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Chaos-Based ETC System with ANM

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Abstract

Information and communication technology is the back bone of a number of momentous innovations in research, industry and in society. Network and mobile communications made a change in lifestyles leasing people to exchange information from any place at any point of time. Huge amount of data is transferred every second and the use of digital images are also increased. Digital images require more time for transmission because of their larger size. Hence, it is important to compress the images before transmission to improve the processing speed. Encryption technique is used to provide security for images. This paper proposes an image Encryption-then-Compression (ETC) system. A chaotic encryption technique is used to encrypt the images and Asymmetric Numeral Method (ANM) is used to compress the encrypted images. The performance results are carried out for various image sizes and compared with Arithmetic and Huffman compression techniques and it shows that the proposed system is better in terms of security, compression ratio and computation time.

Keywords--Encryption, Image Compression, Decompression, Chaotic system and Asymmetric Numerical Method.

I. Introduction

In recent years, lot of applications based on internet are emerging such as on-line shopping, stock trading, internet banking, electronic bill payment and social media like Twitter, WhatsApp, Facebook, etc. Images are widely used in all these network applications. Generally, the size of the image files are huge and consume lots of hard disk space. But, when it is compressed, the size of the file becomes smaller and results it as an optimized one when communication bandwidth or storage is limited. Security of image is also an important requirement in network applications. Encryption is the most effective technique which provides security to images by converting original image to another image which is difficult to understand. Both encryption and compression are needed to ensure security of images and to reduce the file size.

Image compression is minimizing the image size in bytes without degrading the quality of the image by removing redundancy and irrelevancy. The reduction in file size allows more images to be stored in a given amount of disk or memory space. It also reduces the time required for images to be sent over the internet. Compression methods can be classified into lossy or lossless compression. Lossy compression can achieve a high compression ratio but it cannot completely recover the original data. Original image is not identical to decompressed image that means it allows some acceptable degradation. Lossy compression is generally used for natural and photography images [10]. Lossless compression has low compression ratio but it provides better compression for highly sensitive applications.

Lossless compression can completely recover the original data. In medical applications, lossless compression has been a requirement because it facilitates accurate diagnosis as there is no degradation on the original image. Encryption techniques are of two categories, namely Symmetric and Asymmetric encryption techniques. Symmetric encryption is the simplest encryption where the same key is used for encryption and decryption. Asymmetric encryption uses two keys to encrypt a plain text. One of the key is known as the private key and the other is known as the public key. The private key is kept secret by the owner and the public key is either shared among authorized recipients or made available to the public at large [10].

The combination of compression and encryption includes three categories based on their process sequences. The first category, i.e. encryption technique followed by compression method (ETC), focuses more on image security than the reduction of an image size. The second category, compression method followed by the encryption

technique, where the compression method can be lossy, lossless, or combination of both. The third category, i.e. compression and encryption in a single process either partially or in the form of compressive sensing [4]. In the proposed ETC System the image is encrypted by using chaos method and then compressed using Asymmetric Numeral Method [ANM]. Number of chaos-based image encryption algorithms shown their best performance, which have been studied and designed by many researchers. Chaos-based image encryption techniques are suitable for practical use as they provide a good combination of speed, high security, complexity, reasonable computational overheads and computational power. This is because chaotic systems have many attractive properties such as the sensitive dependence on initial conditions and system parameters, the density of the set of all periodic points, topological transitivity and so on. Most of these properties are desirable for performing permutation(mixing) and diffusion in cryptography [1]. Multiple chaotic maps related to the image generates encryption algorithm with variable control parameters to resist statistical attacks [3]. The main shortcomings in chaotic system are slowness and small key space. The proposed system includes an image encryption scheme based on the combination of chaotic maps to improve the encryption robustness and ANM compression to improve compression performance without compromising the speed.

The rest of this paper is organized as follows. Section II explains the related researches briefly; Section III describes the proposed methodology. Section IV provides the experimental results and their discussions. Section V concludes the research work.

II. Related Works

Abanda et al. [1] proposed a chaos encryption technique to improve the compression ratio by using two oscillators. The mixed chaotic maps from the Colpitts and Duffing oscillators are used to encrypt images and proved that the chaos-based image encryption provide high security with reduced encryption time. Experimental results showed the robustness and efficiency of chaotic encryption. Alsafasfeh et al. [3] presented an encryption technique based on multiple Chaotic system to encrypt images by shuffling pixel values and then changing the grey scale values. Structural parameters and initial value are used as encryption key to overcome the drawbacks of small key space and weak obscure in the chaotic encryption method. Experimental analysis demonstrated that the encryption algorithm has the advantages of large key space, high-level security and high speed. Gao et al. [5] discussed about recent researches of image encryption algorithms based on chaotic systems and studied the drawbacks of small key space and weak security in one-dimensional chaotic cryptosystems and introduced new Nonlinear Chaotic Algorithm (NCA) which uses power function and tangent function instead of linear function. Its structural parameters are obtained by experimental analysis and an image encryption algorithm in a one-time password system is designed. The experimental results showed that the image encryption algorithm based on NCA has the advantages of large key space and high-level security, while maintaining acceptable efficiency.

Kwok et al. [7] proposed a fast chaos-based image encryption system with stream cipher structure. The major core of the encryption system is a pseudo-random key stream generator based on a cascade of chaotic maps, serving the purpose of sequence generation and random mixing. An image is first converted into a binary data stream. By masking these data with a random key stream generated by a chaos-based Pseudo-Random Key Stream Generator (PRKG), the corresponding encrypted image is formed. where the PRKG is formed by two chaotic maps, serving the purpose of stream generation and random mixing. The experimental results concluded that it outperforms the existing schemes in terms of both speed and security. Sun et al. [11] presented a novel image encryption scheme based on spatial chaos map. The basic idea is to encrypt the image in space with spatial chaos map pixel by pixel, and then the pixels are confused in multiple directions of space. In the encryption process initially, the original image is transformed into a matrix and then this matrix is encrypted using results of iteration of spatial chaos map. Using the initial conditions and control parameters of chaotic map, the spatial chaos map is iterated once and a new matrix is generated. Then in the next step the spatial chaos map parameters are modified. This process will be repeated to get the ciphered image. The results proved that the key space is incomparably large to resist the attacks and provide high security. Both encryption and decryption procedures have similar structure, same algorithmic complexity and time consumption. Al-Maadeed et al. [2] proposed an efficient, selective chaos-

based image-encryption and compression algorithm. Encryption used discrete chaotic map algorithm based on chaos conducted on the approximation of the results of the wavelet [DWT] transformation to enhance security by increasing the number of external keys. The fundamental principle used in encryption is to use random numbers dependent on original condition to generate randomized number sequence. This technique creates a significant reduction in encryption and decryption time. Correlation coefficient value between an original image and an encrypted image decreases when the number of external encryption keys increases.Shah et al. [9] stated that image applications have been increasing in recent years. Encryption is used to provide the security for image processing applications. In this paper, various image encryption schemes are classified and analyzed with respect to various parameters like tunability, visual degradation, compression friendliness, format compliance, encryption ratio, speed and security.

III. Proposed Methodology

This section describes about the process of Encryption then Compression [ETC] system. The encryption of image using permutation-based encryption method and compression of images using Arithmetic Coder and Huffman Coder has several flaws such as larger computation time and low compression ratio. To overcome these limitations chaotic system is used in the encryption process to efficiently encrypt the images. Asymmetric Numeral Method (ANM) is used for lossless compression of encrypted images.

Chaotic Encryption

The conventional encryption algorithms usually based on discrete mathematics, while the chaos-based encryption algorithms relied on the complex dynamics of nonlinear systems or maps which are deterministic and simple [13]. chaotic encryption systems have more practical applications. The system based on chaotic sequence is relatively simple and the time taken for the encryption process is very less [2]. Chaotic system can be considered as source of randomness because the basic principle of encryption with chaos is based on the ability of some dynamic systems to produce sequence of numbers that are random in nature. This sequence is used to encrypt the images. The sequence of random numbers is highly dependent on the initial condition used for generating this sequence. A very minute deviation in the initial condition produces a different **s**equence, so the sensitivity to initial condition makes chaotic system optimal for encryption. Chaotic techniques provide an effective combination of speed, high security, complexity and reasonable computational overhead [2]. The basic principle of chaos-based encryption is to use the dynamic systems to generate a sequence of numbers that are pseudo-random in nature and these sequences could be used as a key to encrypt input image. For given parameters two initial conditions deviate exponentially into two different trajectories [8]. These parameters used for encryption and decryption and keys can be chosen from these conditions.

Due to these chaotic parameters and initial condition, it generate a large key space which enhances the security. Because of the random behavior, the output seems random to the attacker whereas only the sender and receiver know that the system is well defined [9].

Chaotic maps can be represented using continuous and discrete time parameters. The maps are usually iterative functions with the general representation of f: X → X. The process of recurrently calling the same function, where the result generated from the initial condition is fed to the same function again and the process is continued. The output from these chaotic maps exhibits fractal-like property. Fractals are expanding symmetry which are repeating patterns [12]. Mathematically chaotic map is defined as,

$$X_{n+1} = f(X_n)$$

where $0<X_n<1$ and n=0,1,2….

a) Colpitts chaotic system

The colpitts based chaotic system is represented as

$$\begin{cases} x = -\sigma(-1 + e^{(-y-1)} + XZ \\ y = -\Upsilon + e^{(-y-1)} + \mu Z \\ Z = \rho(x + y) - \lambda z \end{cases} \quad (1)$$

This system is solved numerically using the fourth-order Runge Kutta method with integration step Δt = 10−3 and initial values (x0, y0, z0) = (0.4, 0.1, 0.1). The values taken by the elements of the quintuplet (σ, χ, γ, μ, ρ) determine the nature of the solution of the system [1]. The time series of the state variable x(t) and phase portrait of the system are plotted for σ = 1.915η, χ = 1.92η, γ = 0.008η, μ = 1.92η, ρ = 1.921η with η = 3.9.

b) Duffing chaotic system

The Duffing's equation 2) is a non-linear, non-autonomous equation, exhibiting various dynamic behaviors, including chaos and bifurcations.

$$x + \varepsilon x + bx^3 = Bcos(\omega t) \quad (2)$$

It can be transformed into an autonomous system of (3) by introducing a new state variable z = t [1].

$$\begin{cases} \dot{x} = y \\ \dot{y} = \varepsilon y + bx^3 + Bcos(\omega z) \\ \dot{z} = 1 \end{cases} \quad (3)$$

This system is solved numerically using the fourth-order Runge–Kutta method with parameters: ε = 0.1, b = 0.25, B = 400, ω = 0.8and initial values (x_0, y_0, z_0,) = (0,1,1).

c) Henon chaotic system

Henon map was discovered by Michel Henon in 1976.The Henon map is a discrete-time dynamical system. It is one of the most studied examples of dynamical systems that exhibit chaotic behavior. The Henon map takes a point (x_n, y_n) in the plane and maps it to a new point.

$$\begin{cases} x_{n+1} = 1 - ax_n^2 + y_n \\ y_{n+1} = bx_n \end{cases} \quad (4)$$

The map depends on two parameters, a and b, which for the classical Henon map have values of a = 1.4 and b = 0.3. For the classical values the Henon map is chaotic. For other values of a and b the map may be chaotic, intermittent, or converge to a periodic orbit.

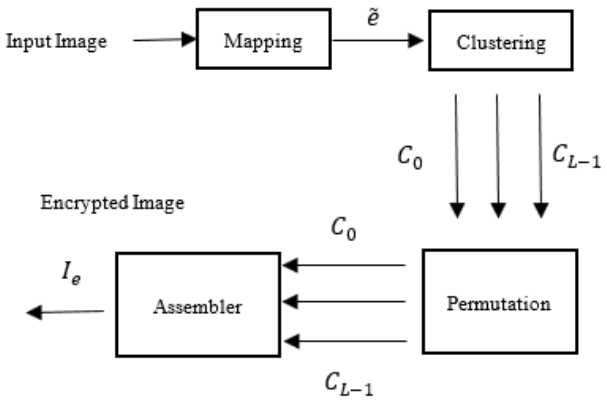

Fig. 1 Schematic diagram of image encryption

Encryption Algorithm:
Step 1: Calculate all the mapped prediction errors E, of the image I.
Step 2: Split all the prediction errors into L number of clusters (C_k for $0 \leq k \leq L-1$). k is the cluster index.
Step 3: Resize the prediction errors in every C_k into a two-dimensional block which have four columns and $C_k/4$ rows. $|C_k|$ denotes the number of prediction errors in C_k.
Step 4: To get the permuted cluster C_k, apply cyclic shift operations to each prediction error block output and read the data in a raster scan manner.
Step 5: The assembler combines all the permuted clusters C_k for $0 \leq k \leq L - 1$, and generate encrypted image, in which each prediction error is represented by 8 bits.
Step 6: Pass encrypted image along with the length of each cluster $|C_k|$ for $0 \leq k \leq L - 1$. The values of $|C_k|$ helps to divide encrypted image into L clusters.

Description of the Encryption Method

Let us consider an $n \times m$ image P to be encrypted. The matrix K_{ij} of the same size $(n \times m)$ is obtained from the two chaotic maps. The new pixel value is obtained from the old one by the transformation.

$$New_{ij} = \left(k_e * \left(OLD_{ij}\right) + (1 - k_e) * 10^{12} * round\left(K_{ij}\right)\right) mod\ (2^8)$$

Asymmetric Numeral Method

Asymmetric Numeral Method (ANM) is an entropy coding method used for compression to improve the compression performance. Entropy encoding is a lossless data compression scheme that is independent of the specific characteristics of the medium and also used to measure the amount of similarity between streams of data. The Entropy coder are Huffman Coder (HC) and Arithmetic Coder (AC). Huffman coder is faster but uses approximate probabilities with powers of 2 which leads to relatively low compression rates [6]. The arithmetic coder uses nearly exact probabilities with larger computational time. ANM has the advantage to combine the compression ratio of arithmetic coder with speed of Huffman coder and it is used in image compression because of high performance and efficiency [10].

In standard binary numeral system, one can add bit of information from a digit S € (0, 1) to an existing number X either to the most significant position (x' → x+s2^m) or to the least significant position (x' → 2x+s). In most significant position, new digit S can choose between ranges and two numbers [position of digit and range at given moment] are required to represent the current state[6]. In least significant position, the current state is single natural number, this is the advantage of ANM. While in standard binary system, X becomes X-th appearance of even (s = 0) or odd (s = 1) number, so it redefines the splitting of N into even and odd number and uniformly distributed with different densities corresponding to symbol probability distribution[10]. From both approaches,

half of the range is enough to represent 1 bit of information, so the current content is lg (size of range/size of sub range) bits of information. While encoding symbol of probability p, the size of sub range is multiplied by p, it increases informational content by lg (1/p) bits. According to ANM, X contains lg (X) bits of information, informational content should increase to

$$\lg(x) = \lg\left(\frac{1}{p}\right) = \lg\left(\frac{x}{p}\right)$$

ANM add information in the least significant position. Its coding rule considered X as X-th appearance of S-th subset of natural numbers corresponding to currently encoded symbol[6]. When uniform (symmetric) probability distribution of symbols is considered, in figure 3, X value 5 represent 10 (if s=0) and 5 represent 11(if s=1). ANM makes it optimal for asymmetric probability distribution of symbols[7]. In ANM, even/odd division of natural numbers are replaced with division into subsets having densities corresponding to the assumed probability distribution. Here, X value 5 represent 8 (if s=0) and 5 represent 16(if s=1) is explained in figure 2.

IV Experimental Analysis

This research attempt to prove that, the encryption schemes improve the security and compression performance when it is used with ETC scheme. Chaos based encryption method always place the values sequentially in pseudo-random orders. In Colpitts-Duffing's encryption the values are placed in sequential manner, which magnifies the small differences. So, it leads to loss of predictability. To avoid the loss of predictability a small negative value is materialized in each vector or block. At the same time Colpitts-Henon uses large negative value to materialize the loss of predictability; this leads to make an arc type curve, which enhance the compression performance of ANM coder with minimal iteration. Experimental results reveals that the Proposed Colpitts-Henon map encryption improves the security and compression performance.

The proposed chaos-based image encryption and ANM compression algorithm is implemented in MATLAB. The experiment is done on various standard 512 × 512, 256×256, 128 ×128 test images like Lena, Baboon, Pepper, Airplane, medical and Satellite images. The proposed algorithm is analyzed based on the performance measures such as compression performance, computation time, number of pixels change rate [NPCR] and unified average changing intensity [UACI]. The main aim of the proposed system is to improve the security and compression efficiency. The method is tested by using several test images composed of 100 images with various characteristics, 10 of which are used to display the result.

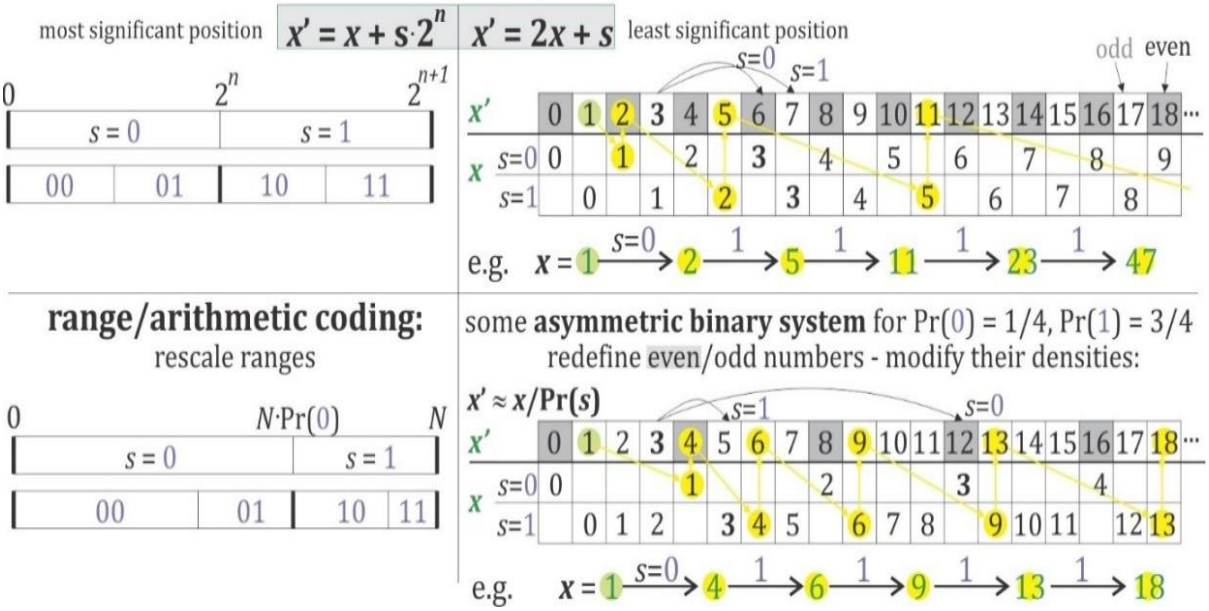

Fig. 2 Asymmetric Numerical Method for Compression

Compression Performance

Table 1 shows the compression performance of Colpitts-Henon Chaos map, Colpitts-Duffing Chaos map and Predictive Error Method in Bytes. Three different compression techniques are used namely Asymmetric Numeral Method [ANM], Huffman Coder [HC] and Arithmetic Coder [AC]. It is observed that the ANM coder with Colpitts-Henon Chaotic system gives good performance than the traditional Huffman and Arithmetic coders irrespective of image size.

Table 1 Comparison Of Compression Performance

Images [512*512]	**Colpitts-Henon Chaotic system**			**Colpitts-Duffing Chaotic system**			**Predictive Error Method**		
	ANM	HC	AC	ANM	HC	AC	ANM	HC	AC
Lena	146867	143789	142456	146742	143851	142517	134267	133789	132456
Boat	156253	153189	152123	155208	153276	152212	144563	143189	142123
Man	186260	161456	181763	176349	161555	171856	164260	162456	161763
Satellite	198277	171234	194845	188342	171294	184899	183277	181234	179845
Medical	199213	182267	160089	197303	182346	160156	194213	192267	190089
Airplane	184852	164154	145009	184712	164224	145088	154852	154154	154009
House	156475	154123	114475	152561	154177	114563	142475	142123	141475
Baboon	156647	154231	143756	153729	152323	143815	135647	135231	134756
Pepper	152847	152142	152035	152713	152208	152097	125647	125142	125035
Bridge	196685	194254	181254	181763	181313	180346	119685	119254	118254

Number of Pixel Change Rate [NPCR]

Number of Pixel Change Rate [NPCR] determines the number of pixels whose values have changed in the encrypted image in the same position for the two plain images, the original and the one with one pixel value changed with respect to the original at some random position. NPCR is measured for the images to analyze the security of the ciphers. Table 2 shows the average of NPCR values and indicates that the sensitivity of the encrypted ciphers of 512 x 512 image is 95.66%, leading to the conclusion that the Colpitts-Henon Chaotic system provides better encryption and it is very sensitive with respect to small pixel changes.

$$\text{NPCR} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} D(i,j)$$

$$D(i,j) = \begin{cases} 0, & \text{if Im } o(i,j) = \text{Im } c(i,j) \\ 1, & \text{if Im } o(i,j) \neq \text{Im } c(i,j) \end{cases}$$

Table 2 Comparison of NPCR

Coder	**Colpitts-Henon Chaotic system**			**Colpitts-Duffing Chaotic system**			**Predictive Error Method**		
Image Size	512*512	256*256	128*128	512*512	256*256	128*128	512*512	256*256	128*128
Lena	99	83	81.5	98.4	82.4	75.6	91.6	83.5	72.4

Boat	98	85	75.6	97.8	84.6	77.8	94.6	85.1	73.4
Man	95.6	86.5	74.8	91.3	82.3	74.6	97.6	82.4	74.5
Satellite	93.5	86.5	77.6	95.3	87.6	72.6	91.6	85.4	75.2
Medical	92.6	89.6	78.4	97.4	88.7	74.6	94.6	81.2	71.6
Airplane	98.5	81.5	74.6	97.1	89.4	78.6	91.4	84.6	74.8
House	92.5	84.6	77.8	91.5	81.6	70.6	96.4	83.6	72.6
Baboon	98.7	82.3	74.6	97.5	87.6	75.6	97.8	87.9	74.6
Pepper	94.8	86.4	78.6	96.4	84.6	73.5	92.5	82.7	75.2
Bridge	93.4	87.6	75.6	95.6	81.3	71.6	94.3	89.4	73.5
Avg	**95.66**	**85.3**	**76.91**	**95.83**	**85.01**	**74.51**	**94.24**	**84.58**	**73.78**

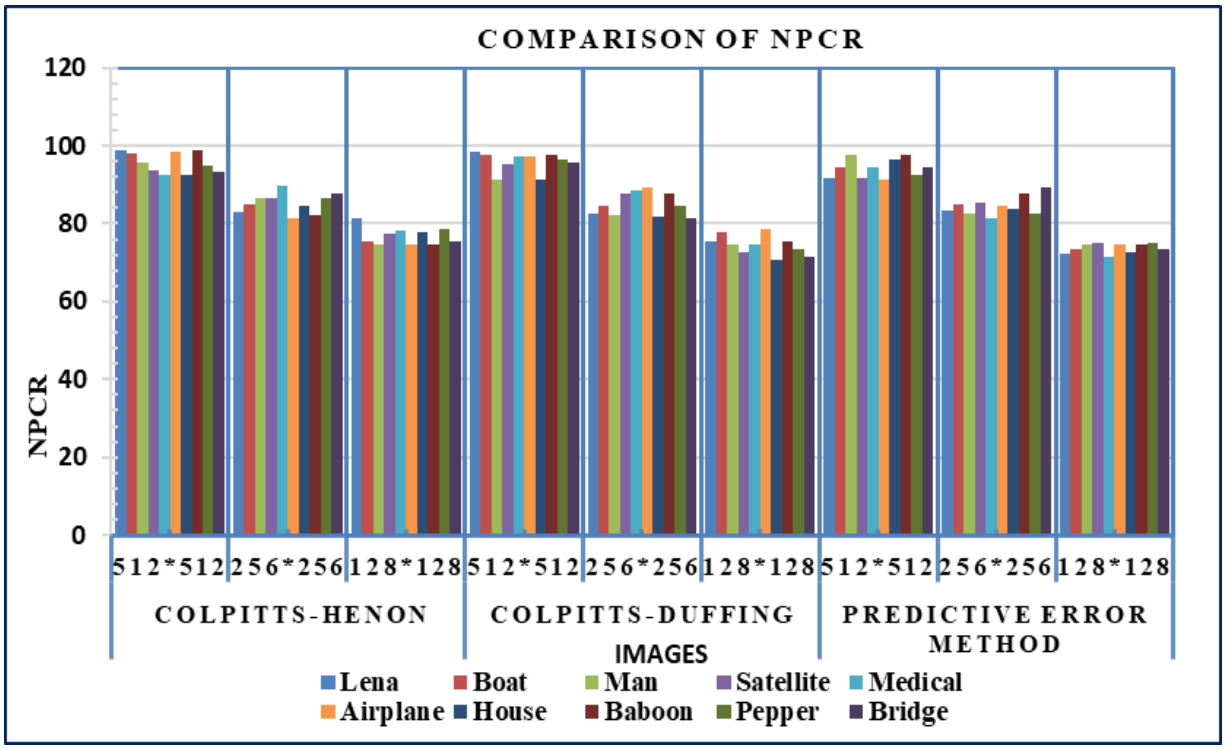

Fig.3 Comparison of NPCR

Unified Average Changing Intensity [UACI]

UACI determines the average change in pixel intensities in corresponding positions in the two encrypted images as a percentage with F, the maximum supported pixel value (F = 255 in gray scale images). From the table 3, the average value of UAIC is 35.36%. UACI value of the proposed encryption scheme is higher than other encryption schemes. The higher value indicates the rate of one pixel change which shows that the Colpitts-Henon Chaotic system provides better encryption.

$$\mathrm{UACI} = \frac{100}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{|\mathrm{Im}\ o(i,j) - \mathrm{Im}\ c(i,j)|}{255}$$

Table 3 Comparison of UACI

Coder	**Colpitts-Henon Chaotic system**			**Colpitts-Duffing Chaotic system**			**Predictive Error method**		
Image Size	512*512	256*256	128*128	512*512	256*256	128*128	512*512	256*256	128*128
Lena	34.4	25.2	19.5	35.4	24.8	17.5	33.2	23.3	13.1
Boat	34.8	25.4	14.4	34.5	21.5	14.5	30.2	22.1	16.4
Man	35.5	22.6	17	32.2	24.7	12.8	32.2	20.4	17.7
Satellite	33.5	24.7	15.4	35.6	25.6	18.6	35	21.7	17.7
Medical	35.4	24.6	14.8	36.7	24.8	18.1	36.2	19.3	16.5
Airplane	37.8	29.4	19.6	31.1	21.7	17.5	35.4	21.9	16.7
House	34.5	23.5	16.5	34.7	26.4	19.4	30.4	19.9	19.4
Baboon	37.8	27.6	18.2	33.5	21.4	16.4	31.2	23.3	13.4
Pepper	34.2	24.5	17.6	34.7	27.4	18.4	30.4	23.1	15.5
Bridge	35.7	23.6	17.9	31.7	25.8	16.5	34.9	28.9	22.5
Avg	**35.36**	**25.11**	**17.09**	**34.01**	**24.41**	**16.97**	**32.91**	**22.39**	**16.89**

Table 4 Comparison of COMPUTATION TIME

Coder	**Colpitts-Henon Chaotic system**			**Colpitts-Duffing Chaotic system**			**Predictive Error method**		
Image Size	512*512	256*256	128*128	512*512	256*256	128*128	512*512	256*256	128*128
Lena	2.134	1.553	0.632	2.775	1.912	0.878	2.267	1.203	0.398
Boat	2.169	1.743	0.725	2.834	1.302	0.587	2.567	1.601	0.745
Man	2.155	1.867	0.854	2.043	1.056	0.950	2.479	1.967	0.500
Satellite	2.743	1.732	0.902	2.065	1.089	0.454	2.343	1.467	0.513
Medical	2.676	1.389	0.802	2.883	1.089	0.543	2.912	1.789	0.856
Airplane	2.545	1.542	0.556	2.853	1.885	0.454	2.984	1.595	0.854
House	2.754	1.65	0.545	2.545	1.954	0.754	2.785	1.754	0.796
Baboon	2.864	1.85	0.654	2.556	1.825	0.454	2.865	1.385	0.565
Pepper	2.684	1.84	0.854	2.948	1.954	0.885	2.954	1.754	0.754
Bridge	2.665	1.56	0.565	2.544	1.745	0.684	2.174	1.854	0.865
Avg	**2.5389**	**1.6726**	**0.7089**	**2.6046**	**1.5811**	**0.6643**	**2.633**	**1.6369**	**0.6846**

Computation Time

The computation time of encryption schemes are given in table 4. It is found that the average computation time is stable for all the encryption schemes. From the analysis it is clear that the proposed chaotic based encryption system with ANM coder shows better result in ETC system.

IV. Conclusion

In this paper, Chaotic image encryption and asymmetric numeral method for compression has been introduced to improve the image compression ratio with security. Colpitts-Henon and Colpitts-Duffing Chaotic systems are used to encrypt the images. Colpitts Henon overcomes the limitation in the Colpitts Duffing system. The numerical simulation results proved that the Colpitts Henon system is efficient. From the experimental results, it is seen that the average of NPCR and UACI value is 95.66% and 35.36% which gives the conclusion that the cipher is very sensitive with respect to small pixel changes in plain image of Colpitts henon system. Table values shows that the combination of proposed Colpitts-Henon method with ANM provides better compression performance.

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