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Encryption and decryption of Grayscale and Colour MRI Medical Images Using Scrambling Algorithm

Alaa H.Alarajey and Kawther H. Al-khafaji

College of Education for Girls, Department of Physics, University of Kufa, Najaf, Iraq.

*Corresponding Author E-mail: alaah.alarajey@student.uokufa.edu.iq
Kutherh.kafajy@uokufa.edu.iq

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ABSTRACT

Considering the rapid development of digital communications technologies and the massive distribution of multimedia images, the need to prevent sensitive content of images to unlawful use has become a core requirement. The same can be applied to medical imaging, as intensity values and spatial positioning of adjacent pixels are strongly interdependent. The described technique modifies the natural pixel correlation by increasing the positional and intensity entropy with the help of row and column permutation. Experimental tests proved that the algorithm is able to encode and decode pictures with a private key without any danger. Even though the encryption algorithm is computationally efficient and easy to execute, it is invulnerable to possible cryptographic attacks. The investigation utilized a range of performance indicators, such as Encryption Duration (ET), Decryption Duration (DT), and the Information Entropy of the original image (Eo).

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تشفير وفك تشفير صور الرنين المغناطيسي الطبية ذات التدرج الرمادي والملونة باستخدام خوارزمية الخلط

الاء حسن الاعرجي   ا.م.د.كوثر حسن الخفاجي

(قسم الفيزياء , كلية التربية بنات, جامعة الكوفة,النجف, العراق)

الـــخُـــلاصـــة

الكلمات المفتاحية:

في ضوء التطور السريع لتقنيات الاتصالات الرقمية والانتشار الواسع للمواد المرئية متعددة الوسائط، أصبحت حماية معلومات الصور الحساسة من الوصول غير المشروع ضرورةً أساسية. في التصوير الطبي، يوجد ترابط وثيق بين قيم الكثافة والترتيب المكاني للبكسلات المتجاورة. تُغيّر الطريقة المُقدّمة الارتباط الجوهري للبكسلات من خلال تعزيز إنتروبيا الموضع والكثافة من خلال تبديل الصفوف والأعمدة. تؤكد التقييمات التجريبية أن الخوارزمية قادرة على تشفير الصور وفك تشفيرها بأمان باستخدام مفتاح خاص. على الرغم من أن عملية التشفير فعّالة حسابيًا وسهلة التنفيذ، إلا أنها تفتقر إلى المرونة ضد هجمات التشفير المحتملة. استخدم البحث مجموعة من مؤشرات الأداء، مثل مدة التشفير (ET) ومدة فك التشفير (DT) وإنتروبيا المعلومات للصورة الأصلية (Eo).

1. INTRODUCTION

Telemedicine has emerged as a fast-developing field that allows healthcare provision within distances without the need to have a physical presence of a patient and/or a medical practitioner [1,2]. Imaging diagnostic data and confidential patient information are frequently shared through internet based systems or mobile phone communication systems [3,4,5]. In order to sustain sophisticated medical facilities, a secure and small network of storing clinical images is necessary that only the verified individuals should have access to it, no matter where in the world they are based on[6,7,8]. Nevertheless, much of the available literature has been dedicated to the development of computational advances to enhance patient outcomes, advances in protecting vulnerable medical information in transit and storage has been relatively slow[9]. Encryption procedures that make the data inaccessible to any unauthorized party without the relevant decryption keys are one of the efficient measures of securing medical images [10,11,12]. As the digital communication technologies are growing, the communication of text and images over the public networks has been raised escalated. Thus, a reliable and efficient cryptographic solution is essential to protect image data through transmission and storage [13,14]. Image encryption converts the original visual representation into unintelligible form, which can only be read by the user with the appropriate decryption key and algorithm [15,16]. An effective encryption model generally involves several steps that include pixel permutation, value replacement, diffusion and confusion to increase security. Encryption is generally advised to offer the following fundamental objectives; authenticity, [17,18,19,20,21] confidentiality, data integrity, and non-repudiation in the medical field; the diagnostic imagery should not be accessible to unauthorized party [22]. This study presents a novel encryption approach based on row and column permutation, applied to grayscale and coloured MRI scans.

2. Image Encryption Using Scrambling

Image scrambling is the process of arbitrarily rearranging pixels to render the image visually unintelligible and disrupt the correlation between neighbouring pixels. Typically, the pixel values remain unaltered during the scrambling process.[23] Bit-level scrambling and pixel-level scrambling are among the numerous varieties of scrambling. Because it does not necessitate any additional internal operations, such as converting pixels to binary as in the bit-level method, the pixel level method is simpler to implement. However, it may not effectively scramble image pixels, as it may rely solely on changing the locations of the image pixels.[24] The scrambling algorithm is an effective method for securing digital images by rearranging pixels or their values in a way that mimics randomness, making it difficult to recover the original image without the encryption key. [25]

3.Literature Survey

In 2018 Mondal, studied on different cryptographic scrambling techniques was presented. The study included matrix based, Fibonacci series based, and key based scrambling techniques, [26]in 2019 Sivabalan and Balakrishnan, proposed method deeply focuses on encrypting and decrypting the file contents using session based keys, [27].in 2020 Gutierrez researched explore and analyze the scrambling processes used in code based cryptography [28]In 2021 Abdulateef suggested New image encryption methods such as Stage Scrambling and Slant Transform are allowing images to be scaled in new and powerful ways Slant Transform image coding possesses a “discrete saw tooth-like basis vector which efficiently represents linear brightness variations along an image line [29]in 2022 Mattar et al ,proposes a simple new method for scrambling gray images using a Chaotic Logistic Map and pixel-level rotation. [30] in 2023 Thomas et al, suggested a chaotic encryption system combined with two-pass Block-XOR operations followed by scrambling techniques is proposed to encrypt grayscale images, thus ensuring their security against malicious attacks. Plaintext images contain large amounts of sensitive information, [31] in 2024 Abdel Hameed, use of 9-dimensional chaotic systems and 3-dimensional bit-level substitutions for secure colour image encryption. [32]

4. Image Quality Measures

Image-quality evaluations “Evaluation metrics” are crucial to determining whether an image encryption technology is effective [33].

4.1 Signal to Noise Ratio (SNR)

SNR is the ratio of the desired information or the power of a signal to the undesired signal or the power of the background noise. It is frequently abbreviated as S/N or SNR and is typically expressed in decibels (dB)[34]. - The SNR index is indicated by:

$$SNR = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_O(i,j)\right)^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_O(i,j)-I_D(i,j)\right)^2} \quad (1)$$

Where;

$I_O(I,j)$ the original image

$I_D(I,j)$ decrypted image.

M and N pixel coordinates

4.2 Mean Signal to Noise Ratio (MSNR)

MSNR the ratio of the original signal power to the noise (error) power [35]. Is what determining this:

$MSNR = \frac{\frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} I_O(i,j)^2}{MSE}$	(2)

Where;

$I_O(I,j)$ the original image

MSE is the mean squared error

4.3 Number of Pixel Change Rate (NPCR)

NPCR are designed to test the number of changing pixels between two encrypted images NPCR can be computed as follows:

$$NPCR = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} D(i,j)}{M \times N} 100\% \quad (3)$$

$$D(i,j) = \begin{cases} 0 & if\ E(i,j) = E^{`}(i,j) \\ 1 & if\ E(i,j) \neq E^{`}(i,j) \end{cases} \quad (4)$$

Where;

M and N represent width and height of image, respectively

$E(i,j)$, $E^{`}(i,j)$ are the encrypted images before and after a slight change, respectively

$D(i,j)$ indicates the difference between corresponding pixels of encrypted image of original image $E^{`}(i,j)$ and encrypted image of changed image $E(i,j)$.

4.4 Correlation Coefficient Analysis (CC)

CC measures the strength of the relationship between two variables (relationship between two adjacent pixels) in an image [36].

$$CC = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (I_O - \hat{I}_O)(I_E - \hat{I}_E)}{\sqrt{(\sum_{i=1}^{M} \sum_{j=1}^{N} (I_O - \hat{I}_O)^2)(\sum_{i=1}^{M} \sum_{j=1}^{N} (I}} \quad (5)$$

Where;

I_O and I_E represent the original images and encrypted images

$\hat{I}_O$ and $\hat{I}_E$ represent mean value of original images and mean value encrypted image.

4.5 Unified Average Changed Intensity (UACI)

UACI is designed to test the number of mean intensities modified between two encrypted images[37]

$$UACI = \frac{1}{(M \times N)} \left[\sum_{i=1}^{M} \sum_{j=1}^{N} \frac{C_1(i,j) - C_2(i,j)}{255} \right] \times 100\% \quad (6)$$

Where:

M and N are the width and height of the encrypted image.

$C_1(i,j)$ is the encrypted image before a pixel change

$C_2(i,j)$ is the encrypted image after a pixel change (i.e.,$C_1(i,j)$ & $C_2(i,j)$) are the encrypted images before and after a slight pixel change.

4.6 Execution Time (ET)

Execution time is the amount of time needed to use a specific image encryption method. It is the sum of the compile time and run time. ET should be the bare minimum for the realistic implementation of image encryption. Typically, it is expressed in seconds, milliseconds, or minutes. [33]

4.7 Information Entropy (IE)

Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image. The information entropy is an evaluation of the uncertainty degree in the system, which also can be used to express the uncertainty in image encryption. The formula of the entropy is shown Equation [38]

$(IE) = \sum_{x=0}^{255} \left[P(x) \times \log_2 \left(\frac{1}{P(x)} \right) \right]$	(4.7)

Where;

log_2 is logarithm with logarithmic base.

$P(x)$ the probability of the pixel value x

5. Proposed Algorithms

As illustrated in **Fig 1** and **2,** we proposed an encryption and decryption algorithm in this paper based on the Scrambling rows and columns

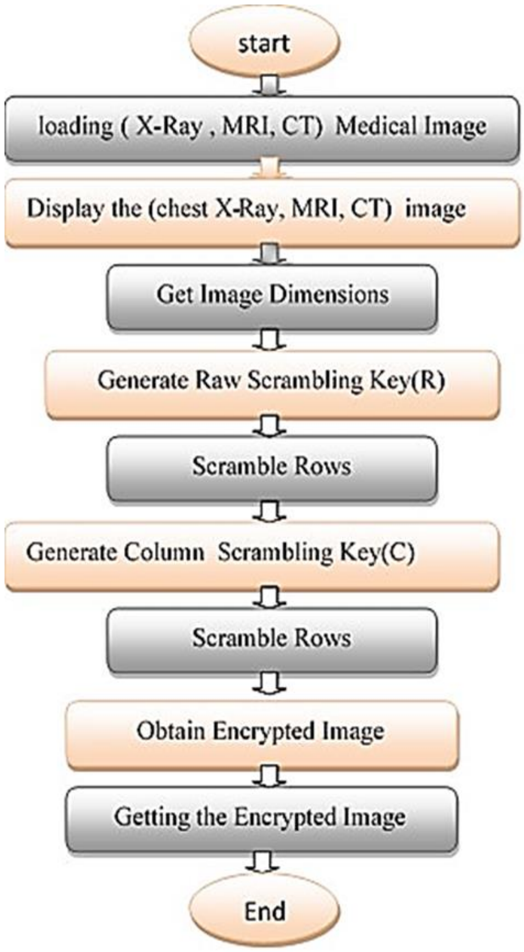


Fig 1. The Algorithm for image encryption

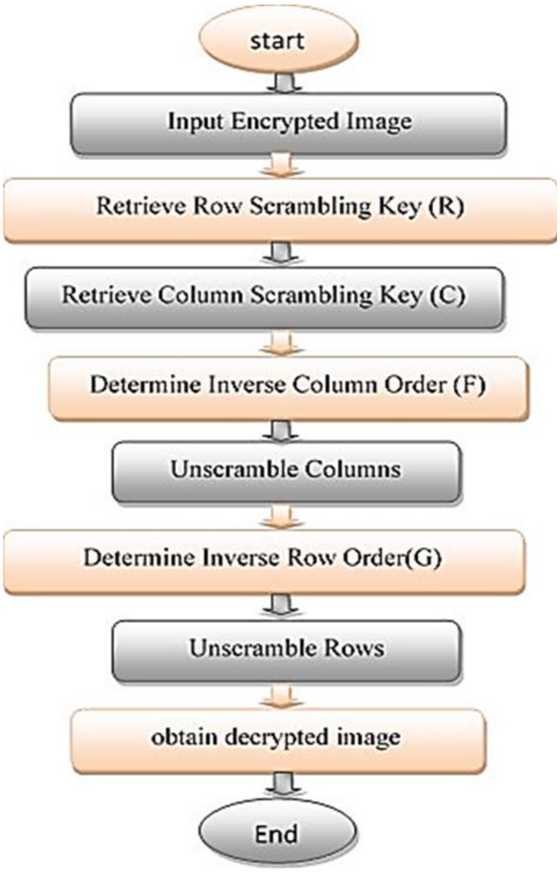


Fig 2. The Algorithm for image decryption

4. Image Acquisition

This work was performed using Matlab R2021a software, and the medical image used was an MRI. The MRI image was taken from the German Hospital in Najaf, Iraq, from a patient suffering from a brain disease

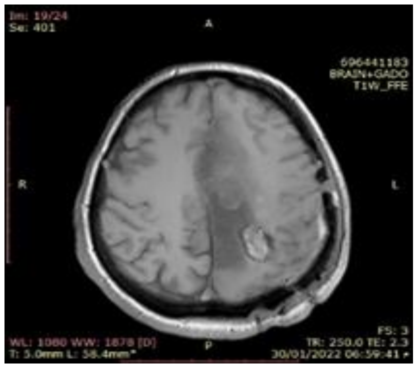
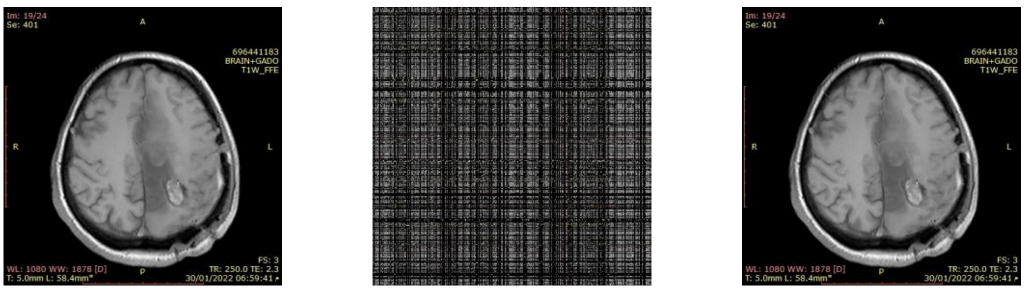


Fig 3. MRI original image

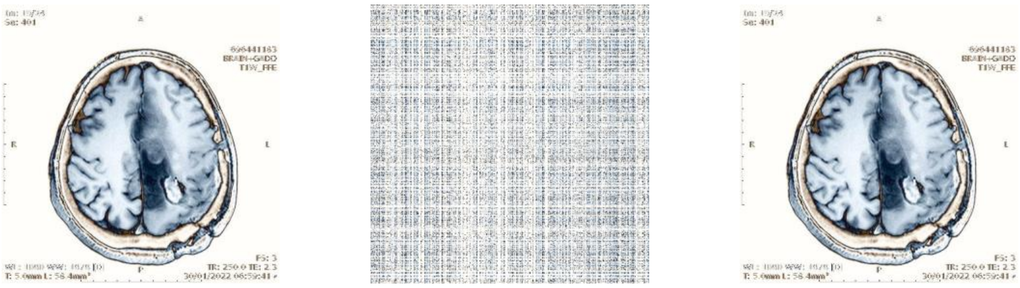
5. Results and discussion

In order to simulate the algorithm proposed in MATLAB, we select grayscale and coloured MRI images as base images



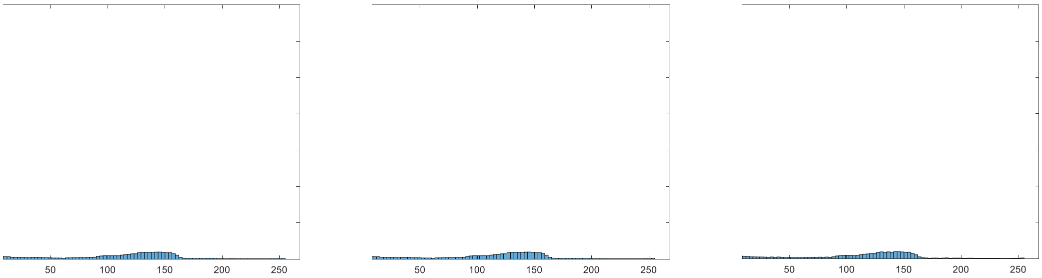
$(\mathcal{A})$ $(\mathcal{B})$ $(\mathcal{C})$

Fig 4. Gray Medical MRI Image :($\mathcal{A}$) Original MRI Image, ($\mathcal{B}$) Encrypted X-ray Image, and ($\mathcal{C}$) Decrypted MRI Image



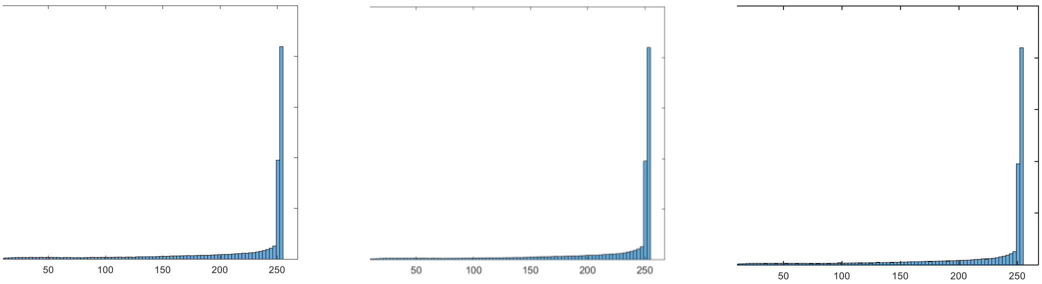
($\mathcal{A}$) ($\mathcal{B}$) ($\mathcal{C}$)

Fig 5.Color Medical MRI Image: $\mathcal{A}$) Original MRI Image, ($\mathcal{B}$) Encrypted X-ray Image, and ($\mathcal{C}$) Decrypted MRI Image



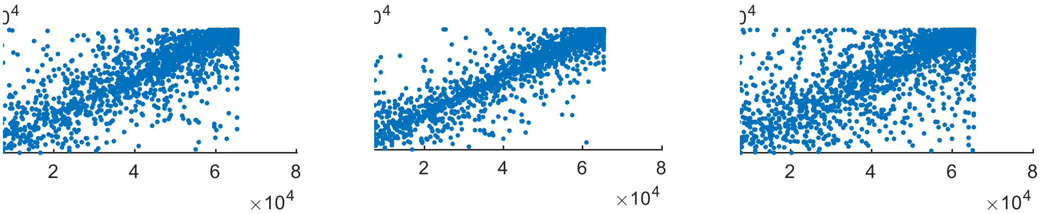
($\mathcal{A}$) ($\mathcal{B}$) ($\mathcal{C}$)

($\mathcal{A}$) Original MRI image : Gray Medical MRI Image Histogram.Fig 6 Histogram, ($\mathcal{B}$)Encrypted MRI image Histogram, ($\mathcal{C}$) Decrypted MRI image Histogram



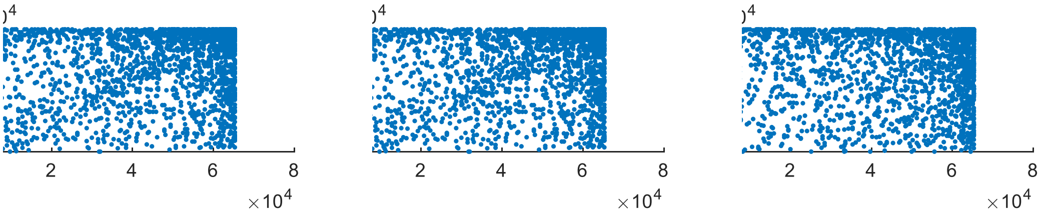
($\mathcal{A}$) ($\mathcal{B}$) ($\mathcal{C}$)

Colour Medical MRI Image Histogram: ($\mathcal{A}$) Original MRI image .Fig7 Histogram, ($\mathcal{B}$)Encrypted MRI image Histogram, ($\mathcal{C}$) Decrypted MRI image Histogram



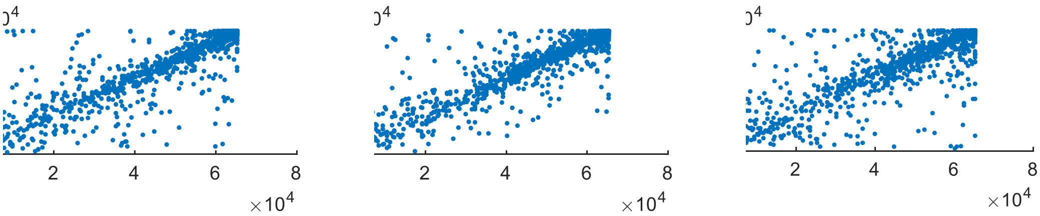
($\mathcal{A}$) Horizontal ($\mathcal{B}$) Vertical ($\mathcal{C}$) Diagonal

Correlation of Adjacent Gray-Level Pixels in the Original MRI Image.8 Fig



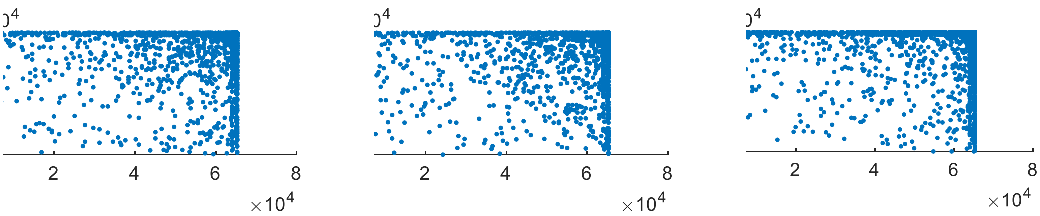
($\mathcal{A}$) Horizontal ($\mathcal{B}$) Vertical ($\mathcal{C}$) Diagonal

Correlation of Adjacent Gray-Level Pixels in the Encrypted MRI .9 Fig Image



($\mathcal{A}$) Horizontal ($\mathcal{B}$) Vertical ($\mathcal{C}$) Diagonal

Correlation of Adjacent Color Pixels in the Original MRI Image.10 Fig



($\mathcal{A}$) Horizontal ($\mathcal{B}$) Vertical ($\mathcal{C}$) Diagonal

Correlation of Adjacent Color Pixels in the Encrypted MRI Image.Fig11

Table 1. Some IQM Encryption and decryption using the Scrambling algorithm for medical image MRI

NO	IQM	Gray MRI image	Colour MRI image	NO	IQM	Gray MRI image	Colour MRI image
1	ET	1.208	1.353	**10**	PSNR1	99.000000	9.000000
2	DT	0.565	0.650	**11**	PSNR2	28.934051	29.033769
3	UACI	0.2651558	0.22455	**12**	MSNR1	99.0000	99.0000
4	NPCR	0.708162	0.76306	**13**	MSNR2	1.345091	3.095384
5	CC1	1.000000	1.00000	**14**	WSNR1	Inf	Inf
6	CC2	0.011053	0.00704	**15**	WSNR2	5.616459	11.837045
7	UIQI1	1.000000	1.00000	**16**	Eo	4.524290	4.715053
8	SNR1	38.243314	37.0279	**17**	Ee	4.524290	4.715053
9	SNR2	38.243314	37.02793	**18**	Ed	4.524290	4.715053

The following points present some observations regarding the behaviour and performance of the proposed encryption and decryption algorithm:

1. From the Table1, we observed that the encryption time for the grayscale MRI image is 1.208, and the decryption time is 0.56. This is the shortest time for grayscale resonance images, indicating the speed of this algorithm in encrypting and decrypting MRI images.
2. When observing the results related to the metrics (PCR, CC1, CC2, UIQI1, SNR1, SNR2, PSNR1, PSNR2, MSNR1, MSNR2, WSNR1, WSNR2, Eo, Ee, Ed, NPCR), it was noted that the proposed algorithm achieved similar performance for both grayscale and colour MRI images. This demonstrates the algorithm's efficiency in handling different image types. The results indicate that the recovered images were identical to the original images and no information is lost, demonstrating the success of the decryption algorithm. While the encryption algorithm succeeded in scattering the pixels, it is less secure.

3. Examining the figures (6,7), the histogram of the encrypted images found to be identical to the histogram of the original images because the encryption algorithm did not change the pixel values, but rather changed the pixel locations. As for the histogram of the retrieved grayscale and coloured images, it is equal to the histogram of the original grayscale and coloured images, which indicates the success of the decryption algorithm in retrieving information.

4. When observing figures (8,10) which show the correlation of adjacent pixels horizontally, vertically and diagonally for original gray and colour MRI images, this correlation is strong between pixels, but after encryption as in figures (9,11) the pixels became randomly spread, which indicates that the correlation between adjacent pixels has been greatly reduced. This is desirable in image encryption as it aims to hide any relationships or patterns in

the original image, which makes decryption most difficult.

6. Conclusion

This research offers a valuable contribution to the domain of image encryption by proposing a foundational security mechanism that effectively obscures textual content within images. The paper proposes an encryption algorithm, using row and column shuffling, that overcomes a number of constraints that have been found in the traditional image encryption systems. The initial tests on the technique proved it to be quite efficient in terms of speed and low resource usage, so it is most applicable to restricted computational settings. Although the method has its benefits as far as its operation is concerned, it fails to offer adequate protection to highly sensitive data and this limits its usage in situations where maximum security is needed. Besides, the evaluation metrics, such as NPCR, UACI, CC, SNR, PSNR, WSNR and IE demonstrated a similar pattern of performance in both grayscale and color resonance images, which indicates the algorithm does not lose its performance depending on the type of image.

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