BALTIC JOURNAL OF LAW & POLITICS
A Journal of Vytautas Magnus University
VOLUME 15, NUMBER 4 (2022)
ISSN 2029-0454

sciendo

Cite: *Baltic Journal of Law & Politics* 15:4 (2022): 185-196
DOI: 10.2478/bjlp-2022-004019

Reduction of Correlation in 2D Image Encryption Using Novel Quadratic Chaotic Map in Comparison With Baker Map

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Received: August 8, 2022; reviews: 2; accepted: November 29, 2022.

ABSTRACT

Aim: The aim of the research work is to develop 2D Image encryption using Novel Quadratic chaotic encryption method for reducing the correlation coefficient and it is compared with Baker chaotic encryption method. **Materials and Methods:** Comparative analysis of correlation is performed by Novel Quadratic Map where number of samples (N = 10) and Baker map where number of samples (N = 10) techniques with pre-test power of 80% using MATLAB software. **Results:** The correlation coefficient of novel quadratic chaotic map is 0.00304 in vertical, 0.00238 in horizontal, -0.00065 in diagonal direction and whereas the correlation coefficient of baker chaotic map is 0.00019 in vertical, 0.00196 in horizontal, 0.00115 in diagonal. There is a significant difference in the results obtained and were considered to be error-free since it has the significance value p = 0.045 ($p < 0.05$) in SPSS analysis. **Conclusion**: The Novel Quadratic Chaotic Map performs significantly better in reducing the correlation in 2D image encryption when compared to Baker Chaotic map.

Keywords

Novel Quadratic chaotic map, Baker chaotic map, Image encryption, Correlation, Random Shuffling, Diffusion.

INTRODUCTION

The basic idea behind chaotic encryption is to use a few dynamic structures to generate a series of numbers that can be random in nature. Encryption of images or communications is done with this set of numbers (H. Li et al. 2021). A numerical measure of how closely two random variables vary in reaction to one another is called correlation. A positive means that when one variable rises, the other tends to fall. A negative correlation means that when one variable rises, the other climbs with it (Yang, Pan, and Ding 2022).If there is no correlation, then there is no predictable link between the variables. In order to provide consumers with such security and privacy, image encryption is necessary (Zhang et al. 2021). To combat unwanted user access, image encryption is essential (Ding et al. 2021).

Pixels in chaotic maps are confused or disordered. The chaotic encryption has a wide range of applications in the cipher generation for medical imaging, in DNA cryptography, to perform security protocol (Noorbasha and Suresh 2018).

Many researches on 2D image encryption utilizing various techniques have recently been undertaken using quadratic chaotic map and baker chaotic map. IEEE Xplore published 42 research papers and in google scholar found 45 articles. In (Guo et al. 2020) a pseudo random generator is produced using the quadratic chaotic map in improvement of the diffusion algorithm. In (Herbadji et al. 2020) proposed an enhanced quadratic map (EQM) and implied on color image scheme. Results indicate that the scheme has higher sensitivity and weaker correlation. In (Zhu et al. 2019) constructed quadratic polynomial chaotic maps with three parameters. Gaussian measurement matrix are discussed. In (Wang and Ding 2019) proposed polynomial chaotic maps that control the amplitude of chaotic time series and stability analysis of fixed points. In (Z. Li et al. 2020) proposed an efficient and safe chaos based color image encryption system employing bit level permutation is suggested to protect the security of digital images during transmission and storage. In (Alhumyani 2020) used a chaotic baker map in the discrete cosine transform to create an efficient image cipher. The proposed DCT based baker map image cipher encryption module performs a DCT on the original plain image, then random shuffling is done on the plain DCT image coefficients with the baker map. In (Ozturk and Kilic 2019) on digital platforms, new approaches such as integer domain chaotic systems (IDCS) in all dimensions were developed. A LSB -extension has also been proposed by generalizing the 2D baker map, BSCM is presented in all dimensions.

Previously our team has a rich experience in working on various research projects across multiple disciplines (Venu and Appavu 2021; Gudipaneni et al. 2020; Sivasamy, Venugopal, and Espinoza-González 2020; Sathish et al. 2020; Reddy et al. 2020; Sathish and Karthick 2020; Benin et al. 2020; Nalini, Selvaraj, and Kumar 2020).The Quadratic chaotic map and baker chaotic map are two known techniques for minimizing vertical, horizontal and diagonal correlation in 2D image encryption. The fundamental disadvantage of present approaches is that they have a high correlation coefficient due to poor random pixel shuffling and confusion. In comparison with the novel Baker chaotic map, the major goal of this research is to provide an effective solution for reducing correlation in vertical, horizontal and diagonal directions using quadratic chaotic map.

MATERIALS AND METHODS

This research was carried out at saveetha school of engineering, SIMATS, Tamilnadu, India, at the digital image processing laboratory of the department of electronics and communication engineering. The modified data set includes 20 original images each of which has been scaled to 512x512 size. The sample size was established based on the findings of prior studies and found to be 10 for each group.A device with specifications (CPU 8th gen, i5, 8GB RAM, 1TB HDD) and MATLAB programme with the needed library functions and tool functions are required to simulate this software. The computation is done with G-power at 80%, threshold at 0.86% confidence interval at a 70% confidence level.

Novel Quadratic chaotic map is one form of chaotic map that shows some type of chaotic behavior. The quadratic function is given below as eq (1) and eq (2) where a, b, c and d denote system parameters considered a 0.9, b as 0.6, c as 2, d as 0.50 and x_n, y_n denote as state variables. Since the system is chaotic two chaotic sequences x_n and y_n can be generated (Herbadji et al. 2020). The quadratic function is used to generate two random arrays of key values Now these key values are used to encrypt the image.

$$x_{(n+1)} = x_n^2 - y^2 + ax_n + by_n \quad (1)$$

$$y_{(n+1)} = 2x_n y_n + cx_n + dy_n \quad (2)$$

Baker chaotic map is another sort of chaotic map that displays some type of chaotic behavior, such as confusion and random shuffling of pixels (Abitha and Bharathan 2016). In these designs, the baker map diffuses the image in an unanticipated manner, traveling horizontally to the block's end and then to the row above the current row. The other function which is considered in this paper is a baker chaotic map. The baker function is given below as eq (3) and eq (4) where a, b denotes the system parameters considered a = 1.4 and b = 0.3 and x_n and y_n as state variables. This function also generates two chaotic sequences.

$$x_{(n+1)} = 1-ax_n^2+y_n \quad (3)$$
$$y_{(n+1)} = by_n \quad (4)$$

An customized image is used as an input to the programme, with each pixel represented in decimal form. To conduct the XOR operation, each pixel must first be translated to binary form. Now a function is built to generate two keys in the 256 and 512 range. The image pixel will be xored with the key in the range 256, and the second key in the range 512 will be used to shuffle the row and column of another key matrix. In order to attain a lower correlation coefficient, the encrypted image pixels are shuffled. Diffusion and random shuffling are also one of the important factors to be considered for better encryption. The encrypted image will be saved in a new variable. The encrypted image binary is transformed to decimal once again, resulting in a series of pixels that are merged to create a digital image.

The tool used to execute the process was MATLAB software version 21a (Kim 2017) . The pixels are confused using the random key process containing a sequence of values, which undergoes diffusion. This process provides a set of pixels which are not related to each other. This makes the encrypted image to achieve very low correlation coefficients.

STATISTICAL ANALYSIS

SPSS version 21 was used for statistical analysis of collected data for parameters vertical correlation coefficient, horizontal correlation coefficient and diagonal correlation coefficient (McCormick and Salcedo 2017). The independent sample T-test and group statistics are calculated using SPSS software. Correlation is a dependent variable and size of the image is an independent variable.

RESULTS

Figure 1 The original, encrypted and decrypted images are shown. The original images are shown in figures (a), (d) and (g). The encrypted images utilizing the quadratic chaotic map are shown in figures (b), (e) and (h). The decrypted images of encrypted images are shown in figures (c), (f) and (i).

Figure 2 The original, encrypted and decrypted images are shown. The original images are shown in figures (a), (d) and (g). The encrypted images utilizing the baker chaotic map are shown in figures (b), (e) and (h). The decrypted images of encrypted images are shown in figures (c), (f) and (i).

Figure 3 illustrates the quadratic chaotic map's correlation analysis of the cameraman image. Figure (a), (c) and (e) shows the original image correlation in vertical, horizontal and diagonal directions. Whereas figures (b), (d) and (f) show the encrypted image correlation in vertical, horizontal and diagonal directions respectively.

Figure 4 illustrates the baker chaotic map's correlation analysis of the cameraman image. Figure (a), (c) and (e) shows the original image correlation in vertical, horizontal and diagonal directions. Whereas figures (b), (d) and (f) show the encrypted image correlation in vertical, horizontal and diagonal directions respectively.

Figure 5 shows the graph created with SPSS that compares the mean of diagonal correlation coefficients of quadratic chaotic map and baker chaotic map. It represents the quadratic chaotic map having lesser correlation coefficient in comparison with the Baker chaotic map. For quadratic chaotic map the correlation is -0.00065 but the baker chaotic map has correlation 0.00115.

Table 1 shows the values of the correlation coefficient of the original image and the encrypted images using the quadratic chaotic map in vertical, horizontal and diagonal directions.

Table 2 shows the values of the correlation coefficient of original and encrypted images using the baker chaotic map in vertical, horizontal and diagonal directions.

Table 3 shows that from spss statistical analysis, mean, standard deviation and standard error rate for quadratic encryption method and the baker encryption method were obtained. There is a statistical significance difference between correlation coefficients of two methods. The quadratic encryption method obtained a maximum standard deviation of 0.00149 and minimum standard error 0f 0.00033 while the baker encryption method obtained a maximum standard deviation of 0.00131 and minimum standard error of 0.00017. The mean correlation using the quadratic encryption method of -0.00065 was better than the baker encryption method of 0.00115 and the standard deviation of the quadratic encryption method is 0.0015 which is slightly higher than 0.00131 of the baker encryption method.

Table 4 shows the statistical computations for independent sample t-test between quadratic chaotic map and baker chaotic map. The correlation coefficient has a value of 0.0048 with a confidence level of 95 percent and a threshold of significance of 0.6959, an independent sample t-test is used to compare the quadratic chaotic map with the baker chaotic map. The independent sample test includes 0.0010 significance(2-tailed), mean difference, standard error difference, lower and upper interval difference.

DISCUSSION

To minimize the correlation of the pixels in the encrypted image, two distinct methods were used. The novel quadratic chaotic map performs significantly better in reducing the correlation 0.00304 in vertical, 0.00238 in horizontal and -0.00065 in diagonal direction, when compared to the baker chaotic map 0.0019 in vertical, 0.00196 in horizontal and 0.00115 in diagonal direction. The results are obtained with a significance value $p = 0.045$ ($p < 0.05$) in SPSS statistical analysis.
From the study of previous performance analysis (Herbadji et al. 2020), the technique used was enhanced quadric map (EQM) and obtained a minimum correlation coefficient of -0.00019 in diagonal direction and (Guo et al. 2020) used the quadratic chaotic map with improved confusion and diffusion algorithms, further used cyclic shift operators and obtained a minimum correlation coefficient of -0.0098. On the other hand (Alhumyani 2020) by applying DCT on the original image, shuffling the pixels and inverse DCT obtained a correlation coefficient of -0.0065. (Musanna and Kumar 2020) obtained a correlation coefficient of 0.0036 in vertical, -0.0016 in horizontal, -0.0057 in diagonal by using the quantum gates like C-NOT and Ripple-carry adder. Overall research studies show that quadratic chaotic encryption technique is better in all the above studies. There are no opposite findings found.

The disadvantage of this chaotic encryption approach was that it takes a longer time for random shuffling and encryption of images. The goal of this future research is to develop an efficient encryption method that produces the least amount of correlation in the shortest amount of time.

CONCLUSION

Two different methods to determine correlation coefficient were evaluated using performance parameters such as horizontal, vertical and diagonal correlation coefficients. The Novel Quadratic Chaotic map achieved the correlation of about 20% and the Baker map achieved the correlation of about 30%. It is found that the Novel Quadratic chaotic map is found to be significantly better by reducing the correlation levels compared to Baker chaotic map.

DECLARATIONS

Conflicts of Interest

No conflict of interest in this manuscript.

Author Contribution

Author PVS was involved in the data collection, data analysis and manuscript writing. Author RN was involved in conceptualization, guidance and critical review of manuscript.

Acknowledgement

The authors would like to express their gratitude towards Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences(formerly known as Saveetha University) for providing the necessary infrastructure to carry out this work successfully.

Fundings

We thank the following organizations for providing financial support and enabling us to complete the study.

1.Kacho Pvt.Ltd,Chennai
2.Saveetha University.
3.Saveetha School of Medical and Technical Sciences.
4.Saveetha School of Engineering.

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TABLES AND FIGURES

Table 1. Comparison of correlation coefficients of original images and the novel quadratic chaotic map encrypted images.

Standard images	Standard image			Encrypted image		
	Vertical	Horizontal	Diagonal	Vertical	Horizontal	Diagonal
cameraman	0.9334	0.9723	0.9647	0.00270	0.00236	0.00018
coins	0.9872	0.9654	0.9576	0.00505	0.00137	-0.00142
fabric	0.9845	0.9934	0.9845	0.00203	0.00377	-0.00311
football	0.9345	0.9746	0.9933	0.00441	0.00300	-0.00103
forest	0.9849	0.9847	0.9847	0.00286	0.00301	-0.00113
lenna	0.9843	0.9473	0.9476	0.00354	0.00297	0.00135
mandril	0.9873	0.9883	0.9877	0.00305	0.00308	0.00109
pears	0.9766	0.9643	0.9465	-0.00043	0.00246	-0.00270
rice	0.9822	0.9887	0.9753	0.00382	0.00023	0.00008

Table 2. Comparison of correlation coefficients of original images and the baker chaotic map encrypted images.

Standard images	Standard image			Encrypted image		
	Vertical	Horizontal	Diagonal	Vertical	Horizontal	Diagonal
cameraman	0.9334	0.9723	0.9647	-0.00001	0.00221	-0.00144
coins	0.9872	0.9654	0.9576	-0.00032	0.00132	0.00038
fabric	0.9845	0.9934	0.9845	0.002585	0.00196	0.00210
football	0.9345	0.9746	0.9933	-0.00052	0.00304	0.00214
forest	0.9849	0.9847	0.9847	-0.00063	0.00152	-0.00026
lenna	0.9843	0.9473	0.9476	0.00014	0.00162	0.002451
mandril	0.9873	0.9883	0.9877	0.00029	0.00192	-0.00002

pears	0.9766	0.9643	0.9465	-0.00057	0.00139	0.00244
rice	0.9822	0.9887	0.9753	0.00103	0.00204	0.00110
cameraman	0.9334	0.9723	0.9647	-1.27E-07	0.00221	-0.00144

Table 3. Group statistics of image encryption can be done for analysis of Vertical, Horizontal, Diagonal comparison between the novel quadratic chaotic map encryption and the baker chaotic map encryption.

	Groups	**N**	**Mean**	**Std.Deviation**	**Std.Error Mean**
Vertical Correlation coefficient	Quadratic	10	0.00304	0.00149	0.00047
	Baker	10	0.00199	0.00098	0.00030
Horizontal Correlation coefficient	Quadratic	10	0.00238	0.00104	0.00033
	Baker	10	0.00196	0.00054	0.00017
Diagonal Correlation coefficient	Quadratic	10	-0.00065	0.00150	0.00047
	Baker	10	0.00115	0.00131	0.00041

Table 4. The independent samples test between novel quadratic chaotic map and baker chaotic map was done using statistical technique. The correlation coefficient has a significance of 0.048. The quadratic chaotic map and baker chaotic map are compared using an independent sample T-test with a confidence interval of 95 percent and a level of significance of 0.69595. The significance level is 0.0010, the significance level is two-tailed, the mean difference, the standard error difference, and the lower and upper interval difference are all included in this independent sample test.

Group		**Leven's Test for Equality of Variance**		**T-test for Equality of Means**						
		F	**Sig**	**t**	**df**	**sig(2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval (Lower)**	**95% Confidence Interval (Upper)**
Correlation	**Equal variance**	0.200	0.045	-2.858	18	0.010	-0.0018	0.00063	-0.00313	-0.00047

	assumed									
	Equal variance not assumed			-2.858	17.687	0.011	-0.00180	0.00063	-0.00313	-0.00047

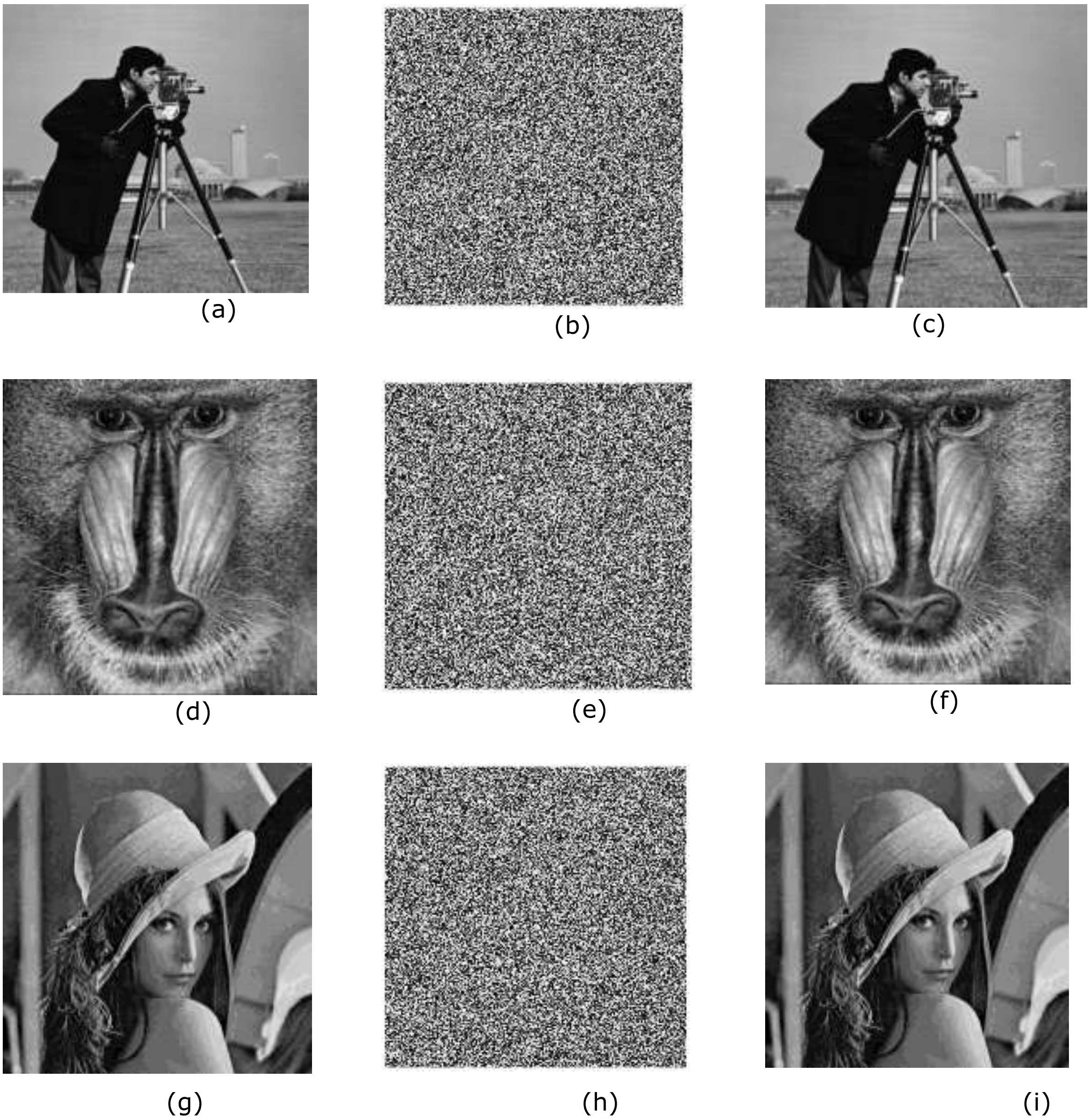


Fig. 1. Novel Quadratic chaotic map encryption technique (a)sample image cameraman of size (512x512) (b) encrypted cameraman using quadratic chaotic map (c) decrypted cameraman image (d)sample image mandril of size (512x512) (e) encrypted mandril using quadratic chaotic map (f) decrypted mandril image (g) sample image lenna of size (512x512) (h) encrypted lenna using quadratic chaotic map (i) decrypted lenna image.

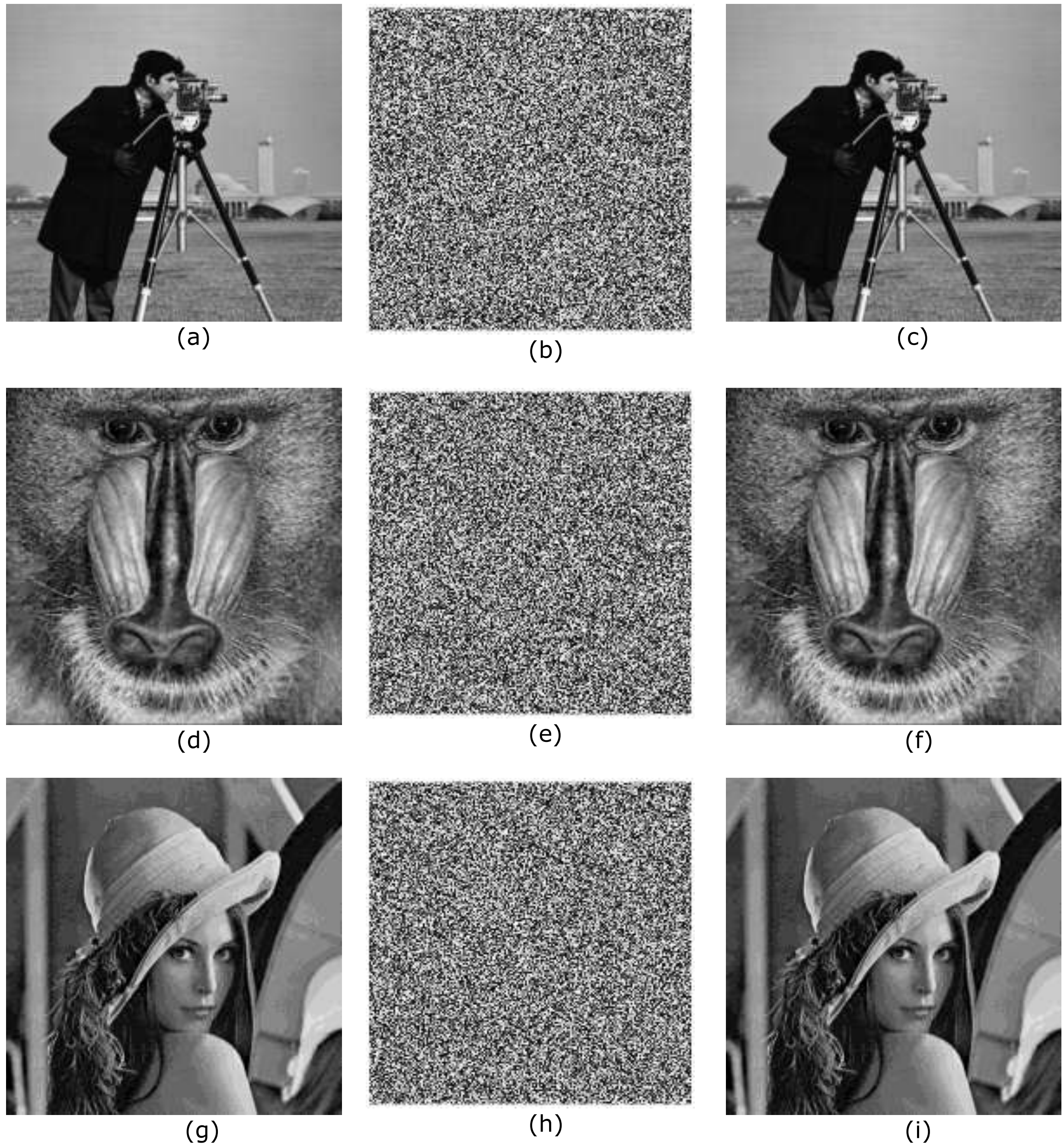


Fig. 2. Baker chaotic map encryption technique (a) sample image cameraman of size (512x512) (b) encrypted cameraman using baker chaotic map (c) decrypted cameraman image (d)sample image mandril of size (512x512) (e) encrypted mandril using baker chaotic map (f) decrypted mandril image (g) sample image lenna of size (512x512) (h) encrypted lenna using baker chaotic map (i) decrypted lenna image.

ISSN 2029-0454
2022

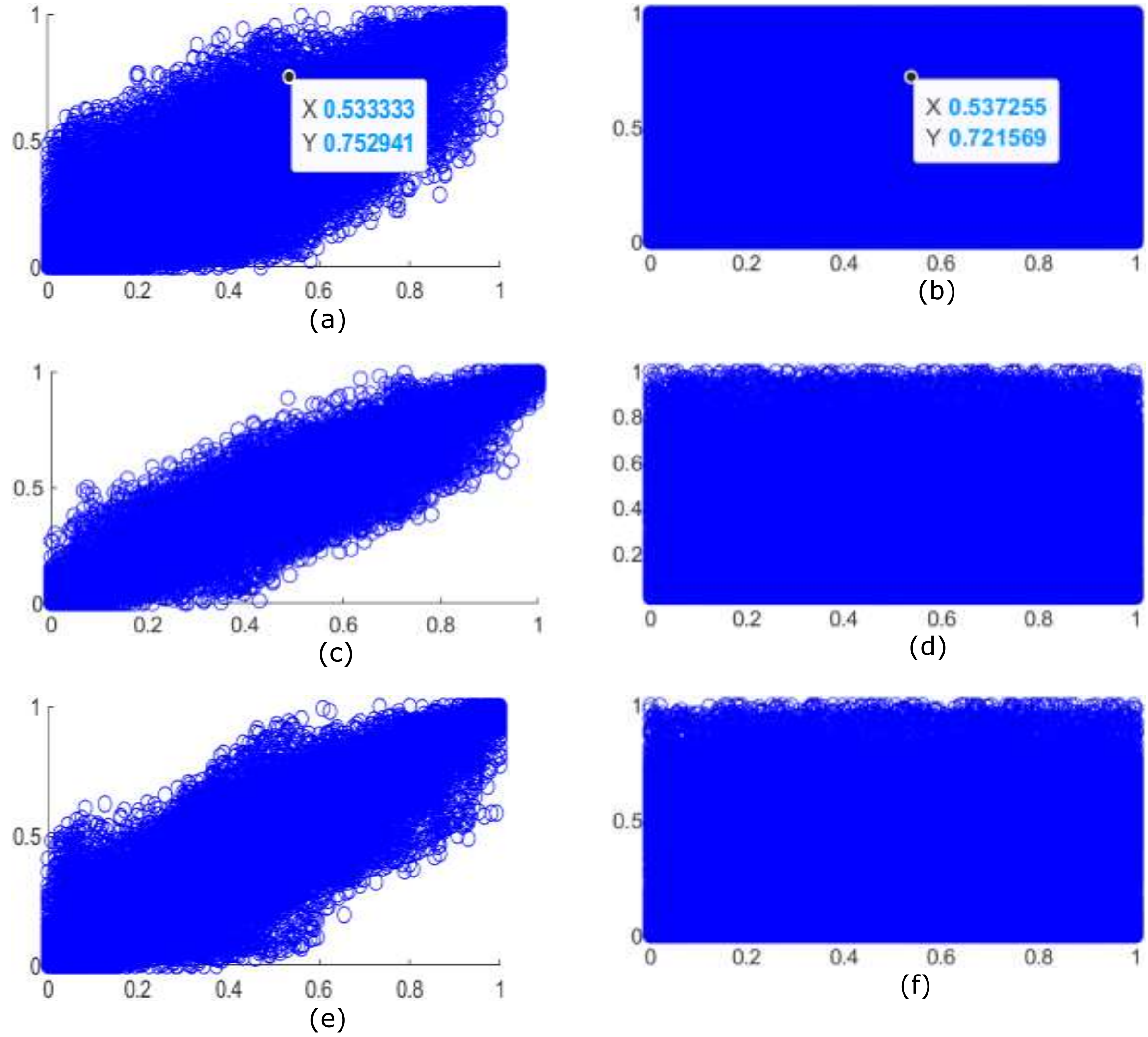
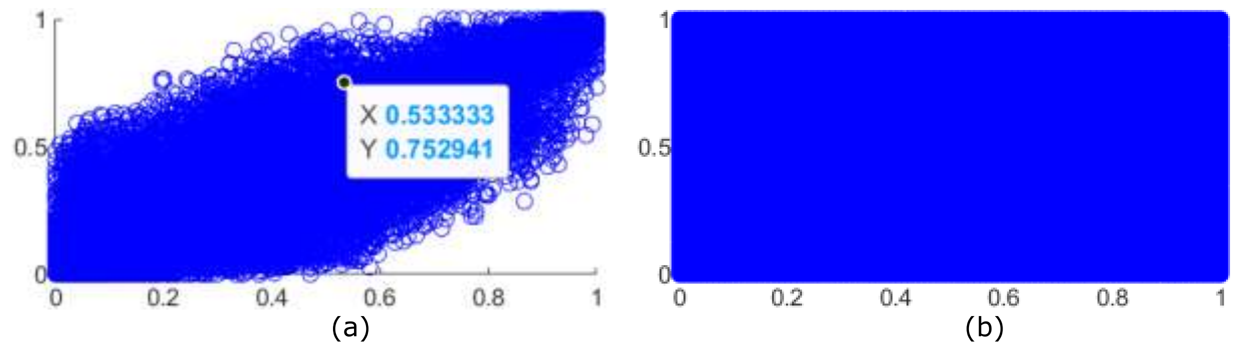


Fig. 3. Correlation analysis of novel Quadratic chaotic method of cameraman standard image (a)vertical correlation of standard image (b) vertical correlation of encrypted image (c) horizontal correlation of standard image (d) horizontal correlation of encrypted image (e) diagonal Correlation of standard image (f) diagonal correlation of encrypted image



 ISSN 2029-0454
2022

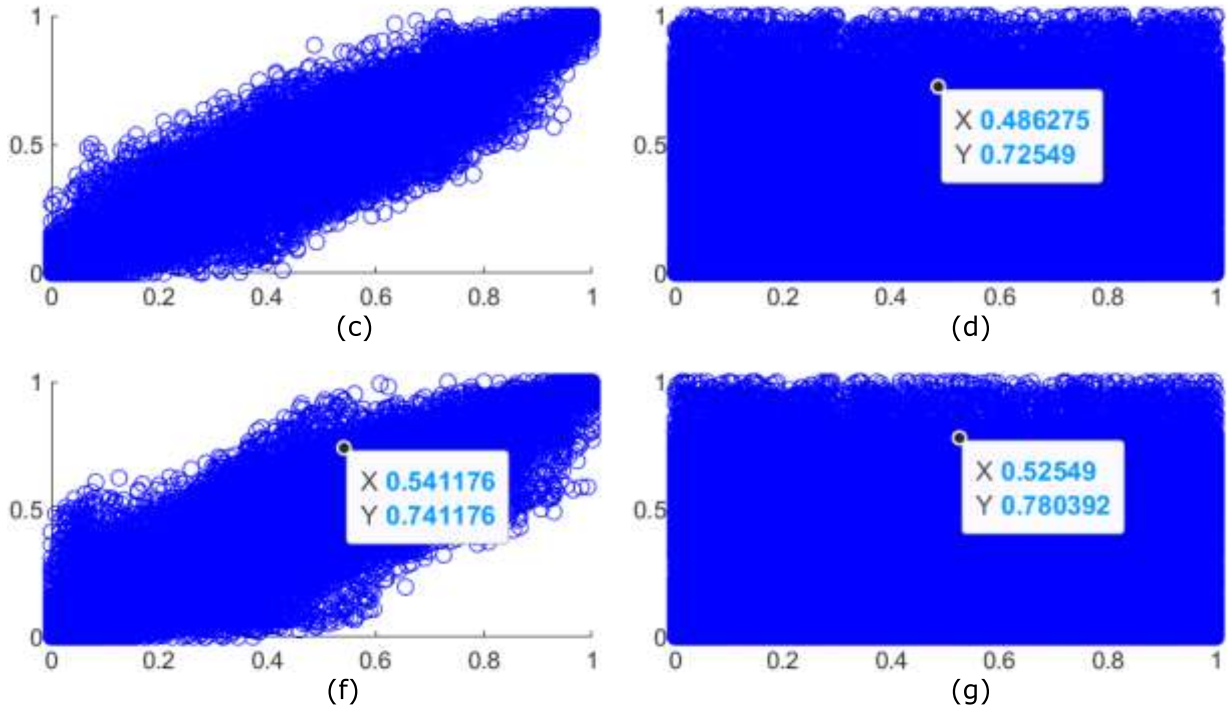


Fig. 4. Correlation analysis of Baker chaotic method of cameraman standard image (a)vertical correlation of standard image (b)vertical correlation of encrypted image (c)horizontal correlation of standard image (d)horizontal correlation of encrypted image (e)diagonal Correlation of standard image (f) diagonal correlation of encrypted image

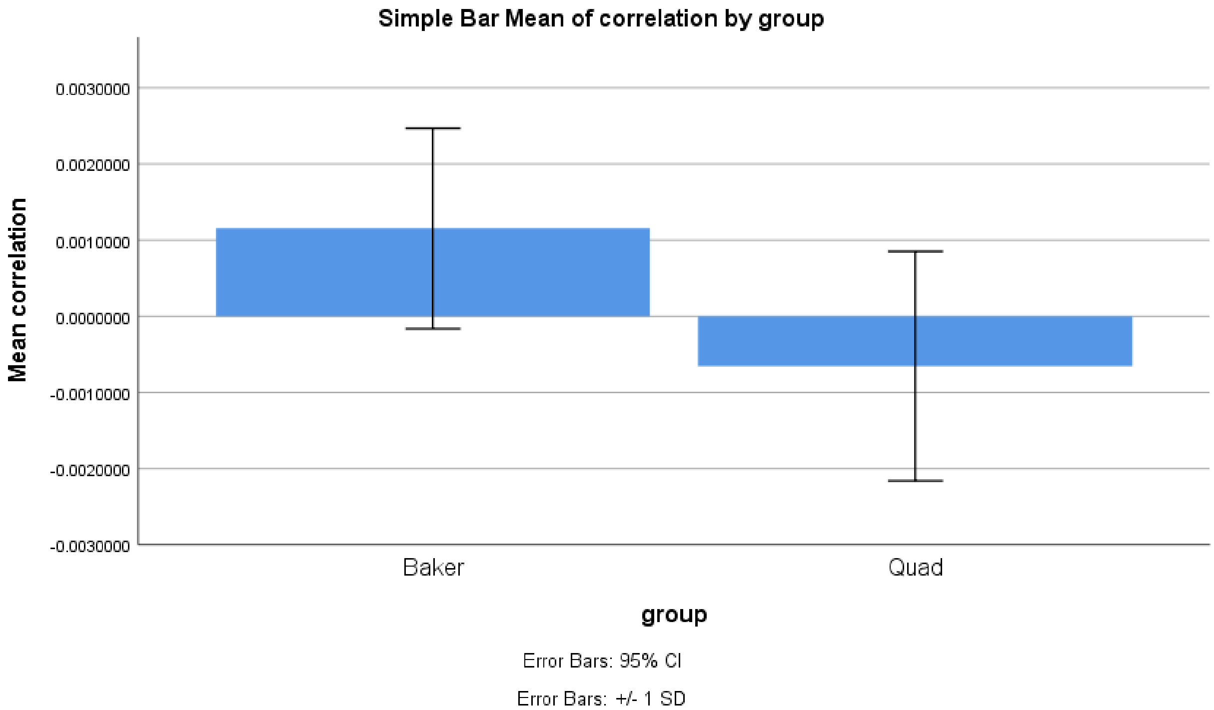


FIG. 5. Simple Bar mean of Correlation. X-Axis: Baker chaotic encryption vs Quadratic chaotic encryption. Y-Axis: Correlation. The graph compares groups on the x-axis and y-axis using the mean of baker and quadratic with +/- 1 standard deviation (SD). The Quadratic chaotic encryption provides better correlation (-0.00065) when compared to Baker chaotic encryption correlation is (0.00115).