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An Image Encryption Approach With Improved Security Using Chaotic Map In Frequency Domain

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Abstract

For the purpose of representing complex data, images are the most convenient and effective way. In these days, huge amount of images are often moved from one location to another location of world with the application of internet. Moreover, as it's common that the Internet more sensitive for the wide range of issues for security. In form of consequences, such images may become victim of content manipulation, unauthorized access, content destruction, privacy leakage, etc. To troubleshoot these issues, our system must have capability to encrypt the image before transmitting it over the Internet. In order to fix these issues, so many encryption approaches has been proposed by expert from all over the world. Most of these encryption approaches are worked either in spatial or frequency domain, but mostly only suitable with gray scale images. The main aim of this paper is to propose an image encryption approach that is to be done into spatial domain along with frequencies domain, but effective for color images as well as gray scale images. In encryption process of proposed work, the color images are first confused in frequency domain using the Discrete Cosine Transformation (DCT) and Arnold Cat Map. In second step, the confused image's frequencies are converted into spatial domain using the Inverse Discrete Cosine Transformation (IDCT), and defused the image's pixel using the Logistic Map followed by the Henon Map. At the end, we get the resulted encrypted image. At last, various tests will be performed and there result's has been analyzed to prove the strength and effectiveness of the proposed approach of encryption. The experimental result of proposed work has also been compared with the existing encryption techniques. The result of various test claim the effectiveness of the proposed work.

Keywords: Encryption, Decryption, Diffusion, Confusion, Chaotic Map, Discrete Cosine Transformation, Key-Sensitivity.

Introduction

In these days, huge amount of images are often moved from one location to another location of world with the application of internet. However, store or transmit them in the plain format having higher risks. The adversary can steal or tap the plain-images, so that confidentiality of plain-images needs to be protected. Images encryption is the solution to this problem. The plain images are encrypted so that it cannot be recognized by unauthorized party. In the literature, there exist a wide range of well-approved efficient algorithms for the text message encryption, such as: Data Encryption Standard (DES), Advanced Encryption Standard (AES), International Data Encryption Algorithm (IDEA) and the Rivest-Shamir-Adleman cryptosystem (RSA). However those algorithms are not well appreciated for image or video file encryption applications. Since the images differ from the text data in many aspects such as high redundancy and correlation, the local structure and the characteristics of amplitude frequency, the conventional encryption methods cannot be applicable to the images.

A lot of encryption techniques for images encryption have been proposed by the experts. These image encryption techniques are worked in spatial domain or in frequencies domain or in both domain. An Image Encryption Algorithm Based on Henon Chaotic System in spatial domain has been proposed in [1]. A Block-based Image Encryption Algorithm in Frequency Domain using Chaotic Permutation has been proposed in [2]. A Robust Color Image Encryption Algorithm in Dual Domain using Chaotic Map has been proposed in [3].For a whole color image DWT based lossless chaotic encryption in frequency domain has been proposed in [4]. An Images encryption technique in spatial domain using Cubic Map, Henon Map, Quadratic Map, and Logistic Map has been proposed in [5]. An Image Encryption Using Hybrid Chaotic Map with Arnold' Cat Map, Logistic Map, and Henon Map has been proposed in [6]. An Image encryption algorithm based on Fractional Fourier Transform using Arnold's Map and Henon Map has been proposed in [7]. The image encryption techniques that worked in spatial domain are either confused the pixel location or diffused the pixel's value using various chaotic maps. The image encryption techniques that worked in frequencies are either confused the location of frequencies or diffused the frequency's value using various chaotic maps, or with suitable alteration or modification in chaotic maps. Image encryption performed in either domain has its own pros and cons. The advantages that available in one domain are generally not available in other.

With the inspiration of the presented studies, we introduce a new image encryption algorithm that performed encryption operation in frequency domain followed by the encryption in spatial domain. The proposed encryption algorithm is based on chaotic Logistic system along with the dynamical system of Michel Henon. According to the present method, our proposed algorithm first confuses the image pixel in frequency domain. Then, chaotic system runs in spatial domain for the generation of pseudo-random sequences, and then these pseudo-random sequences are used to diffuse the value of image pixels.

In this proposed algorithm includes the features of both as an encryption in spatial domain followed by an encryption infrequency domain. The analysis of experimental result revealed that how much our proposed image encryption technique is effective to resist any types of attacks.

Preliminary Theories

Discrete Cosine Transformation

The two-dimensional DCT of an M by N matrix is defined as follows [3]:

$$C(u,v)=\alpha_u\,\alpha_u\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} I(x,y)\cos\frac{\Pi(2x+1)u}{2M}\cos\frac{\Pi(2y+1)v}{2N}$$

and the inverse DCT (or IDCT) is given by

$$I(x,y)=\alpha_u\,\alpha_u\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} C(u,v)\cos\frac{\Pi(2x+1)u}{2M}\cos\frac{\Pi(2y+1)v}{2N}$$

Where

$$\alpha_u=\begin{cases}\frac{1}{\sqrt{M}} & ,u=0\\ \frac{1}{\sqrt{M}} & 1\le u\le M-1\end{cases} \quad ; \quad \alpha_v=\begin{cases}\frac{1}{\sqrt{N}} & ,v=0\\ \frac{1}{\sqrt{N}} & 1\le v\le N-1\end{cases}$$

The values C(u, v) are called the DCT coefficients of image I. The upper leftmost element is called DC coefficient and the rest are called AC coefficients. The DCT can be applied to transform the whole image or image blocks (8 × 8 pixel).

Henon MaP

Pseudo-random has been produced by using Henon map which is considered a prototypical twodimensional.The map relies on two parameters a and b that pick a point (xi, yi). The Hénon map is a discrete-time dynamical system. It is one of the most studied examples of dynamical systems that exhibit behavior. This map is given by the equation below [7]

$X_{n+1}=1-aX_n^2+Y_n$

$Y_{n+1}=bX_n$

Usually, a is around1.4 and b is around 0.3 which makes Henon map gainchaotic behavior.

Logistic Map

Logistic map show chaotic behavior that it is considered one the modest nonlinear chaotic discrete systems. It is one dimensional chaotic system that can be described as follows [3]:

$$X_{n+1}=\mu X_n(1-X_n)$$

whereμ isthe chaotic factor and n is the quantity of iterations, $\mu\epsilon[0,4]$, $x\epsilon[0,1]$ in which, the chaotic behavior is realized when $r\epsilon[3.54,4]$.

Arnold Cat Map

Arnold Cat Map (ACM) is a two-dimensional chaotic map after discovered by Vladimir Arnold in 1960. ACM transform the coordinates x, y) in the image of size N *N to the new coordinates (x ', y'). The equation of ACM [3] is

$$\begin{bmatrix} x_{i+1} \\ y_{i+1} \end{bmatrix}=\begin{bmatrix} 1 & K_b \\ K_a & K_bK_a+1 \end{bmatrix}\begin{bmatrix} x_i \\ y_i \end{bmatrix}\bmod(N)$$

where (xi, yi) is position of the pixel in the image, (xi +1, yi +1) is new pixel position after iteration i. Parameters b and c are any positive integer. Determinant of the matrix must be equal to 1 so that the transformation is area-preserving (remain in the same area of the image). ACM is iterated as m times, and each iteration produces a random image. Values of b, c, and m can be considered as the secret keys. The scramble image can be reconstructed into the original image using the same key (b, c, and m). The inverse equation of ACM [3] is

$$\begin{bmatrix} x_i \\ y_i \end{bmatrix}=\begin{bmatrix} 1 & K_b \\ K_a & K_bK_a+1 \end{bmatrix}\begin{bmatrix} x_{i+1} \\ y_{i+1} \end{bmatrix}\bmod(N)$$

The Proposed Algorithm

In this presented approach, the algorithm first takes a plain image and two keys K_a and K_b as an input. Then, it reads image pixel-by-pixel and each color component of every pixel are stored in respective matrix μ_{Red}, μ_{Green}, and μ_{Blue}. At this stage, we have three matrices μ_{Red}, μ_{Green}, and μ_{Blue} that have contain the value of red, green, and blue of plain image respectively. In the next step, IR, IG, and IB are divided into 8 × 8 blocks. Now, DCT is applied on each block of μ_{Red}, μ_{Green}, and μ_{Blue}. As a result, we get μ_{Red}, μ_{Green}, and $\mu_{Blue}$with modified value that represent DCT coefficient. To add confusion, the algorithm scrambled each 8 × 8 block of every matrix μ_{Red}, μ_{Green}, and μ_{Blue} using ACM transformation with keys K_a and K_b. Next, algorithm performed the reverse DCT operation on μ_{Red}, μ_{Green}, and μ_{Blue} to get the image with confused frequency into spatial domain. Now in spatial domain the algorithm performed the diffusion operation twice with each element of matrices IR, IG, and IB. For the first step of diffusion operation, the algorithm produces a stream of keys using the Logistic Chaotic Map, and the XOR operation are performed between the key and each element of matrices IR, IG, and IB. For the second step of diffusion operation, the algorithm produces a stream of keys using the Henon

Chaotic Map, and the XOR operation are performed between the key and each element of matrices IR, IG, and IB. The matrices IR, IG, and IB would now contained the twice diffused value of every color component of every pixel of the plain image. Finally, each color component matrices are combined to get the encrypted image.

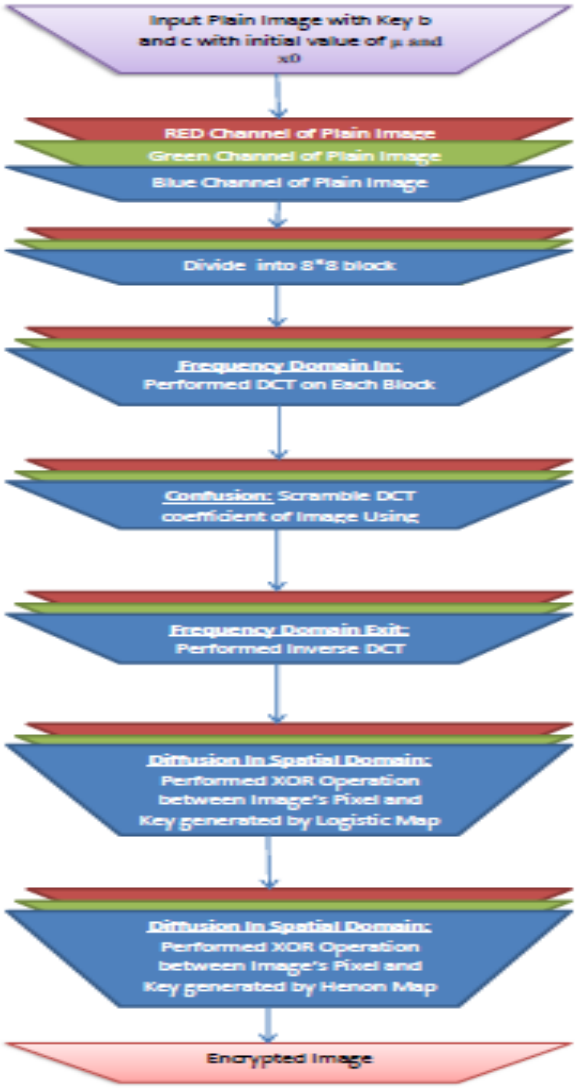


Fig. 1: Flow of Encryption Process by Proposed Approach

Experimental Result And Analysis

For this study, the initial values and the parameters are adjusted as follows with a good accuracy:

$\mu = 3.9600$; $x_0 = 0.1234$; $K_a = 94$; $K_b = 50$;

In this study, we used three colorful images of Lena, Pepper, and Baboon for the demonstration of the efficiency of the proposed image encryption algorithm.When we applied our proposed encryption and decryption algorithm with the mentioned initial value and keys, we get the result as shown in figure-2.

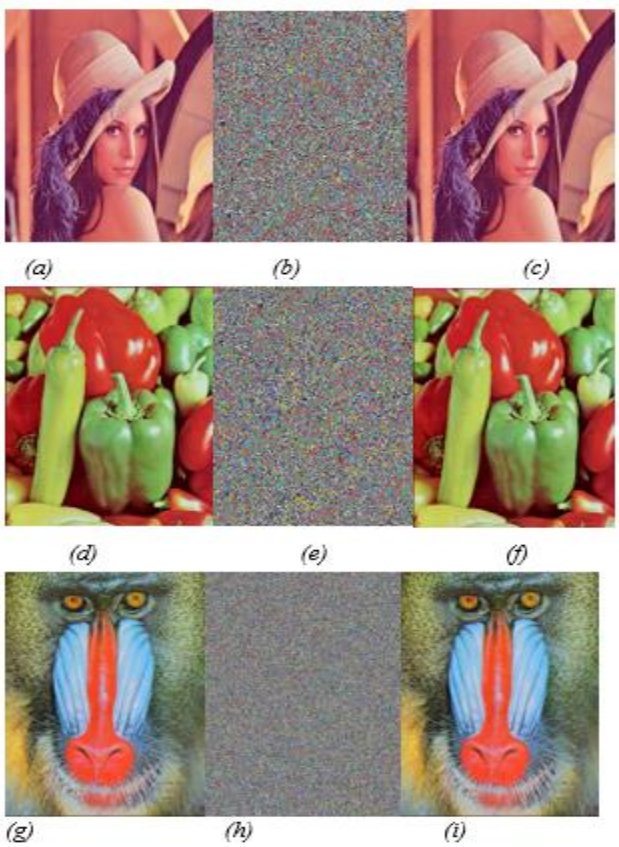


Fig. 2 (a) Original image of Lena, (b) Encrypted image of Lena, (c) Decrypted image of Lena, (d) Original image of Peppers, (e) Encrypted image of Peppers, (f) Decrypted image of Peppers, (g) Original image of Baboon, (h) Encrypted image of Baboon, (i) Decrypted image of Baboon

To test and analyze the result MATLAB R2015a is used with a system of Intel CORE i3 processor and 4 GB of RAM.

Histogram Analysis

The image histogram determines the distribution of each color intensity level of the individual pixels of an image. An ideal histogram for an encrypted image should be flat, implying the uniform distribution on the image range and the complete randomness. Infact, the flatness of a histogram could better preventthe leakage of the information by the statistical attacks. Figure-3shows the histograms of theoriginal Lena image and it's encrypted one.

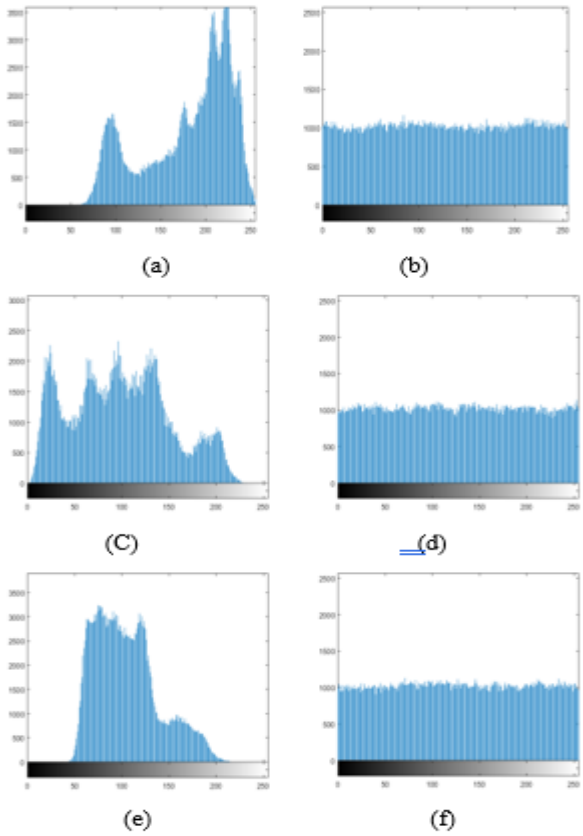


Fig. 3 (a) Histogram of Red color of plain image of Lena, (b) Histogram of Red color of encrypted image of Lena, (c) Histogram of Green color of plain image of Lena, (d)Histogram of Green color of encrypted image of Lena, (e) Histogram of Blue color of plain image of Lena, (f) Histogram of Green color of encrypted image of Lena,

The histogram of the original image contains several peaks. However, the histogram of the ciphered image is uniform. Hence, it is proven that the histograms of the encrypted image do not give any clue to operate any statistical attack to recover the original one.

Entropy Analysis

The information entropy measures the strength of the cryptosystem and gives the equally probable gray levels for a good image encryption algorithm by applying it to the encrypted image.

Table I gives the entropy values of three original images and their encrypted ones. According to the results, the information entropy is increased by the encryption system and the information entropies of the encrypted images are nearly 8. This proves that the proposed encryption algorithm is highly resistive to the information leakage.

Table 1: Entropy values for the plain images and the corresponding decrypted image

Entropy Value of Plain and Encrypted Image						
Images	Plain Image			Encrypted Image		
	R	G	B	R	G	B
Lena	7.2531	7.594	6.9684	7.9989	7.9988	7.999
Pepper	7.3576	7.5929	7.129	7.9991	7.9989	7.9987
Baboon	7.7067	7.4744	7.7522	7.9991	7.9991	7.9993

Table 2: Entropy values for the encrypted image in previous and proposed work

Entropy Analysis of Previous Work and Proposed Algorithm						
Images	Ref [3]			Proposed Work		
	R	G	B	R	G	B
Lena	7.9979	7.9987	7.998	7.9989	7.9988	7.999
Pepper	7.9985	7.999	7.9968	7.9991	7.9989	7.9987

Correlation Coefficient

In this section, the horizontal, vertical and diagonal correlation coefficients of the ciphered pixels have been calculated. Correlation between any two adjacent pixels of an image is a clue for attackers to gain the statistical information about the image. The value of correlation coefficient near to zero of an image has less meaningful statistical information of any two adjacent pixel. So, we take all pairs of two adjacent pixel first in horizontally and then vertically from plain image and encrypted image. In addition, we randomly take 2000 pairs of diagonally adjacent pixel from plain image and encrypted image. The table III shows the correlation coefficient of each plain image and correlation coefficient of respective encrypted image that used in this experiment.

Table 3: Correlation coefficients of two adjacent pixels in the plain image and the cipher-image

Correlation Coefficient of Plain and Encrypted Image							
Images	Direction	Plain Image			Encrypted Image		
		R	G	B	R	G	B
Lena	Vert.	0.9894	0.9824	0.9578	0.0749	0.0727	0.063
	Hor.	0.9798	0.9690	0.9329	-0.0356	-0.0274	-0.0124
	Diag.	0.9697	0.9555	0.9184	0.003	0.0016	0.0032
Pepper	Vert.	0.9750	0.9882	0.9752	0.0765	0.0734	0.0768
	Hor.	0.9719	0.9864	0.9748	-0.0245	-0.037	-0.033
	Diag.	0.9524	0.9765	0.9549	1.02e-04	-3.30e-04	0.0048
Baboon	Vert.	0.8597	0.7578	0.8777	0.0501	0.0468	0.0565
	Hor.	0.9228	0.8656	0.9072	-0.0236	-0.0181	-0.0263
	Diag.	0.8543	0.7352	0.8399	0.0062	0.0039	0.0051

Table 4: Correlation coefficients of two adjacent pixels in decrypted image in Previous and proposed work

Comparative Analysis of Previous Work and Proposed Algorithm						
D direction	Ref [4]			Proposed Algorithm		
	Encrypted Image of Lena			Encrypted Image of Lena		
	R	G	B	R	G	B
Vertical	0.4807	0.4745	0.4553	0.0749	0.0727	0.063
Horizontal	0.4850	0.4925	0.4873	-0.0356	-0.0274	-0.0124
Diagonal	0.4841	0.4791	0.4565	0.003	0.0016	0.0032

PSNR Analysis

If the PSNR value of two images is equal or greater than 30, then human eyes can't differentiate between these two images. To analyze the quality of visibility of the decrypted image, we used the PSNR (Peak Signal-to-Noise Ratio) test with decrypted images and their respective plain images. The bigger PSNR value between plain image and its respective decrypted image confirm the less distortion in the original plain image. The table V has shown the PSNR value of images that we used in our experiments and it always above the standard. So, our proposed algorithm is enough capable to recover the decrypted image with enough visual quality.

Table 5: The PSNR results between plain-image and corresponding decrypted image

PSNR Analysis	
Decrypted Image	PSNR
Lena	62.251
Pepper	65.626
Baboon	63.536

Table 6: The PSNR results of decrypted image by previous work and proposed work

Comparative Study of PSNR Analysis		
	Ref [3]	PROPOSED
Decrypted Image	PSNR Value	PSNR Value
Lena	34.2466	62.251
Peppers	34.6704	65.626

Key Sensitivity Analysis

In this section, the horizontal, vertical and diagonal correlation coefficients of the ciphered pixels have been calculated.In our proposed algorithm the initial value of μ and x_0, and value of K_a and K_b are used as the key of algorithm. In this test, we have tried to decrypt an encrypted image of Lena, Peppers, and Baboon with same value of Ka, Kb, and same initial value of x_0 with a minor difference in initial value of μ. As mentioned earlier, we have used following value of the key at the time of encryption of Lena image:

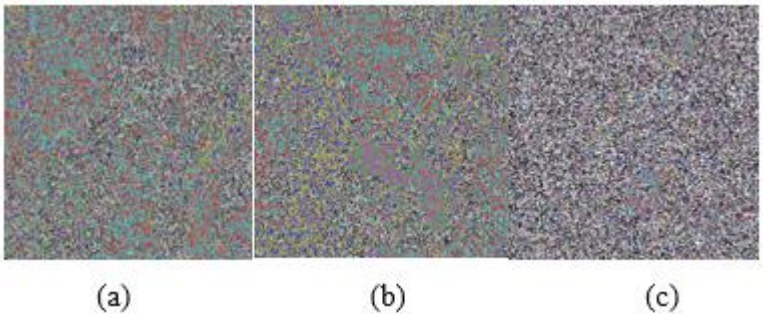
μ = 3.9600;

x0= 0.1234;

K_a= 94;

K_b= 50;

Now we have the same value of x_0, K_a, K_b, and make a minor difference of μ=3.9600 to μ=3.9601. In this case, the decrypted image of Lena, Peppers, and Baboon is shown in figure 4. (a),(b), and (c).



(a) (b) (c)

Fig. 4 (a) decrypted image of Lena with minor different key, (b) decrypted image of Peppers with minor different key, (c) decrypted image of Baboon with minor different key.

The result has shown that, the least possible change in the key produce an image that is a totally meaningless and even not to be a little bit of close to the original plain image. So, it is clarify that how much our proposed algorithm is sensitive about its key.

Conclusion

In this paper has presented a block-based image encryption algorithm using a chaotic permutation. Experiment shows that the cipher-images that resulted from the algorithm are robust to common image processing operations. Such image processing are JPEG compression, image noising, and image resizing. The decrypted images can be still recognized well, although they are just like noised.

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