Secret Image Communication Scheme Based on Visual Cryptography and Tetrolet Tiling Patterns

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Abstract: Visual cryptographic scheme is specially designed for secret image sharing in the form of shadow images. The basic idea of visual cryptography is to construct two or more secret shares from the original image in the form of chaotic image. In this paper, a novel secret image communication scheme based on visual cryptography and Tetrolet tiling patterns is proposed. The proposed image communication scheme will break the secret image into more shadow images based on the Tetrolet tiling patterns. The secret image is divided into 4×4 blocks of tetrominoes and employs the concept of visual cryptography to hide the secret image. The main feature of the proposed scheme is the selection of random blocks to apply the tetrolet tilling patterns from the fundamental tetrolet pattern board. Single procedure is used to perform both tetrolet transform and the scheme of visual cryptography. Finally, the experimental results showcase the proposed scheme is an extraordinary approach to transfer the secret image and reconstruct the secret image with high visual quality in the receiver end.

Keywords: Tetrominoes tile, visual secret share, image transmission, security, visual cryptography

1 Introduction

Information hiding is an incredible platform to enable the protection of secret documents. It is noticed that the protection of image content is always very difficult in any application domain. But visual cryptography plays a vital role in area of image security. The first visual cryptography scheme for binary image was proposed by Moni Naor and Adi Shamir. This traditional scheme encodes the secret image into 'n' shadows based on the pixel expansion technique. Simply stacking or human visual system is used to decrypt

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Received: 27 April 2020; Accepted: 03 July 2020.

the shadow images. Many secret sharing approaches were proposed for binary images, grayscale and color images by the investigators.

Some investigators make use of non-computational techniques and some researchers used complex computational techniques to generate the shadow images.

Pixel expansion technique is the very oldest form of visual cryptography technique, especially for binary secret images [Martin (2012); Yan, Liu and Yang (2015)]. In connection with the development of visual cryptography, a reversible data hiding method for medical images based on the histogram shifting was proposed [Wei, Hou and Lu (2015)]. This reversible method is performed for high bit depth medical images to achieve the six criteria requirements. Young et al. [Young, Quan, Tsai et al. (2013)] have developed block-based progressive visual secret sharing to overcome the several problems which was identified in the previous progressive visual secret sharing scheme. This method also results in the same implementation results which are similar to the previous image protection scheme. Chen et al. [Chen, Chen and Chen (2014)] suggested a visual secret checking scheme between two parties in a meaningful format. Superimposition results leads to quality degradation at the receiving end. 2D bar code authentication based visual cryptography scheme proposed by the investigators [Wang, Feng and Wei (2016)]. New information hiding scheme for color images has been proposed [Prisco and Santis (2013)]. This scheme is implemented based on the visual cryptographic scheme and Boolean Exclusive-OR (XOR) to achieve the better sharing capability with good visual quality.

Haar based tetrolet transformation is invented by the mathematician Krommweh [Krommweh (2010)]. Effective filter bank algorithm is passed into every 4×4 block of the digital image. A novel image retrieval technique based on the tetrolet transformation has been proposed. The concentration of secret image sharing is less based on the tetrolet [Jain and Tyagi (2015); Murat and Canbilen (2017)]. Tetrolet patterns [Raghuwansh and Tyagi (2016); Rajasekhar and Rangababu (2019)] are more effective to construct the secret shares. Therefore, this investigation mainly concentrates on the generating of shadow images based on the tetrolet tiles. Kang et al. [Kang, Liu, Yang et al. (2019)] proposed a color image steganalysis algorithm based on channel gradient correlation. This scheme extracts the co-occurrence matrix feature from the gradient amplitude among different color channels. Subsequently, these features are combined with existing methods to train the classifier for improving the performance.

Min et al. [Min, Yang, Wang et al. (2019)] proposed a BGN-type parallel matrix scheme to preserve privacy in the cloud. This attempt results in higher speed-up ratio when processing big data. Reversible data hiding scheme is highly fashionable technique in cryptography domain. Peng et al. [Peng, Lin, Zhang et al. (2019)] presented a reversible mapping framework for 2D vector graphics. This reversible scheme encrypts 2D vector images and stores the encrypted image in a cloud. Long et al. [Long, Peng and Li (2017)] proposed a separable reversible data hiding and encryption scheme for high efficiency video coding standards. RC4 stream cipher is used for encryption and nonzero AC residual coefficients are used for hiding the data. A hybrid forensics strategy is used to detect object removal by exemplar-based inpainting with or without post processing [Zhang, Liang, Yang et al. (2018)]. Song et al. [Song, Yang, Xie et al. (2017)] introduced a dictionary learning-based residual reconstruction method for compressed sensing videos. They analyzed sparse representation using Karhunen-Loeve transform and multi frame reference. A modified threshold selection scheme based on Particle Swarm Optimization (PSO) and support vector machine (SVM) offered an accuracy of 90. 93% [He, Yu, Hong et al. (2018)]. Zhang et al. [Zhang, Yang, Li et al. (2018)] proposed a detection mechanism for seam carved images using uniform local binary patterns. These methods are used to embed watermark image into two cover images. Gurunathan et al. [Gurunathan and Rajagopalan (2020)] used the cuckoo search algorithm to find an optimal substitution matrix for transforming the message to be hidden. Xiao et al. [Xiao, Yang, Li et al. (2019)] proposed a lesion extraction method with reversible data hiding scheme. Patient details will be embedded into the lesion part of the image which achieves privacy preserving. Yan et al. [Yan, Xiang and Hua (2019)] proposed analysis-by-synthesis (AbS) framework to improve the quality of reconstructed images.

The rest of the paper is organized as follows: In Section 2 brief description on the tetrominoes, construction of 4×4 random tetrolet patterns for the visual secret sharing and reconstruction procedures are presented. The experimental results and various analysis of image quality are presented in Section 3. Finally conclusions are presented in Section 4.

2 Methodologies used for image sharing and reconstruction

2.1 The main concepts

Many secret sharing algorithms were proposed for image protection and secure transmission. Traditional visual secret sharing schemes, pixel expansion, non-pixel expansion techniques, extended visual cryptography, dynamic visual cryptography and progressive visual secret sharing are the major techniques used to construct the shadow images. However, investigators faced many problems while attempting to implement these crypto schemes such as very hard to configure the matrix elements and quality loss in the reconstructed image.

To deal with the aforesaid problems, it is most pressing requirement to find the non-expandable block based technique for protecting secret images. In this paper, we propose a novel secret image communication scheme based on visual cryptography and tetrolet tiling patterns. The base idea of the proposed scheme is to identify the 4×4 block of tetrolet and non tetrolet patterns to construct the shadow images from the original image. The secret image is divided into equal size of odd and even blocks to allocate tetrominoes in the appropriate blocks. In each sector every alternate pattern is sealed by tetrolet tiles and rest of the patterns are marked as zero value matrices. After compilation of the both tetrolet and non tetrolet tiles, the patterns are chained together to construct the shadow images. Finally, by using the overlapping operation the original image has reconstructed without quality loss.

2.2 Symbols

Symbols in the proposed schemes are defined as follows:

- I: The secret image with pixel intensity $I_{i,j}$
- OddB: odd block
- S: Shadow image with pixel intensity $S_{i.j}$
- Sec: Sector

- T: tetrolet block
- evenB: even block
- NT: non tetrolet block
- stack: stacking
- M×N: Image dimension
- m: modulo value
- Hist: Histogram of image pattern
- i, j: index range from 0≤i, j≤M

2.3 Framework for tetrolet patterns

The base concept of tetrolet is composing of different types of tetrominoes with proper assembling sequence. Tetrominoes are Haar based wavelet model by connecting equal sized squares. Four equal sizes of tetrominoes are used to make the shape of tetrolet pattern.

Consider a digital image I with size of M×N. Let I=$\{(i,j): i,j = 0,\dots,N-1\} \subset Z^2$ be the index set of a digital image and the four connected neighborhood pixels and denoted as:

$$N_4(i,j) = [(i-1,j),(i+1,j),(i,j-1),(i,j+1)] \quad (1)$$

Sample connectivity is illustrated in the following Fig. 1.

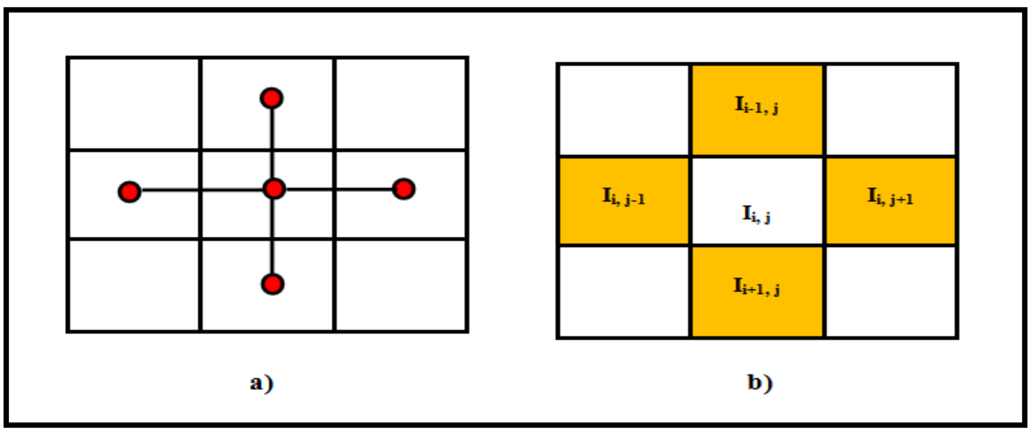


Figure 1: a) Four neighboring pixel connectivity diagram; b) Index position of the connectivity

Tetromino must satisfy the following two conditions

- Each subset I_V contains the four indices, i.e., $|I_v| = 4$
- Every index of I_V has a neighbor pixel

I_V , $\forall\ (i,j) \in I_V \exists (i',j') \in\ I_V : (i',j')\ \in N_4(i,j)$

The above conditions express how the traditional tetromino is constructed and classified into tetrominoes. Five different types of free tetrominoes are illustrated in Fig. 2.

1. Square-O-Type
2. Rectangle-I-Type

3. T-Type
4. S-Type
5. L-Type

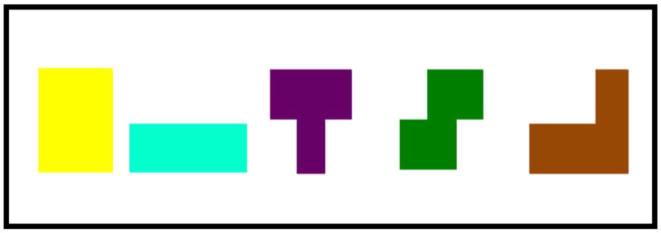


Figure 2: Five free tetrominoes O-I-T-S-L

Considering the one dimensional tetromino, the indexing of four elements is described as:

$$I_v = \{(i_1, j_1), (i_2, j_2), (i_3, j_3), (i_4, j_4)\} \quad (2)$$

The rule of tetromino for the index position is defined as,

$$\text{L}: \xrightarrow{yields} \{0, 1, 2, 3\} \quad (3)$$

Table 1: Mapping operation

Order	Map	Identification
i_1, j_1	0	Smallest
i_2, j_2	1	-
i_3, j_3	2	-
i_4, j_4	3	Largest

Tab. 1 explains the mapping operation of tetromino. In connection with the concept of isometrics, the size of N should be even for every square $[0, N]^2$. Figs. 3 and 4 illustrate the sketch of general matrix to isometric pattern.

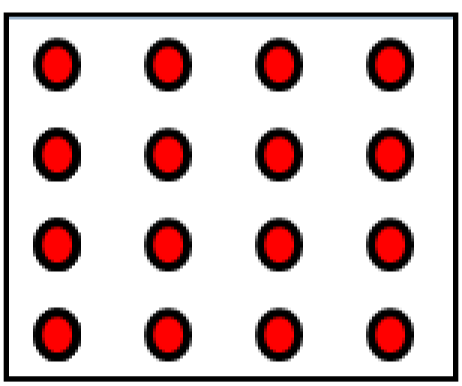


Figure 3: Matrix elements with 4×4 board

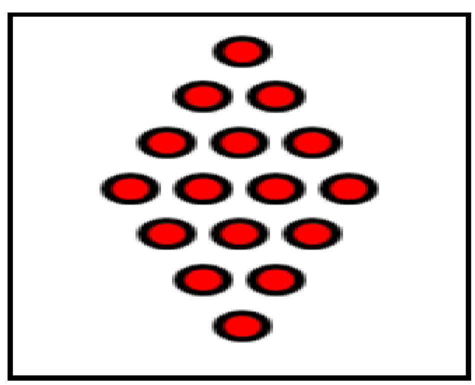


Figure 4: Isometric display of 4×4 board

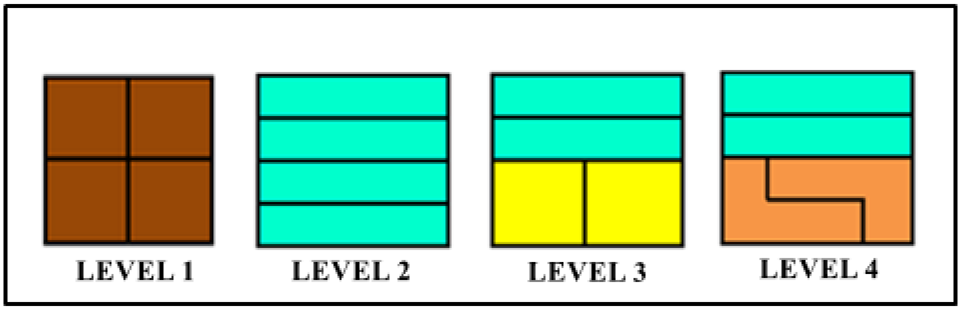


Figure 5: Sample tetrominoes patterns with size of 4×4 board

Various possible tetrolet solutions for different size of board are represented in Tab. 2. The Sample tetrominoes patterns are illustrated in Fig. 5. The detailed tetrolet pattern formation by rotations and a reflection for 4×4 board is presented in the Tab. 3.

Table 2: Possible tetrolet solutions by rotations and reflections

Size of the board	Possible Solutions
4×4 board	117
8×8 board	$117^4 > 10^8$

Table 3: Logical scheme for 4×4 board tetrolet pattern

Range	No. of samples	Logical scheme
Level 1	1	Rotation and reflections
Level 2	4	Applying Isometrics
Level 3	7	Four orientations
Level 4	10	Asymmetric case

2.4 Tetrolet in visual cryptography

A Digital image is composed of 'n' number of finite elements with fixed size. Each element is perfectly arranged by its pixel index position to make a two dimensional digital image. Consider a digital image I with size of 16×16 contains 256 pixels and position range from $I_{1,1}$ to $I_{16,16}$.

Generally the tetrolet tiles are 4×4 based square matrices so that the secret image is divided into fixed number of 4×4 non overlapped blocks for tetrolet tiling process. Furthermore, the chaotic sequence is a most important factor of visual cryptography for constructing secret shares. Therefore, a sub block of original image is classified into two types of clusters as Tetrolet pattern and Non Tetrolet pattern. Visual representation of cluster combination area is presented in the Fig. 6.

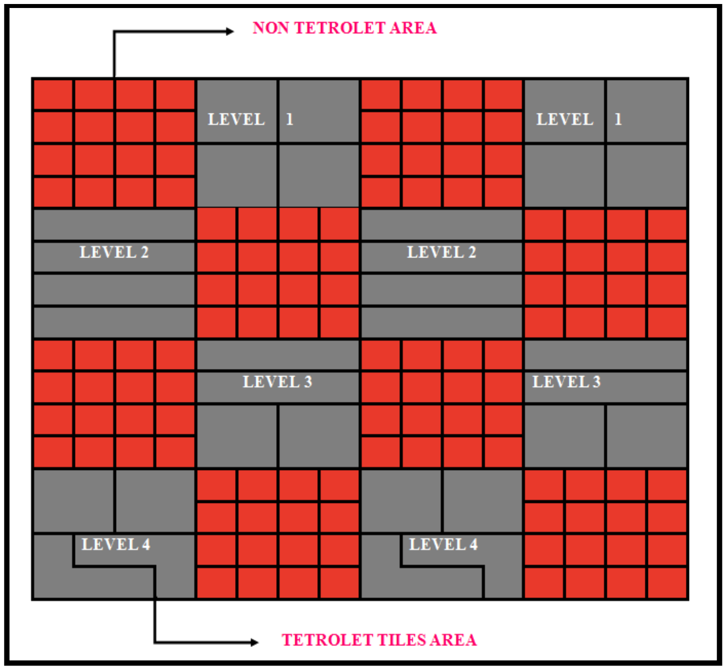


Figure 6: Cluster combination area for both Tetrolet and non Tetro Tiles on 16×16 board

2.5 Preliminaries for tetrolet tiles

The security of secret image is achieved by the determination of tetrolet patterns, non tetrolet patterns, number of clusters and number of blocks. Arithmetic operations are needed to calculate the perquisites for the proposed communication scheme. Tab. 4 shows that calculation of cluster and block size for the secret image.

Table 4: Algorithm for determining the correct cluster and block size

1: procedure FIND THE SIZE OF SECRET IMAGE
2: if M!=0 then
3: block=M/4
4: Cluster=block×block
5: end if
6: disp (block)
7: disp (cluster)
8: end procedure

2.6 Construction of visual cryptography secret shares

After the determination of cluster size, the number of tetrolet tiles is identified for preprocessing. The proposed construction of visual secret sharing scheme fixed tetrominoes in the respective blocks and rest of the non tetrolet blocks are fixed by zero matrices.

The steps involved in generating the shadow images are as follows:

Input: M×N size of secret image I

Output: M×N size of secret share image S, Framed by both tetro and non-tetro patterns

Step 1: Read the Original Image.

Step 2: Calculate the block and cluster size by the algorithm shown in the Tab. 4.

Step 3: Initialize the variables for block size, sequential processing for row and columns.

Step 4: Initialize tetrolet block size for row 1:4 & column 1:4.

Step 5: Fix the cluster size, if M=128, cluster=32, else if M=256 cluster=64, else cluster=128.

Step 6: Calculate the reminder value R for row process & reminder value C for column process.

Case 1: Apply tetrolet tiles for odd series of row blocks.

Case 2: Apply tetrolet tiles for even series of row blocks.

If Row=ODD
If R=1 : 32
    C=1 : 32
Then

$$block1 = \begin{cases} I_{(x,y)} & \text{when C= 0;} \\ 0 & \text{when C=1;} \end{cases}$$

•

•

$$blockN = \begin{cases} I_{(x,y)} & \text{when C= 0;} \\ 0 & \text{when C=1;} \end{cases}$$

End if
End if
$C1 = C2 + 1;$
$C2 = C2 + 4;$

If Row = Even
If R=1 : 32
    C=1 : 32
Then

$$block1 = \begin{cases} I_{(x,y)} & \text{when C= 0;} \\ 0 & \text{when C=1;} \end{cases}$$

•

•

$$blockN = \begin{cases} I_{(x,y)} & \text{when C= 0;} \\ 0 & \text{when C=1;} \end{cases}$$

End if
End if
$C1 = C2 + 1;$
$C2 = C2 + 4;$

Step 7: For i=1: SECT.

Sect 1=combine (Non-Tetro, Tetro)

End

Step 8: For i=1: Cluster.

Secret Share1=combine (sector1: sector N)

End

Step 9: Repeat the process to generate more shares with different tetrolet tiles.

Step 10: Display the generates secret shares.

2.7 Revealing process

After the generation of multiple secret shares, the secure transmission is ensured at the sender area. In the revealing phase, the receiver must collect all the secret shares from various tetrolet participants and stack the secret shares one by one to reveal the original image. Without huge computational complexities; our proposed scheme performs the overlapping operation to reconstruct the secret image with high visual quality. The steps involved in revealing process are given in Tab. 5.

Table 5: Algorithm for revealing original image

```
procedure GET MAXIMUM NUMBER OF SHARES
  Initialize Share, recon=0
      if share_count≤S then
            for i:2 to share_count
                recon=bitor (share, share_count ( i ))
                Share=recon
            end for
      end if
Display Original Image
end procedure
```

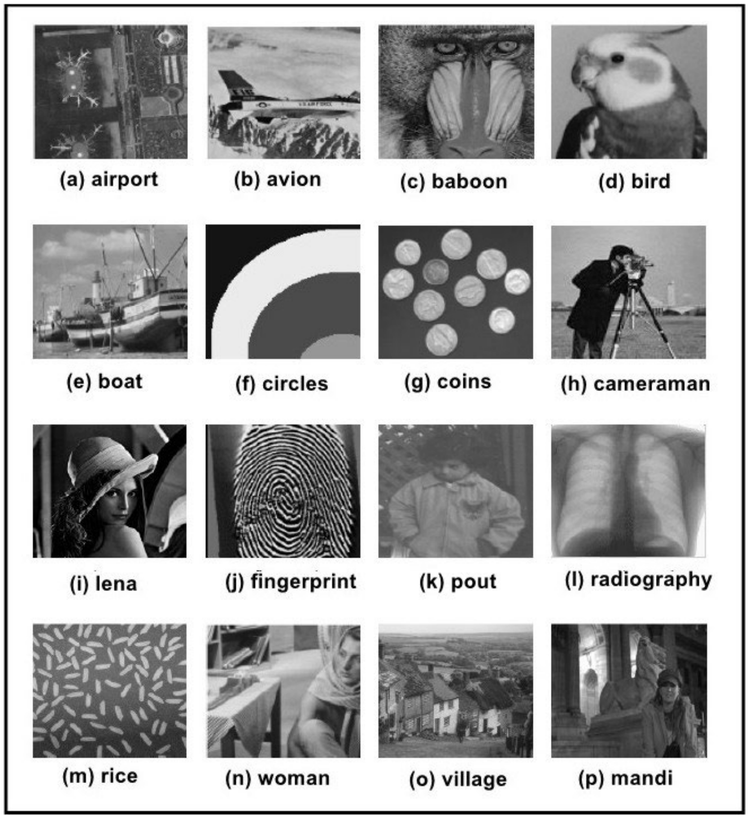


Figure 7: Sixteen gray-scale images used in this experiment

3 Experimental results

In this section, we have conducted experimental test for several domains. Tested images, comparisons, histogram analysis and image quality metrics are presented here. All the experiments are run on an Intel core i3-3110M CPU @ 2.40 GHZ with 2 GB of internal memory space. A gallery of gray scale images is show in the Fig. 7.

3.1 Experiments with 8 secret shares

A radiographic image is successfully communicated to another participant by the proposed secret sharing scheme. Eight secret shares are generated by using tetrolet tiling patterns as shown in Fig. 8. For security reason the secret image has divide into 4×4 block and further it is categorized by two factors like, tetro tile and non tetro tiles. Every secret share contains 256 tetro tiles and 16 tetro tiles in each row. All the information pixels are stored into tetro tile patterns and non tetro tiles contain no information. By stacking all the shadow images one by one, the secret image has revealed with high visual quality. All the share images retain the same size as the original image for tetrolet processing.

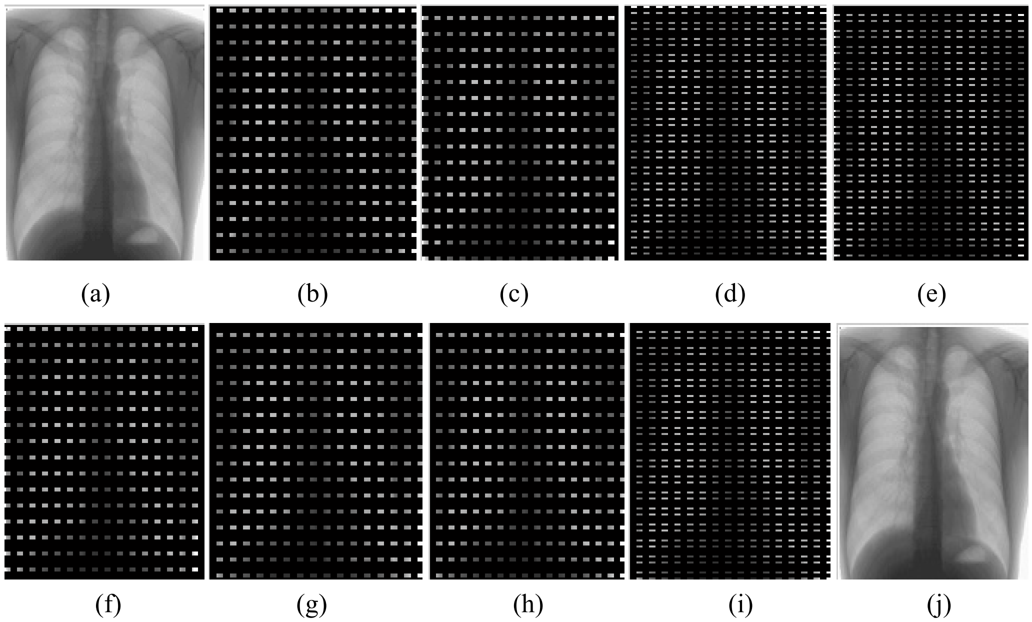
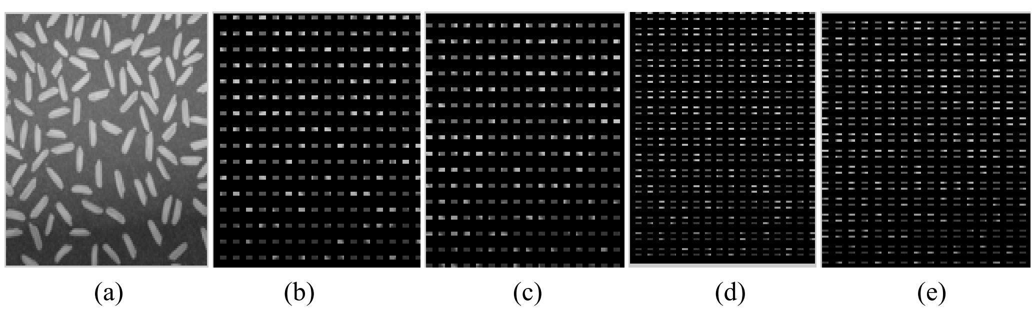
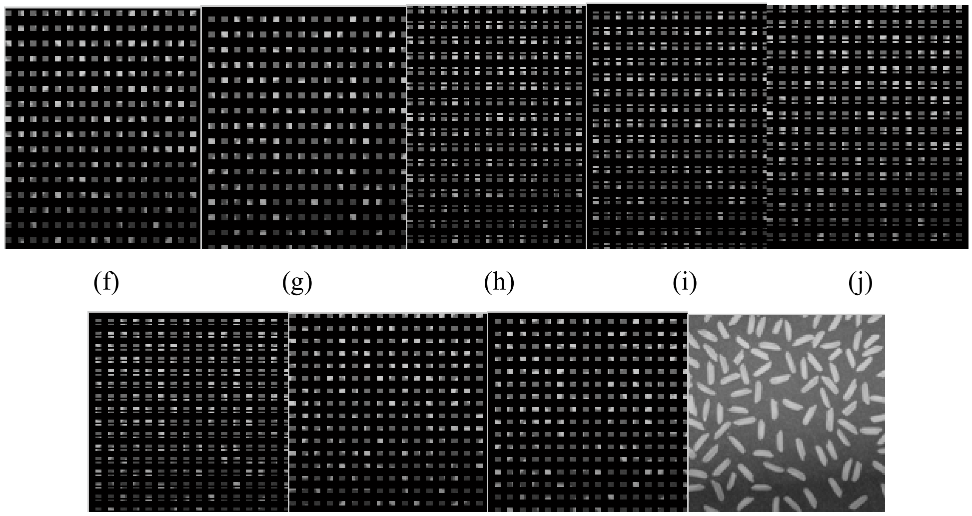


Figure 8: Experimental results of the proposed scheme with 8 shares. **a)** Radiography (Original image); **b)** Secret share #1; **c)** Secret share #2; **d)** Secret share #3; **e)** Secret share #4; **f)** Secret share #5; **g)** Secretshare #6; **h)** Secret share #7; **i)** Secret share #8; **j)** Reconstructed image

3.2 Experiments with 12 secret shares

In addition, the number of shadow images has increased; therefore twelve secret shares are generated by applying non tetro and tetrolet tiling patterns shown in Fig. 9. Every secret share contains 256 tetro tiles, 768 non tetro tiles. Each cell in this pattern has separated by odd and even sectors. An odd row sector contains 16 tetro and 16 non tetro tiles and even row sector contains 32 non tetro tiles to construct the secret shares.





(f) (g) (h) (i) (j)

(k) (l) (m) (n)

Figure 9: Experimental Results of the proposed Scheme with 12 shares. **a)** Rice (Original image); **b)** Secret share #1; **c)** Secret share #2; **d)** Secret share #3; **e)** Secret share #4; **f)** Secret share #5; **g)** Secret share #6; **h)** Secret share #7; **i)** Secret share #8; **j)** Secret share #9; **k)** Secret share #10; **l)** Secret share #11; **m)** Secret share #12; **n)** Reconstructed image

Table 6: Image quality metrics for tested images

Test Image	Image Quality Metrics						
	MSE	PSNR	Cross Correlation	Average Difference	Structural Content	Maximum Difference	Normalized Absolute Error
Airport	0	99	1	0	1	0	0
Avion	0	99	1	0	1	0	0
Baboon	0	99	1	0	1	0	0
Bird	0	99	1	0	1	0	0
Boat	0	99	1	0	1	0	0
Circles	0	99	1	0	1	0	0
Coins	0	99	1	0	1	0	0
Camera man	0	99	1	0	1	0	0
Lena	0	99	1	0	1	0	0
Finger print	0	99	1	0	1	0	0
Pout	0	99	1	0	1	0	0
Radio graphy	0	99	1	0	1	0	0
Rice	0	99	1	0	1	0	0
Woman	0	99	1	0	1	0	0
Village	0	99	1	0	1	0	0
Mandi	0	99	1	0	1	0	0

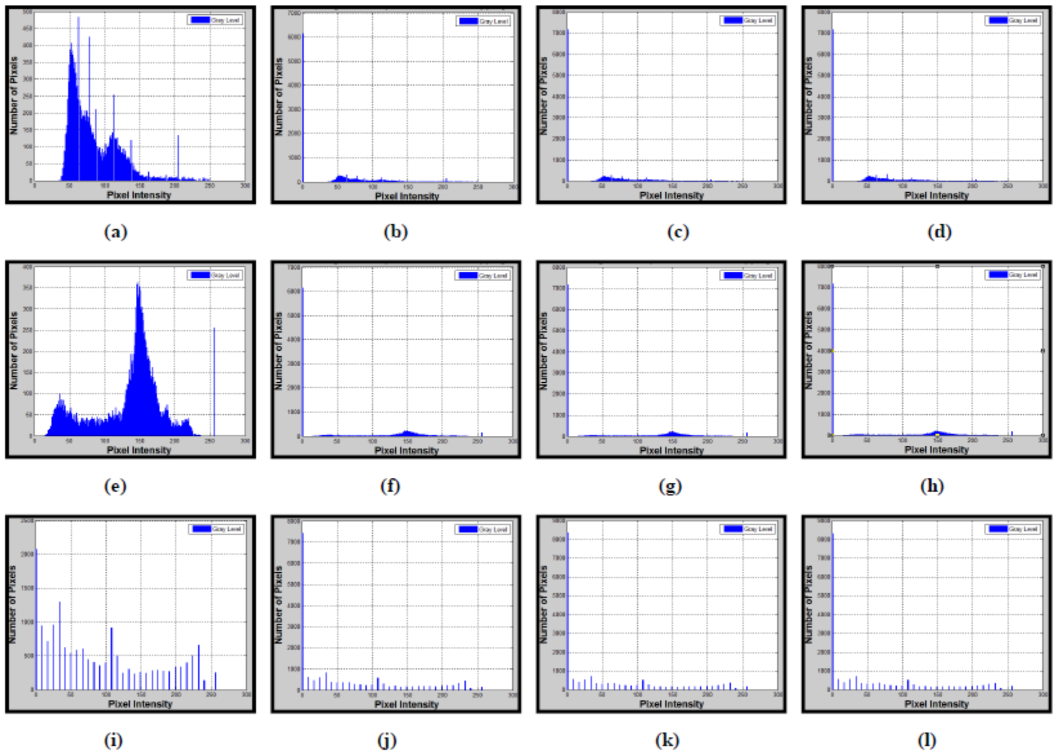


Figure 10: Pixel intensity distribution among the secret image and constructed shares

We analyzed various image quality factors to determine the quality of reconstructed image and the observations is shown in Tab. 6. Considering the mean squared and peak signal noise ratio, the proposed scheme gives the minimum squared error and better peak signal noise ratio. The pixel intensity variations of the secret shares are illustrated in Fig. 10 and Fig. 11. The similarity measurement is calculated and shown in Tab. 7. Newly constructed shares are also compared in various stages like front, middle and last. The comparisons are clearly illustrated in the Figs. 12-14. Some insufficient stacking results are shown in Figs. 15 and 16. Finally we compare several existing visual cryptographic algorithms with our proposed scheme and the results are shown in Tab. 8.

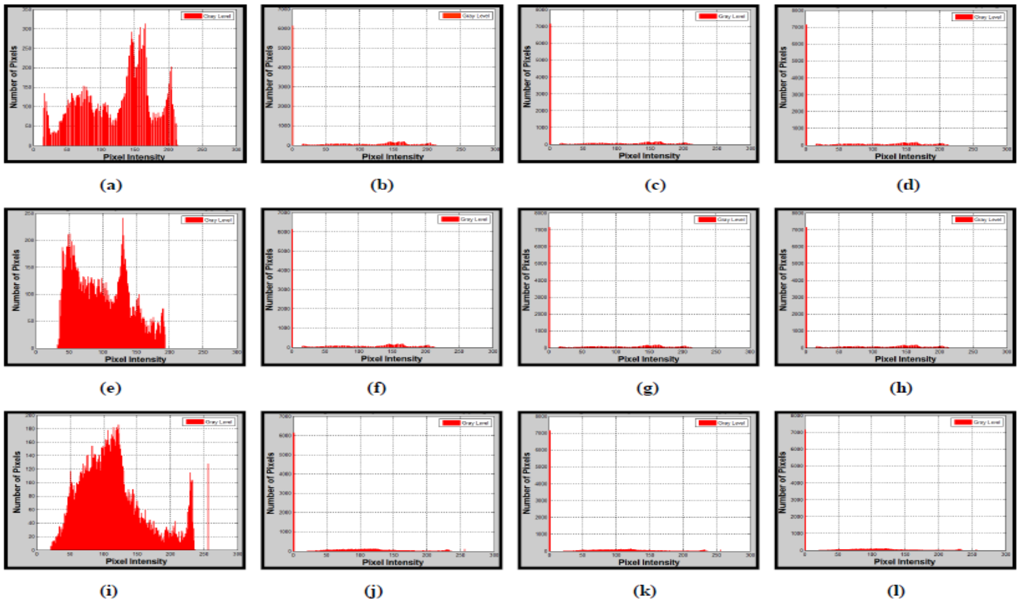


Figure 11: Pixel intensity distribution among the secret image and constructed shares

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}} \sum_{j=1}^{M} \sum_{k=1}^{N} \left(x_{j,k} - x'_{j,k}\right)^2 \quad (4)$$

$$\mathrm{PSNR} = 10 \log \frac{(2^n - 1)^2}{\mathrm{MSE}} = 10 \log \frac{255^2}{\mathrm{MSE}} \quad (5)$$

$$\mathrm{NK} = \sum_{j=1}^{M} \sum_{k=1}^{N} x_{j,k} . x'_{j,k} \Big/ \sum_{j=1}^{M} \sum_{k=1}^{N} x^2_{j,k} \quad (6)$$

Table 7: Correlation coefficients of the tested images

Test Images	Airport			Avion		
	Horz.	Ver.	Diag.	Horz.	Ver.	Diag.
Share 1	0.7090	0.4283	0.2953	0.7128	0.4280	0.2884
Share 2	0.6906	0.4234	0.2809	0.7178	0.4316	0.2931
Share 3	0.6929	-0.1191	-0.1191	0.7141	-0.1236	-0.1236
Share 4	0.6968	-0.1173	-0.1175	0.7165	-0.1218	-0.1220
Share 5	0.6753	0.5809	0.3803	0.6950	0.5872	0.3898
Share 6	0.6927	0.5956	0.4027	0.6996	0.5917	0.3967
Share 7	0.6763	0.1959	0.0958	0.6960	0.1968	0.0983
Share 8	0.6903	0.2224	0.1208	0.6993	0.1989	0.1015
Share 9	0.6761	0.2012	0.0981	0.6956	0.2029	0.1028
Share 10	0.6904	0.1894	0.0938	0.6993	0.1991	0.1008
Share 11	0.6780	0.5948	0.3900	0.6951	0.5990	0.3992
Share 12	0.6894	0.5855	0.3915	0.6982	0.5936	0.3966

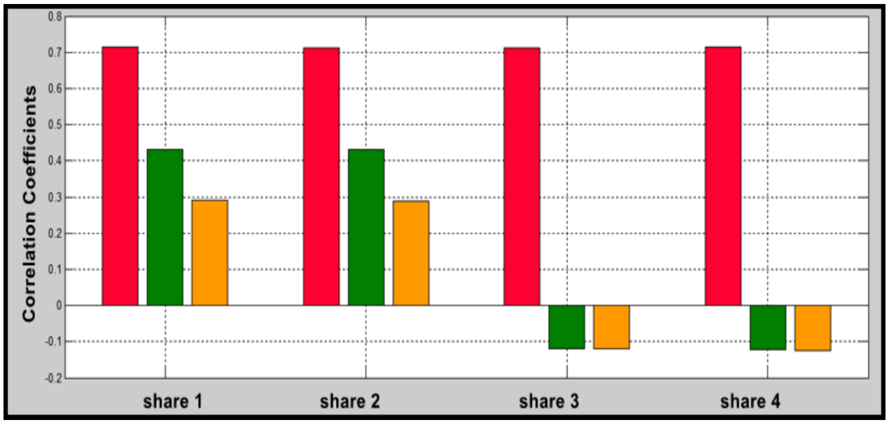


Figure 12: Correlation coefficients comparison between the first four shares of the secret image airport

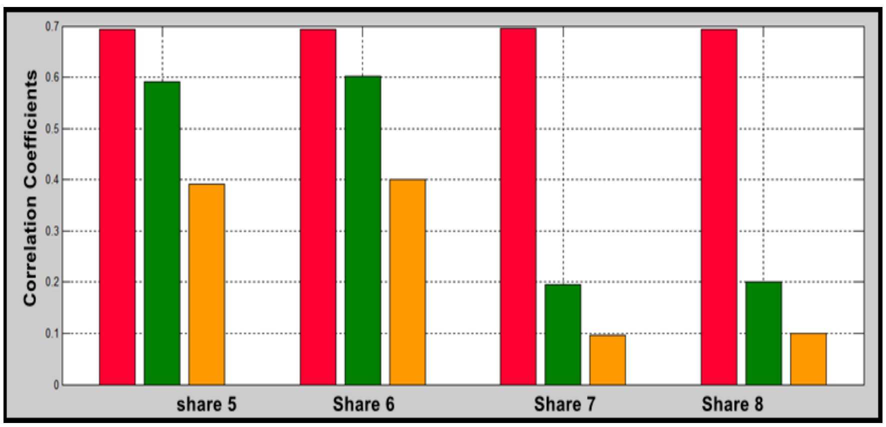


Figure 13: Correlation coefficients comparison between middle four shares of the secret image airport

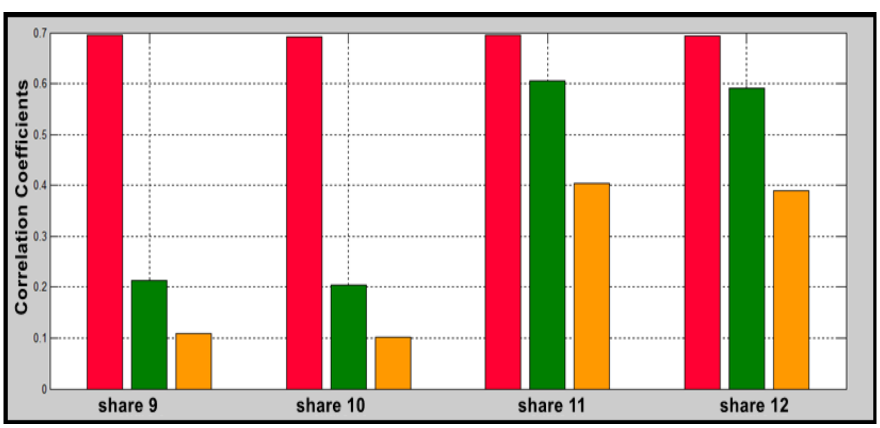


Figure 14: Correlation coefficients comparison between the last four shares of the secret image airport

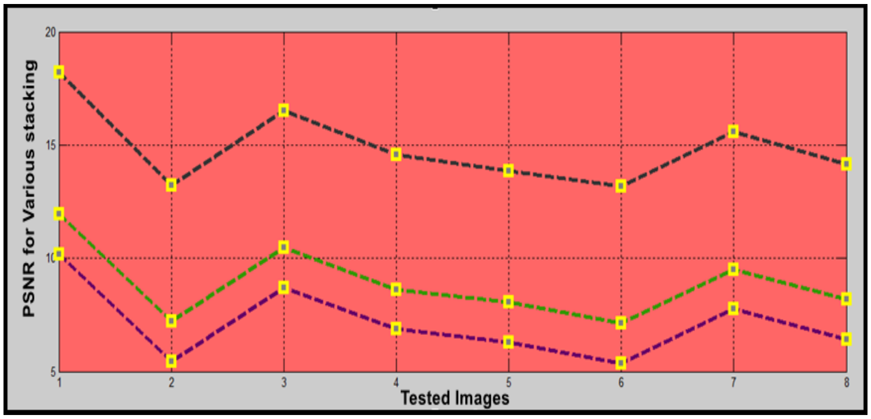


Figure 15: Plotting information for PSNR values between semi stacking operations

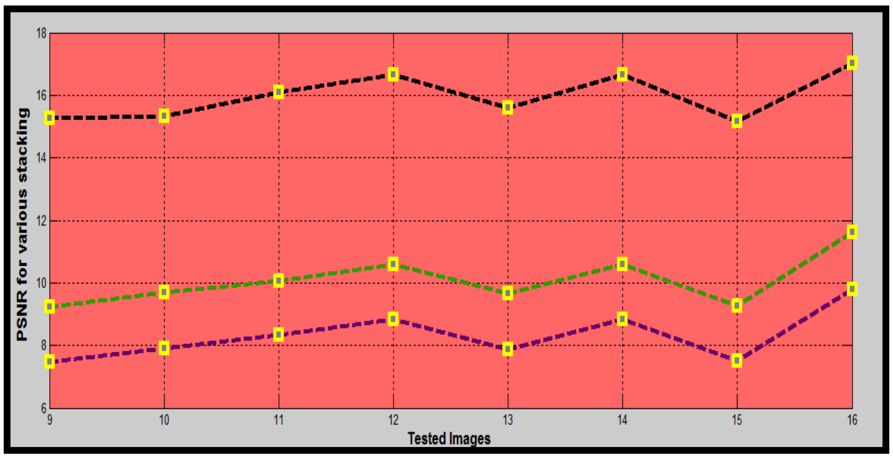


Figure 16: Plotting information for PSNR values between semi stacking operations

Table 8: A comparison among proposed scheme and other secret sharing schemes

Schemes	Features					
	Pixel expansion	Codebook Design	Lossless Secret Image	Image Type	No. of Shares	Visual Quality
Wu	No	No	Yes	Grayscale	6	High
Lin and Tsai	No	No	No	-	2	Low
Feng	Yes	Yes	No	Binary	2	Medium
Chen	Yes	No	No	-	4	Low
Kuang	No	No	Nearly Perfect	Grayscale	4	Good
Prisco	Yes	No	No	Color	4	Medium
Chen	Yes	No	No	Grayscale	2	Low
Lin	No	No	Yes	Grayscale	6	High
Proposed	No	No	Yes	Grayscale	12	High

4 Conclusion

Secret sharing scheme is an astonishing technique to protect the confidential information for any type of applications. Many visual secret sharing schemes have been developed with high level mathematical computations that cause overlapping issues. In this paper, a novel secret communication scheme based on visual cryptography and tetrolet tiling patterns is proposed. At first, the original image is divided into 4×4 sub blocks. The alternative rows and columns of sub blocks are grouped into tetrolet and non-tetrolet blocks. Using the tetrominoes patterns, the proposed scheme encodes the tetrolet blocks of original image into meaningful secret shares. The non tetrolet blocks are completely replaced by zero. Finally, a new shadow image is obtained in regular intervals with different tetrolet patterns. The experimental results show that the secret images were reconstructed successfully with high visual quality. The visual representation of histogram generation is also presented in experimental section. The histogram shows the different level of pixel intensity for different tested images and its corresponding secret share images. The similarity between the original image and share images are also computed by correlation coefficients. The similarity checking has been done in all the orientations like vertical, horizontal and diagonal. Comparisons done between the proposed scheme and other approaches are also listed in the experimental section. Thus, the proposed secret communication scheme provides better security for any type of application with more number of participants involved in secret sharing domain. In future, proposed scheme can be extended for color images with different tetrolet patterns on the same share images.

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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