Contribution for Improvement of Image Scrambling Technique Based on Zigzag Matrix Reodering

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Abstract

In the natural state, all images are most correlated. For improving the image ciphering and eliminating this physical aspect, using the scrambling technique gives the best result. The scrambling technique is a block before or after the image encryption. By reordering the matrix following some specific path, the pixels position becomes scrambled. Indeed our research is based on the fact that when using the scrambling of the pixels position only, the histogram of the image doesn't change and the distribution of the adjacent pixels are predictable. In this, adding some techniques of color scrambling is necessary. This will improve the different criteria of performance evaluation like: PSNR, SSIM, distribution of adjacent pixels, histogram and time following our simulation on Matlab.

Keywords: *scrambling, zigzag, PSNR, SSIM, UACI, NPCR*

I. INTRODUCTION

By the evolution of the digitization, transmission and saving files-multimedia like video, audio, image becomes important. The protection of the information against ill-disposed people should be a priority. The algorithm based on scrambling has the best time for itself either by using the matrix transformation (Arnold, Fibonacci…) or by using matrix reordering [1-10]. Reordering the matrix gives a better time than the transformation. The problem of this technique is that the scrambled image histogram doesn't change after the scrambling and as a matter-of-fact, the distribution of the natural image and the scrambled image have some similarity. This is due to the technique used which only changes the pixel position but not its value for the fundamental colors Red Green Blue [11-17]. To solve this problem [18-27], our research has implemented an algorithm of color scrambling to improve the non-similarity of the ciphered image and the original image like the histogram and the distribution of pixels. The matrix reordering used in this article is the zigzag and the color scrambling with this improves the classic zigzag algorithm.

II. METHODOLOGY

The scrambling of image uses two blocks: the scrambling of pixels position (pixels scrambling) and the scrambling of the value of the pixels (color scrambling). The image is represented in 2 dimensions m*n and has 3 fundamental colors: Red Green Blue which are coded 8 bits each.

A. Pixels Scrambling

The matrix reordering changes only the position of the image in 2D-space by using a specific pattern. The classic pattern used is represented in the Figure 1. [18-27]

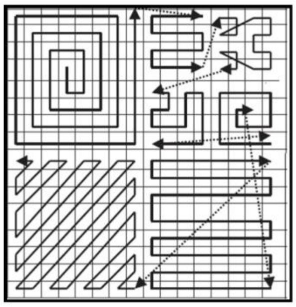

Figure 1:List of patterns for matrix reordering image

This article focuses only on the zigzag path. We can see 8 options of zigzag patterns (4 options with 2 directions each)

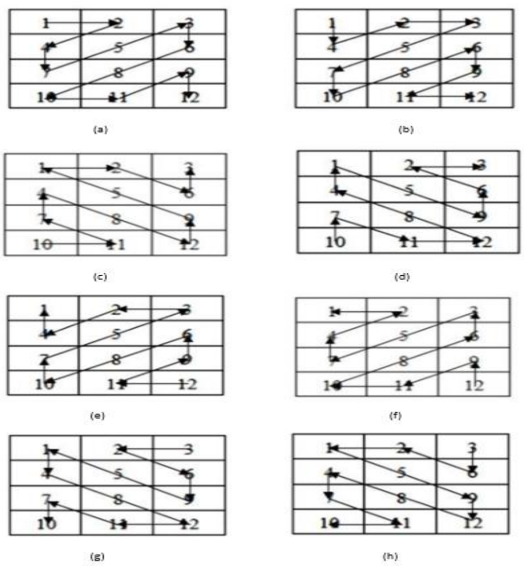

Figure 2:Different patterns of zigzag

The Figure 2 represents all the patterns of zigzag scrambling but we choose only the Figure 2 (a). By using linearization, the calculation of this linearized position will be derived from the original image M having size m*n.

$$C(p,q)=\frac{1+(-1)^{p+q}}{2}\left[\frac{(p-1+q)(p-2+q)}{2}+q\right]+\frac{1-(-1)^{p+q}}{2}\left[\frac{(p-1+q)(p-2+q)}{2}+p\right] \quad (1)$$

*C(p,q)*is the position of the linear index of abscissa and ordinate of the original image.
*p, q*is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image
So the index of abscissa and ordinate issued from the linear position if the scrambled image with the zigzag is noted V has its formula like this:

$$c(p,q) = V(p_{permute}\ , q_{permute}\ ) \rightarrow C(p,q) =$$

$$= m * p\_permute + q\_permute \quad (2)$$

*C(p,q)*is the position of the linear index of abscissa and ordinate of the original image.
*p, q*is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image

V is the scrambled image by zigzag path.

*p_permute, q_permute*is the position of the linear index of abscissa and ordinate of the scrambled image

The index of the scrambled image is calculated by the formula (3) after using the formula (2):

$$\begin{cases} \forall p \in [1;m]; \forall q \in [1;n]; q\_permute = \mathrm{mod}(C(p,q), n) \\ \forall p \in [1;m]; \forall q \in [1;n]; p\_permute = \dfrac{C(p,q) - q\_permute}{m} \end{cases} \quad (3)$$

*C(p,q)*is the position of the linear index of abscissa and ordinate of the original image.

p, q is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image

p_permute, q_permute is the position of the linear index of abscissa and ordinate of the scrambled image

The Formula 1 could be simplified by putting *A=p+q and B=p-q* :

$$C(p,q)=\frac{1}{2}\left[(p+q)^2+(-1)^{p+q-1}(p-q)+1\right]=\frac{1}{2}\left[(A)^2+(-1)^{A-1}B+1\right] \quad (4)$$

C(p,q) is the position of the linear index of abscissa and ordinate of the original image.
*p, q*is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image.
A is *p+q;*

B is *p-q.*

If we launch the function zigzag on Matlab we could have this result:
M = [1 2 3 4 ; 5 6 7 8 ;9 1 2 3]

C = [1 25 9 6 3 4 7 1 2 8 3]

This illustration after the execution of the matrix M could be explained by following the path in the Figure 3:

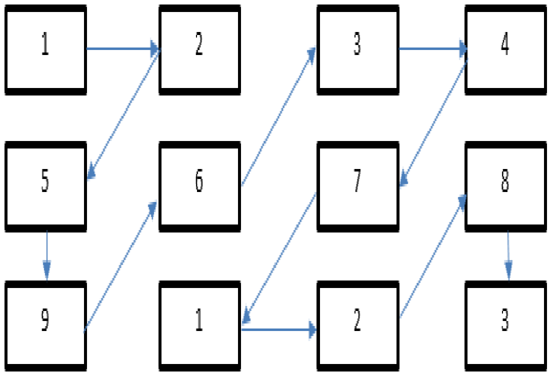

Figure 3: Graphic illustration of a zigzag path

For the classical zigzag, the transformation could be done in affecting the new position to the original position in the scrambled image and the original image:

$$\begin{cases} \forall\, p\_permute\ \in [1;m]; \\ \forall\, q\_permute\ \in [1;n]; \\ \forall\, k \in [1;3]; \\ V(p\_permute\ ,q\_permute\ ,k)=V(p,q,k) \\ \forall\, p \in [1;m]; \forall\, q \in [1;n];\ q\_permute\ = mod\ (C(p,q),n) \\ \forall\, p \in [1;m]; \forall\, q \in [1;n]; p\ \_permute\ = \frac{C(p,q)-q\_permute}{m} \\ \forall\, p \in [1;m]; \forall\, q \in [1;n];\ C(p,q)= \\ \frac{1}{2}[(p+q)^2+(-1)^{p+q-1}(p-q)+1] \end{cases} \quad (5)$$

M is the original image with the size m*n
*C(p,q)*is the position of the linear index of abscissa and ordinate of the original image.
*p, q*is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image
V is the scrambled image
*p_permute, q_permute*is the position of the linear index of abscissa varying between 1 and m and the index of ordinate varying between 1 and n in the scrambled image
k is the fundamental color image : 1 for Red, 2 for Green et 3 for Blue.

B. Color Scrambling:

To improve the classic zigzag, the fundamental colors Red Green Blue should be changed [11-17]. In order to change only the position of the pixelsat the same time, the value of these pixels is also changed by using a xor operator following this formula.

$$\begin{cases} \forall\, p\_permute \in [1;m]; \\ \forall\, q\_permute \in [1;n]; \\ V(p\_permute, q\_permute, 1) = \\ bitxor\left(M(p,q,1), p*\frac{256}{n}\right) \\ V(p\_permute, q\_permute, 2) = \\ bitxor\left(M(p,q,2), p*\frac{256}{m}\right) \\ V(p\_permute, q\_permute, 3) = \\ bitxor\left(M(p,q,3), (p+q)*\frac{256}{m+n}\right) \\ \forall\, p \in [1;m]; \forall\, q \in [1;n];\, q\_permute = mod\,(C(p,q), n) \\ \forall\, p \in [1;m]; \forall\, q \in [1;n];\, p\_permute = \frac{C(p,q) - q\_permute}{m} \\ \forall\, p \in [1;m]; \forall\, q \in [1;n];\, C(p,q) = \\ \frac{1}{2}\left[(p+q)^2 + (-1)^{p+q-1}(p-q) + 1\right] \end{cases} \quad (6)$$

M is the original image with the size m*n
*C(p,q)*is the position of the linear index of abscissa and ordinate of the original image.
*p, q*is the index of abscissa between 1 and m; of ordinate between 1 à and n of the original image
V is the scrambled image.
*p_permute, q_permute*is the position of the linear index of abscissa varying between 1 and m and and the index of ordinate between 1 and n of the scrambled image.

The fundamental colors Red Green Blue are scrambled by using bitxorwith $p*256/n$; $q*256/m$ et $(p+q)*256/(m+n)$.

III. RESULTS

Original image: Lena.jpg, size: 256x256x3

A. Original image distribution

Vertical Distribution | *Horizontal Distribution* | *Diagonal Distribution*

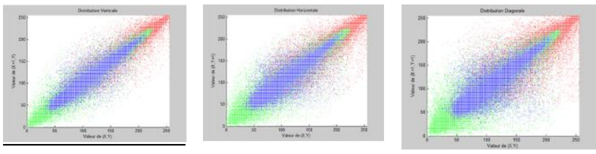

Figure 3: *The pixels adjacent of the original image*

The adjacent pixel of a natural image has a mathematic distribution diagonally drawn because the pixel and the adjacent pixel are quite equal. There are three types of image distribution:
- Vertical distribution (On the left): the pixel value of the image with coordinates *(X, Y)* will be the abscissa. This value corresponds with its value in the vertical adjacent pixel with the coordinates *(X+1, Y)*
- Horizontal distribution (In the middle): the pixel value of the image with coordinates *(X, Y)* will be the abscissa. This value corresponds with its value in the horizontal adjacent pixel and with the coordinates *(X, Y+1)*
- Diagonal distribution (On the left): the pixel value of the image with coordinates *(X, Y)* will be the abscissa. This value corresponds with its value in the diagonal adjacent pixel and with the coordinates *(X+1, Y+1).*

B. Scrambling with zigzag

The Figure 4 gives different stages of image: original, scrambled with zigzag and descrambled. The principal problem of this method is that the number of the colors Red Green Blue doesn't change after the zigzag. The repetition of the color is the same between the original and the scrambled image.

Original Image | *Scrambled Image* | *Descrambled Image*

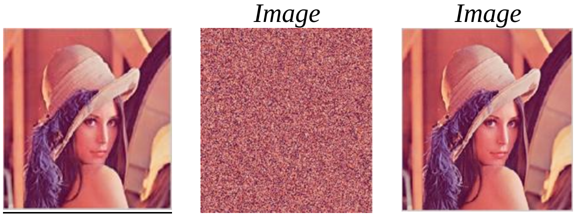

Figure 4: Original, scrambled and descrambled image using zigzag

This similarity could be explained by the equality of the histogram between the original image and the scrambled image by the Figure 5.

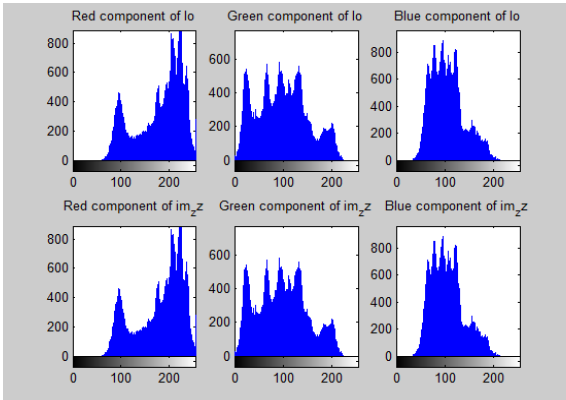

Figure 5: Comparing the histogram between original and scrambled images

In this fact, the adjacent pixels distribution is not due to a random effect.. The 3 fundamental colors should take up all the space in the Figure 6. But in our case, the red takes some place, the blue also, and the green indeed. They have a rectangular shape not so well-drawn because it doesn't take up a large space.

Vertical Distribution | *Horizontal Distribution* | *Diagonal Distribution*

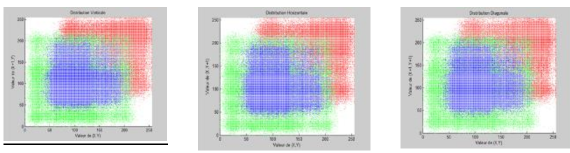

Figure 6: *Adjacent pixel distribution after the zigzag scrambling*

C. Improved Zigzag

Compared to the classical zigzagfigure 4 and figure 7, we could notice that the color red has disappeared from the image. The equality of the colors Red Green Blue between the original image and the scrambled image doesn't exist anymore.

Original Image *Scrambled Image* *Descrambled Image*

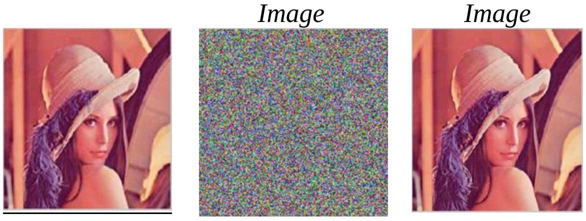

Figure 7: Original, scrambled and descrambled images by the improved zigzag

The Figure 8 confirms this, because the histogram of the original image and the scrambled image isn't equal. By the way, we have invented an algorithm capable to scramble at the same time the pixel and the fundamental colors. When the image is very scrambled, we could also see that the histogram tends to have a flat figure.

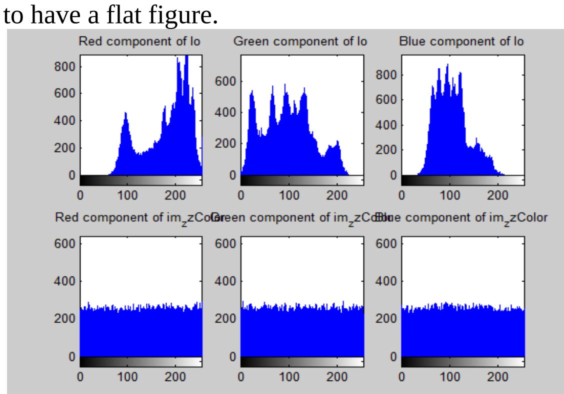

Figure 8: Comparing original and scrambled histogram images after improved zigzag

This color scrambling of image could be explained also by the occupation of all the area in the adjacent pixel distribution like in the Figure 9. All colors have a larger area to scatter in 2D-distribution.

Vertical Distribution *Horizontal Distribution* *Diagonal Distribution*

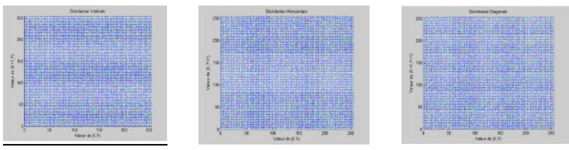

Figure 9: *Adjacent pixels of image distribution by the improved zigzag*

IV. CHART OF RESULTS NTERPRETATION

A. Discussion following the similarity and correlation

1. Definition of the correlation

- The correlation coefficient [28] is defined by :

$$r_{X,Y} = \frac{COV(X,Y)}{\sqrt{V(X).V(Y)}} = \frac{COV(X,Y)}{\sigma_X \sigma_Y} \quad (7)$$

*COV(X, Y)*is the covariance between two random variables X and Y;$V(X), V(Y)$ is the variance between de X and Y;σ_X, σ_Y is the standard deviation between X and Y.

- The covariance is equal to the expectation between the products of the standardised random variable. It is defined by the following formula :

$$COV(X,Y) = E[(X - E[X])(Y - E[Y])] \quad (8)$$

E is the mathematical expectation; X, Y is a random variable.

- The variance is defined by the following formula :

$$V(X) = E[(X - E[X])^2] = COV(X,X) \quad (9)$$

E is the mathematical expectation; COV the covariance.

The goal of the covariance is to quantify the liaison between two random variables X, Y, for the liaison sense and intensity. The coefficient of simple linear correlation, says Bravais-Pearson is a normalized covariance by the product between the two standard deviations. The correlation is between -1 and 1.Near the extreme value 1 and 1, the similarity between the two variables is important. The expression « intensive correlation » means that two variables are very similar and the correlation is near the value 1.The expression « linear independent » or « no correlation » means that the correlation between two variables is nil and there is no similarity between them. The expression « perfect correlation » means that the value r is equal to ± 1.

2. Correlation between the original and the scrambled image using an improved zigzag path

In this article, we use the coefficient correlation for confirming if there are correlations between original and scrambled image. Their values are represented by the following table:

Table1: *Correlation coefficients between the original image and the scrambled image*

Coefficient correlation between original image and scrambled image		
r_{xy} between the Red color of the original image and the scrambled image	0.0013	The value ofr_{xy} is near 0. There is no correlation between the two images.They are linear independent
r_{xy}between the Green color of the original image and the scrambled image	0.0049	
*rxy*between the Blue color of the original image and the	0.0008192	

scrambled image		

The improved zigzag path gives a totally blurred image, so there is no correlation between the original image and the scrambled image. In the result, the correlation of the Red is 0.0013, for the Green it is 0.0049 and for the Blue it is 0.00081924.All the coefficients are near zero. So, the final image is totally random because the correlation between the original image and the scrambled image is near 10^{-2}.

B. Result interpretation by PSNR, SSIM [27, 29]

1. Definition PSNR, SSIM

PSNR (Peak Signal to Noise Ratio) is a numeric distortion used for the numeric image, especially for image compression.The goal is to quantify the performance of coders by measuring the quality of the compressed image and the original image.

Le PSNR is defined by the following formula:

psnr(:,:,1) PSNR (Peak Signal to Noise Ratio) between the Red color of the original image and the scrambled image	7.8825	PSNR very weak
psnr(:,:,2) PSNR between the Green color of the original image and the scrambled image	8.6047	PSNR very weak
psnr(:,:,3) PSNR between the Blue color of the original image and the scrambled image	9.6957	PSNR very weak
mssim(:,:,1) SSIM (Structural SIMilarity) between the Red color of the original image and the scrambled image	0.0088	Mssim very weak near the minimum value 0
mssim(:,:,2) SSIM between the Green color of the original image and the scrambled image	0.0101	mssim very weak near the minimum value 0
mssim(:,:,3) SSIM between the Blue color of the original image and the scrambled image	0.0119	mssim very weak near the minimum value 0

$$PSNR = 10.\log_{10}\left(\frac{d^2}{RMSE}\right) \qquad (10)$$

d is the dynamism of the signal (the pixel's maximum value). In the standard, the pixel is coded 8 bits, so d = 255.

RMSE is the Root Mean-Square Error

- ❖ The RMSE for 2 images I_0 et I_r with size m×n is defined by :

$$RMSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}(I_0(i,j) - I_r(i,j))^2 \qquad (11)$$

$I_0(i,j)$ is the value of the coordinates (i,j) of the image I_0 ; $I_r(i,j)$ is the value of the coordinates (i,j) of the image I_r.

- ❖ The Structural Similarity or SSIM is a reliable measure of the similarity between two numeric images.

$$SSIM(X,Y) = \frac{(2\mu_X\mu_Y + c_1)(2\sigma_X\sigma_Y + c_2)(2COV(X,Y) + c_3)}{(\mu_X^2 + \mu_Y^2 + c_1)(\sigma_X^2 + \sigma_Y^2 + c_2)(\sigma_X\sigma_Y + c_3)} \qquad (12)$$

μ_X , μ_Y is the average value of the random variable X, Y; σ_X^2 , σ_Y^2 is the variance of X, Y; $COV(X,Y)$ is the covariance of X and Y; c_1, c_2, c_3 are 3 values to stabilize the division when the value is too small.

- ❖ The values c_1, c_2, c_3 are defined by the following formula :

$$\forall i \in \{1,2,3\}; C_i = (k_i.L)^2 \qquad (13)$$

c_1 is 0.01, c_2 is 0.02, c_3 is 0.03; L is the dynamic value which is 255 if the image is coded 8bits. The PSNR is used for measuring the proximity between the original image and the compressed image but it doesn't consider the visual quality of the reconstruction, thus, is a simple objective measure for visual quality only.

2. PSNR and SSIM between the original image and the scrambled image by improved zigzag

The Table 2 gives us the result obtained after the Matlab simulation for measuring PSNR and SSIM between the original image and the scrambled image by improved zigzag path. Their value should be the minimum as possible because the original image and the scrambled image shouldn't have any resemblance even in case of visual interpretation. In our case, the PSNR is very weak, it doesn't exceed 10. The SSIM is also near 10^{-1}, Like SSIM, it is near 0 for all fundamental colors Red Green Blue.

Table 2: *PSNR, SSIM between the original and the scrambled image*

The Table 2 gives us the result obtained after the Matlab simulation for measuring PSNR and SSIM between the original image and the scrambled image by improved zigzag path. Their value should be the minimum as possible because the original image and the scrambled image shouldn't have any resemblance even in case of visual interpretation. In our case, the PSNR is very weak, it doesn't exceed 10. The SSIM is also near 10^{-1}, Like SSIM, it is near 0 for all fundamental colors Red Green Blue.

4-3. Results interpretation by UACI, NPCR

4-3-1. Definition of UACI, NPCR

The common parameter to evaluate two images in ciphering is the NPCR (Number of Pixel Change Rate), UACI (Unified Average Changing Intensity) defined by the following formulas:

$$NPCR = \frac{\sum_{p,q} Diff(p,q)}{W*H}*100 \qquad (14)$$

$$UACI = \frac{1}{W*H}\left(\sum_{p,q} M(p,q)-V(p,q)\right)*100 \qquad (15)$$

*M(p,q)*is the pixel value of the original image by the coordinates *p,q*.
V(p,q) is the pixel value of the scrambled image by the coordinates *p,q*.
p,q are the abscissas between 1 and W; ordinates between 1 and H of the original image.
W and H is the width and height of the image.
If the NPCR is near 100, the cipher method is the best and if UACI is near100, the cipher algorithm resists against DPA (Differential Power Analysis).

4-3-2. NPCR and UACI between the original and the scrambled image

Table3: *NPCR and UACI between the original image and the scrambled image*

npcr(:,:,1) NPCR (Number Pixel Change Rate) of Red color	99.5773%	Near the maximum value equal to 100%
npcr(:,:,2) NPCR of Green color	99.5682%	Near the maximum value equal to 100%
npcr(:,:,1) NPCR of Blue color	99.5987%	Near the maximum value equal to 100%
uaci(:,:,1) UACI (Unified Average Change Rate) of Red Color	26.6667%	Not quite near the maximum value
uaci(:,:,2) UACI of Green color	9.5967%	Not quite near the maximum value
uaci(:,:,3) UACI of Blue color	9.4891	Not quite near the maximum value

Our article shows that the performance of the zigzag scrambling like ciphering is near 95%. This technique is not so strong against DPA attacks. Due to this problem, implementing this algorithm should be done with electronic components likely to shade its power dissipation or a DPA resistant algorithm.

4-4. Interpretation according to Time factor

With computer Intel Core i3 2.2 GHz, RAM of 4 Go, the scrambling tested candidate is represented in the following table 4:

Table 4: *Comparing time of permutation and reordering scrambled image*

Scrambling technique	Time for image Lena.jpg 256x256x3
Permutation	
Arnold	0.32521s
Fibonacci	0.32539s
Luca	0.3551s
Fibonacci-Luca	0.43322s
Luca-Fibonacci	0.40446s
Reordering	
Zigzag	0.05935s

V. Comparing the original image and the descrambled image

After the reverse improved zigzag, comparing the original image and the descrambled image consists in subtracting the pixels one by one then make the sumtotal of them all. The result given by the sum is 0. So the original image and the scrambled image are perfectly alike. The SSIM and PSNR have a maximum value; the NPCR and UACI have a minimum value 0 table 5. The two images have a perfect correlation.

Table 5: *PSNR, SSIM, NPCR, UACI and rxy between the original and the descrambled image*

	PSNR	SSIM	NPCR	UACI	rxy
between the Red color of the original image and the descrambled image	Infinite	1	0	0	1

between the Green color of the original image and the descrambled image	Infinite	1	0	0	1
between the Blue color of the original image and the descrambled image	Infinite	1	0	0	1

5. Conclusion

The pre-ciphering or the post-ciphering of an image could be done by the scrambling technique using the transformation (permutation) or the reordering (path non-conventional) of the image. The two methods only help in image scrambling following the position of the pixel not the value of the component of the image color. In this fact, the scrambled image has a similar histogram with the original image. The distribution in 2D of adjacent pixels takes up only some space (not all space) with the square 256*256 of the graph distribution. The image is not really scrambled in its color components. Our choice of reordering matrix could be explained by its best execution time compared to the permutation transformation. With the improved zigzag path, the image histogram is totally random
and tends to have a flat representation and the adjacent pixel distribution takes up all the area 2D. Besides, the results of the calculations of our experimentation could confirm that the original and scrambled images are totally independent and not equal: the image correlation is near 10^{-2}; the PSNR doesn't exceed 10 and the SSIM is near 10^{-2}.The time of the improved zigzag is also very good, it doesn't exceed 0.07s. For the ciphering criteria, the NPCR confirms that this algorithm has 95% of performance. Unlikely, the UACI is not quite good with a value nearing 10%. The ciphering technique
combined with these scrambling techniques should be a cryptographic algorithm resistant to DPA attacks. As a future prospect, to improve the execution times, it's possible to choose simpler patterns like paths: U, L, O, Pi, or Gamma.

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