process was also implemented to evaluate the recoverability of the original image after encryption. In the first method (encryption before colorization), the encrypted greyscale image was decrypted using the inverse operations of the chaotic map, followed by the 2RGB colorization. In the second method (encryption after colorization), each RGB channel was decrypted separately, and the full-color image was reconstructed.

5. Conclusion

The most important results reached by the researcher are as follows:

1. Image Encryption and Decryption Process:

The images demonstrate a clear workflow for encrypting and decrypting MRI images, both in greyscale and colorized forms. The encryption process effectively alters the images' appearance, making them unrecognizable, while the decryption process restores them to their original state. This indicates the robustness of the encryption algorithm used.

2. Histogram Analysis:

The histograms of the original, encrypted, and decrypted images reveal significant differences. The encrypted images exhibit uniformly distributed histograms, which is a desirable trait for secure encryption as it indicates the removal of any identifiable patterns. The decrypted histograms closely match the original ones, confirming the accuracy of the decryption process.

3. Correlation Plots:

The correlation plots of adjacent pixels in the original images (horizontal, vertical, and diagonal) show high correlation, whereas the encrypted images display significantly reduced correlation. This demonstrates the encryption algorithm's ability to break the spatial relationships between pixels, thereby enhancing security.

4. Quality Metrics (IQM Values):

The Image Quality Metrics (IQM) table includes values such as NPCR (0.97), UACI (0.40), and PSNR (99), indicating high encryption efficiency. The high NPCR value suggests that nearly all pixels were changed during encryption, while the PSNR value reflects the quality of the decrypted image compared to the original.

5. Impact of Colorization:

The comparison between greyscale and colorized MRI images shows that colorization does not negatively affect the encryption strength. The encryption and decryption processes remain effective, and the visual interpretability of the decrypted images is preserved.

6. Implementation and Evaluation:

The use of MATLAB for implementation, along with metrics such as PSNR and NPCR for evaluation, highlights a systematic approach to assessing encryption performance. The results confirm that the method is suitable for medical image encryption, ensuring both security and recoverability.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data Availability

No data was used for the research described in the article.

References

Ahmed, S. T., Hammood, D. A., Chisab, R. F., Al-Naji, A., & Chahl, J. (2023). Medical image encryption: a comprehensive review. Computers, 12(8), 160.

Al-Haidari, H. A., & Al-khafaji, K. H. (2024). Studying the Effect of the Primary Coefficients (X, U) of the Logistic Chaotic Encryption Algorithm Equation on the Performance of X-Ray Medical Image Encryption. Sebha University Conference Proceedings,

Al-Khafaji, K. H., & Sahib, H. A. (2024). Designing a Digital System for Enhancing, Coloring, Encryption and Decryption of X-ray Medical Image. 2024 15th International Conference on Information and Communication Systems (ICICS),

Albermani, M. J., Al-Hilo, E. M., & Al-khafaji, K. H. (2022). Color Image Encryption and Decryption by Using Optical Scanning Cryptography Method. International Conference on Emerging Technologies and Intelligent Systems,

Albermani, M. J., Al-Hilo, E. M., & Al-Khafaji, K. H. (2023). Comparative between encryption and decryption of (binary, gray& color) images using optical scanning cryptography. AIP Conference Proceedings,

Geetha, S., Punithavathi, P., Infanteena, A. M., & Sindhu, S. S. S. (2018). A literature review on image encryption techniques. International Journal of Information Security and Privacy (IJISP), 12(3), 42-83.

Gonzalez, R. C. (2009). Digital image processing. Pearson education india.

Kamal, S. T., Hosny, K. M., Elgindy, T. M., Darwish, M. M., & Fouda, M. M. (2021). A new image encryption algorithm for grey and color medical images. Ieee Access, 9, 37855-37865.

Kaur, M., Singh, S., & Kaur, M. (2021). Computational image encryption techniques: a comprehensive review. Mathematical Problems in Engineering, 2021(1), 5012496.

Mohanty, S. P. (2015). Nanoelectronic mixed-signal system design. McGraw-Hill Education New York.

Odeh, A., & Al-Haija, Q. A. (2023). Medical image encryption techniques: a technical survey and potential challenges. no. January, 3170-3177.

Pankaj, S., & Dua, M. (2024). Chaos based medical image encryption techniques: A comprehensive review and analysis. Information Security Journal: A Global Perspective, 33(3), 332-358.

Pareek, N. K., Patidar, V., & Sud, K. K. (2006). Image encryption using chaotic logistic map. Image and vision computing, 24(9), 926-934.

Pavithra, V., & Jeyamala, C. (2018). A survey on the techniques of medical image encryption. 2018 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC),

Seeli, D. J. J., & Thanammal, K. (2025). A comparative review and analysis of medical image encryption and compression techniques. Multimedia Tools and Applications, 84(8), 4457-4473.

Sokouti, M., Zakerolhosseini, A., & Sokouti, B. (2016). Medical image encryption: an application for improved padding based GGH encryption algorithm. The open medical informatics journal, 10, 11.