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On the Sanctuary of a Combined Confusion and Diffusion based scheme for Image Encryption

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Abstract*: Confusion and diffusion are the frequently used embryonics in multimedia (image) encryption systems. Multimedia data protection against cryptanalysis can be effectually fortified by these techniques. Due to inherent properties of images such as high inter-pixel redundancy and bulk data capacity, encryption is performed in two stages: Confusion and Diffusion. In this article, a combined Pseudo Hadamard transformation in the confusion stage and Gingerbreadman chaotic substitution in the diffusion stage are used in the encryption phase of the algorithm. The strong correlation between contiguous elements in the host image is effectually reduced using Pseudo Hadamard transformation and entropy in the cipher image is enhanced using Gingerbreadman chaotic substitution. Secrete key length used in the algorithm is 128 bits, these are the initial conditions for Gingerbreadman chaotic generator. The elements of S-box in the substitution stage are considered from this random sequence generator. Experimental exploration including information entropy, correlation analysis, sensitivity analysis, key space analysis and computational complexity have been performed on set of standard images. Results obtained are better compared to many existing systems.

Keywords*: Confusion; Encryption; Correlation; Entropy; Security; Diffusion; Multimedia.

I. INTRODUCTION

Distinctive and swift evolution in the field of technology fortified significant advancement in past decade. Intellectual Property venders are more concerned about legitimacy of private information in multimedia due to security violations by unauthorized users [1]. Confidentiality can be enhanced by encrypting the original information into cipher form. In order to ensure secure transmission of image data, multimedia encryption mystifies the host stream into cipher form and conceded between two parties over a public channel. Popular encryption standardized, such as Advanced Encryption Standard (AES) and Data Encryption Standard (DES) have been broadly espoused worldwide, since decades. But, the delinquent of image encryption is yonder the solicitation of conventional and renowned encryption algorithms. This is mainly due to the application requirements and constrictions levied by the data structure of images, such as format compliance, perceptibility, complexity, real-time performance, compression efficiency and the security level [2][16-26]. To treatise these disquiets, substantial endeavors have been made to mature robust encryption systems for the image data. Image encryption standards are designed with three diversified methods of operations, due to its grid nature. The three different stages include: value transformation, position permutation and the combination form. Between different maneuvers, permutation (confusion) is a frequently espoused primeval in most of the image encryption algorithms. This is essentially due to the easy enactment and application in both frequency and spatial domains [3]. Traditional and conformist encryption algorithms, such as DES, RSA or AES cannot be applied for images, due to rate adaptation in heterogeneous networks for multimedia transmission and for multimedia content in image extraction [4]. In order develop an efficient encryption algorithm, chaos based encryption schemes are more popular, now a day [5-9]. Shereek et al. [10] described a method for information security by applying a combined RSA and Fermat's algorithm. Even though Fermat's algorithm increases the speed of the RSA, the hybrid technique uses more time to generate the substitution elements. Liu et al. [11] formed a public authority based on privacy-preserving authentication protocol (SAPA) to discourse privacy concern in information stowage. They portrayed an improved Montgomery block Lanczos scheme for encryption in data protection. Rivest et al. [12] revealed a public-key encryption process using a secrete key overtly exposed by the envisioned inheritor where the message was deciphered with a decryption key. Saxena et al. [13] exemplified the review of numerous parallel implementations of RSA algorithm linking diversity of hardware and software enhancements. Symmetric key algorithms use a single key to encrypt as well as to decrypt the data whereas public key algorithms use two distinct keys for encryption and decryption. Padmaja et al. [14] proposed the security of cloud computing using public key cryptography using RSA algorithm. The amount of protection needed to secure data was directly proportional to the value of the data and the performance of the cloud network varies according to the type of the algorithm such as symmetric, asymmetric or hashing algorithms. Genkin et al. [15] exemplified a cryptoanalysis key abstraction technique through the application of RSA. A combined Pseudo Hadamard transformation (PHT) and Gingerbreadman Chaotic (GBC) replacement based image encryption algorithm has been proposed in order to provide two stage security per each round.

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II. METHODOLOGY

Encryption is performed in two phases: Confusion and Diffusion. In the confusion phase, pixel positions in the host and substitution images are interchanged/mapped according to Pseudo Hadamard transformation. Since image is a two dimensional matrix, each pixel can be represented by a two dimensional space. The resultant transformed images of both host and substitution are subjected to logical XOR operation to get the cipher image. S-box is developed for diffusion processes using random sequence generated by Gingerbreadman chaotic key sequence generator. Final cipher image is attained by relieving elements of S-box with each element of cipher image acquired from initial stage.

A. *Ciphering Phase*

Step1: The original (host) and substitution images are first imperiled to PHT.

$$H'(\psi,\mu) = H((\alpha+\beta)\ mod\ 2^n, (\alpha+2\beta)\ mod\ 2^n) \quad (1)$$

$$S'(\psi,\mu) = S^t((\alpha'+\beta')\ mod\ 2^n, (\alpha'+2\beta')\ mod\ 2^n) \quad (2)$$

$$1 \le \alpha, \alpha', \beta, \beta' \le 2^n$$

Where,

H - Original (host) image (2^n X 2^n)

S - Substitution image (2^n X 2^n)

H' - Transformed image (2^n X 2^n)

S^t- Transformed image (substitution) (2^n X 2^n)

Step2: Both transformed images of host and substitute are imperiled to bitwise XOR operation

$$C(\psi,\mu) = H'(\psi,\mu) \oplus S'(\psi,\mu) \quad (3)$$

Where,

$C(\psi,\mu)$ - Encrypted image from stage-1

Step3: Encrypted image from previous stage is imperiled to bitwise XOR operation with the predefined elements of Sbox-1 for first stage substitution (Second stage of encryption).

$$C"(\psi,\mu) = C(\psi,\mu) \oplus Sbox\text{-}1 \quad (4)$$

Step4: Encrypted image from second stage is imperiled to substitution with Sbox-2 created using arbitrary sequences engendered by Gingerbreadman chaotic generator.

$$a'_n = (1 - b_n + |a_n|)\ mod\ 2^n \quad 1 \le n \le 8 \quad (5)$$

$$b'_n = (b_n)\ mod\ 2^n \quad (6)$$

Where

a_n= present key value

$$C'(\psi,\mu) = C"(\psi,\mu) \oplus Sbox\text{-}2 \quad (7)$$

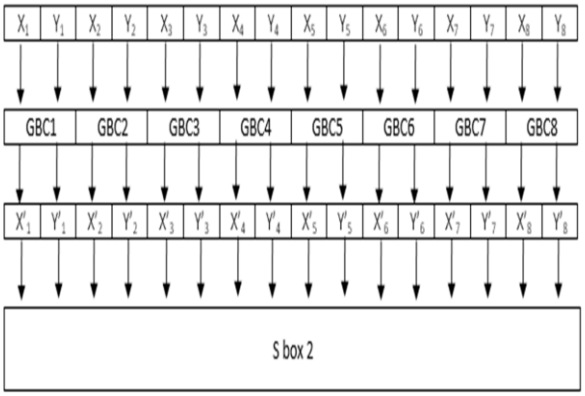


Fig. 1 Key sequence generation algorithm

B. De-ciphering Algorithm

Step1: Obtained cipher image is first bit wise XORed with the elements of Sbox-2, the same used for encryption.

$$a'_n = (1 - b_n + |a_n|)\ mod\ 2^n \quad 1 \le n \le 8 \quad (8)$$

$$b'_n = (b_n)\ mod\ 2^n \quad (9)$$

Where

a_n= present key value

$$C"(\psi,\mu) = C'(\psi,\mu) \oplus Sbox\ 2 \quad (10)$$

Step2: De-substituted image from previous stage is imperiled to bitwise XOR operation with elements of Sbox-1.

$$C(\psi,\mu) = C"(\psi,\mu) \oplus Sbox\ 1 \quad (11)$$

Step3: The substitution image same as that in the encryption stage is imperiled to PHT and then XORed with cipher image from previous stage.

$$S'(\psi,\mu) = S^t(\alpha'+\beta')\ mod\ 2^n, (\alpha'+2\beta')\ mod\ 2^n \quad (12)$$

$$H'(\psi,\mu) = C(\psi,\mu) \oplus S'(\psi,\mu) \quad (13)$$

Step4: The obtained image from substitution stage is exposed to inverse PHT to get original image.

$$H''(\alpha,\beta) = O'((2\psi - \mu)\ mod\ 2^n, (\mu - \psi)\ mod\ 2^n) \quad (14)$$

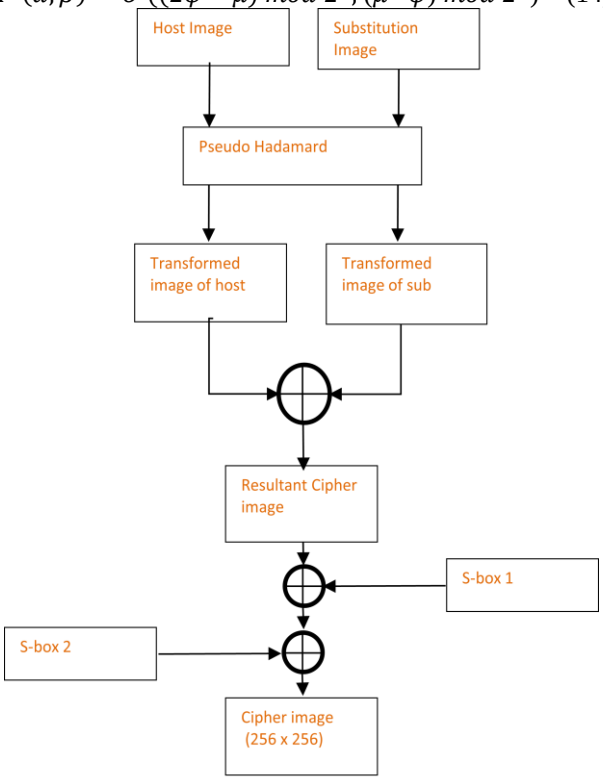


Fig. 2 Flow diagram of proposed encryption algorithm

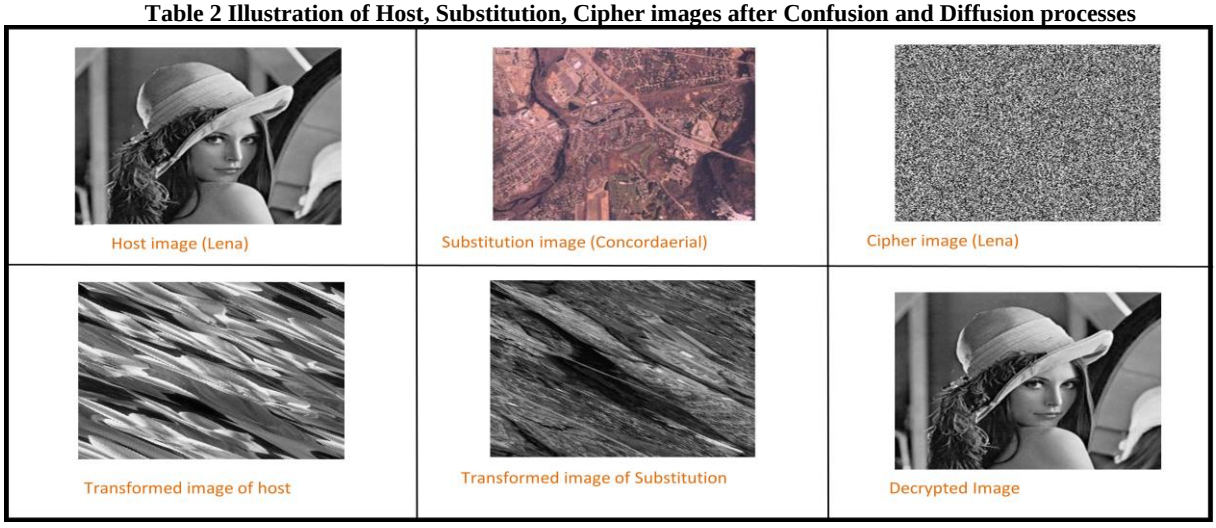
III. EXPERIMENTAL RESULTS

Security exploration is accomplished on the basis of Unified Average Changing Intensity (UACI), Number of Pixel Changing Rate (NPCR), Mean Correlation and Entropy between host and encrypted images as tabulated in Table 1. Experimental scrutiny and enactment are done using Matlab software. Database is considered from Computer Vision Group, Granada, Spain. Illustration of Host images, Substitution image, Cipher images after transformation and substitution in Table 2. The estimated values of UACI and NPCR are neighboring to the ideal values, signifying high competence in contradiction to differential security occurrences. After confusion phase, interpixel redundancy in the cipher image is effective reduced and high entropy is perceived after diffusion phase, very close to the ideal values [30].

Table 1 Comparison of Entropy, Correlation, UACI and NPCR between standard and encrypted images

Images	Entropy = 8 [30]	Correlation	UACI ≥ 33.4635% [30]	NPCR ≥ 99.6093% [30]
Lena	5.5407 (Blow Fish) [28]	0.0021 [28]	31.00 [27]	90.21 [27]
	5.5438 (Two Fish) [28]			
	5.5439(AES 256) [27]			
	5.5439 (RC 4) [27]	0.1500 [27]	32.01 [27]	99.60 [27]
	7.5220 [27]			
	7.6427 [31]			
	7.9958 [27]	0.0256	33.4201 [27]	99.5859 [27]
	7.9970 [29]			
	7.9971 [27]			
	7.9972 [27]		33.46	99.57
	7.9972			
Baboon	7.9947 [27]	-0.0043	30.87 [27]	99.59 [27]
	7.9950 [27]			
	7.9970		33.28	99.59
Peppers	7.9954 [27]	5.1589e-04	30.71 [27]	99.61 [27]
	7.9960 [27]		33.46	99.59
	7.9973			
Plane	7.9971	0.0027	33.40	99.59
Cameraman	7.9972	-0.0037	33.42	99.62
Elaine	7.9973	8.1763e-04	33.49	99.58
Carnev	7.9975	-0.0024	33.49	99.58
Donna	7.9972	0.0028	33.42	99.61
Foto	7.9970	0.0064	33.58	99.60
Galaxia	7.9971	-0.0013	33.53	99.59
Leopard	7.9971	-0.0029	33.40	99.59
Montage	7.9972	0.0066	33.47	99.58
Pallon	7.9973	-0.0012	33.31	99.60
Vacas	7.9971	-0.0016	33.53	99.58
Fiore	7.9971	-0.0008	33.27	99.60
Mapasp	7.9974	-0.0018	33.41	99.58
Mare	7.9973	-0.0008	33.43	99.59
Mesa	7.9973	0.0027	33.63	99.61
Papav	7.9973	-0.0011	33.41	99.62
Tulips	7.9974	0.0034	33.62	99.61

Table 2 Illustration of Host, Substitution, Cipher images after Confusion and Diffusion processes



Inference 1: The average value of Number of Pixel Changing Rate (NPCR) is 99.594% for encrypted images and is very much neighbouring to the ideal value 99.6093% [30] with a very minimum variance of 0.015%. The NPCR value drifts among 99.57% to 99.62%. The average value of Unified Average Changing Intensity (UACI) is 33.4505% for cipher images, neighbouring to ideal value 33.4635% [30] with the minimum variance of 0.013%. The UACI value drifts among 33.27% to 33.63%

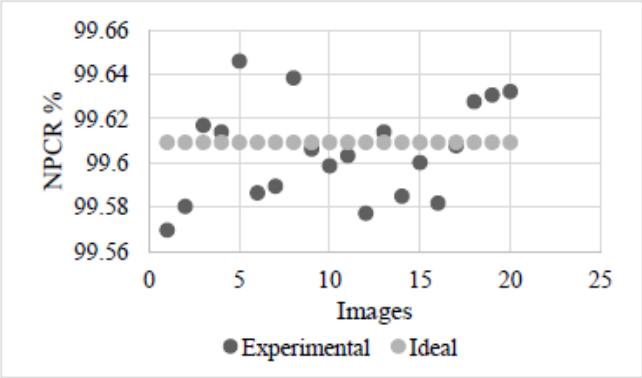


Fig. 3 Number of Pixel Changing Rate of cipher images

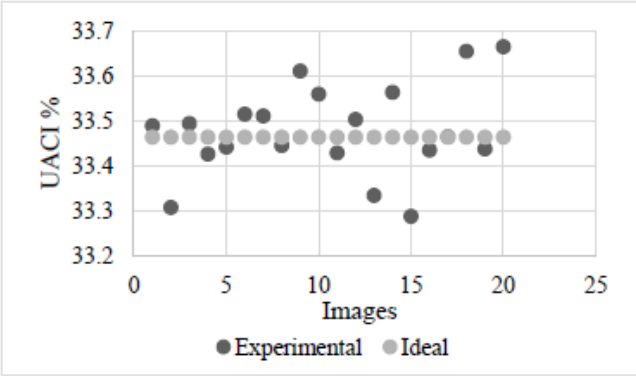


Fig. 4 Unified Average Changing Intensity of cipher images

***Inference 2*:** The average entropy value of encrypted images is 7.9972. Its intimacy to the ideal value is about 99.96%. The average correlation coefficient between encrypted images in relation with host images is 0.0014. Very slightest correlation has been perceived between host and final encrypted image, indicating deprived similarity between them.

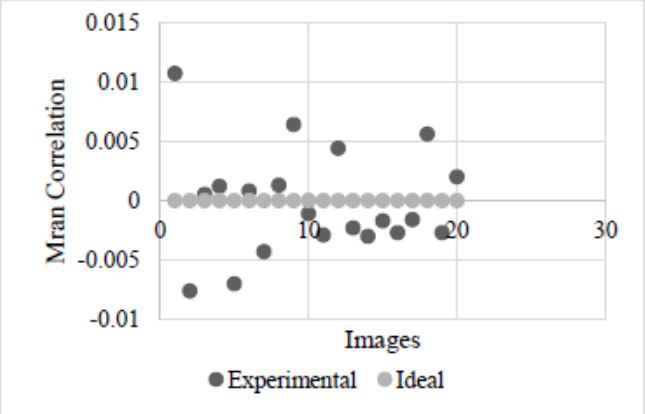


Fig. 5 Mean correlation between original and cipher images

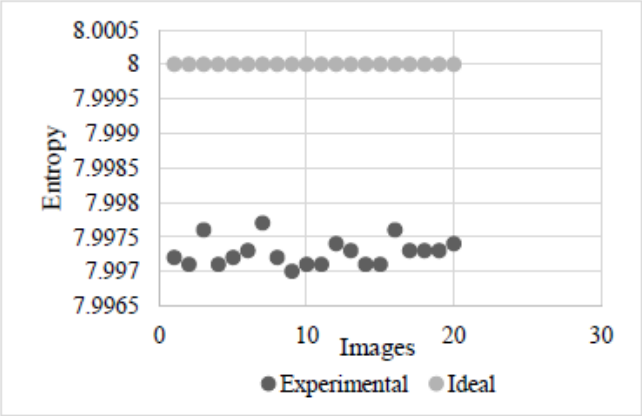
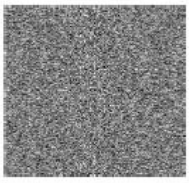
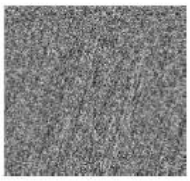
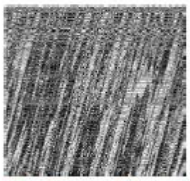
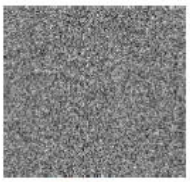
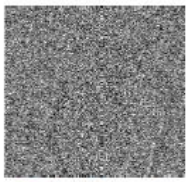
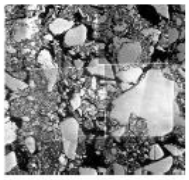
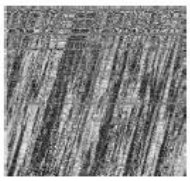
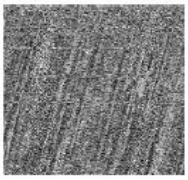
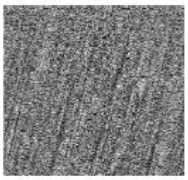
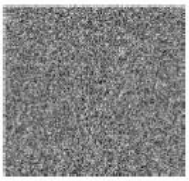
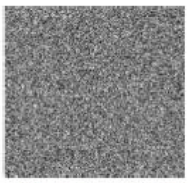
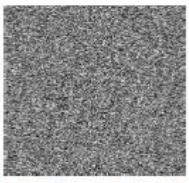
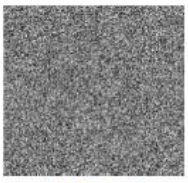
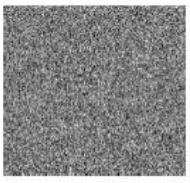
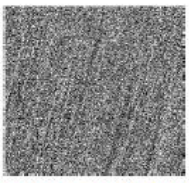
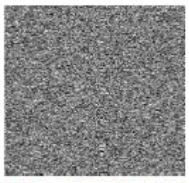


Fig. 6 Information entropy of cipher images

 Lena	 Baboon	 Pepper	 Airplane	 Cameraman
 Cipher Image (Lena)	 Cipher Image (Baboon)	 Cipher Image (Pepper)	 Cipher Image (Airplane)	 Cipher Image of (Cameraman)
 Elaine	 Carnev	 Donna	 Foto	 Soil
 Cipher Image (Elaine)	 Cipher Image (Carnev)	 Cipher Image (Donna)	 Cipher Image (Foto)	 Cipher Image (Soil)
 Barche	 Montage	 Pallon	 Vacas	 Tulips
 Cipher Image (Barche)	 Cipher Image (Montage)	 Cipher Image (Pallon)	 Cipher Image (Vacas)	 Cipher Image (Tulips)

IV. CONCLUSION

A new image encryption/decryption scheme based on diffusion by Gingerbreadman Chaotic (GBC) substitution and confusion by Pseudo Hadamard transformation (PHT) is magnificently proposed. The strong correlation between contiguous elements in the host image is effectually reduced using Pseudo Hadamard transformation with an average correlation of 0.0014 between original and cipher images. Average entropy of 7.9972 in the cipher image is observed using Gingerbreadman chaotic substitution. The algorithm is intended with 128 bits of secrete key.

This is used as initial condition for chaotic generator in the substitution phase of the algorithm. Due to 2^128 combinations of secrete key, brute force attack is tardy with respect to execution speed of the processor. Standard test images are considered for experimental analysis. In the security tests, average values of 33.4505% UACI and 99.594% NPCR are obtained for a set of twenty standard images and they are very close to the ideal values. Further, UACI and NPCR can be increased by introducing constants along with variants in chaotic generator to obtain more randomness in the chaotic sequence.

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