



## Comparative Study and Analysis of Halftone Visual Cryptography via Error Diffusion

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**Abstract**— Visual Cryptography (VC) is a special type of encryption technique where an image or document is encrypted by breaking it down into shares. These shares are then printed on transparencies. Decryption is done by superimposing the shares. Thus one can visually decode the secret image without computation. In this paper, Halftone Visual Cryptography (HVC) construction methods based on error diffusion are proposed. The secret image is concurrently embedded into binary valued shares while these shares are halftone by error diffusion, the workhorse standard of halftoning algorithms. Error diffusion has low complexity and provides halftone shares with good image quality. A reconstructed secret image, obtained by stacking qualified shares together, does not suffer from cross interference of share images. Factors affecting the share image quality and the contrast of the reconstructed image are discussed. Simulation results show several illustrative examples.

**Keywords:** Visual cryptography, Halftoning, Error diffusion, Secret sharing.

### I. INTRODUCTION

Visual Cryptography (VC), first proposed in 1994 by Naor and Shamir [1], is a secret sharing scheme, based on black and white or binary images. Secret images are divided into share images which, on their own, reveal no information of the original secret. Shares may be distributed to various parties so that only by collaborating with an appropriate number of other parties, can the resulting combined shares reveal the secret image. Recovery of the secret can be done by superimposing the share images and, hence, the decoding process requires no special hardware or software and can be simply done by the human eye.

To illustrate the principles of Visual Security (VS), consider a simple 2-out-of-2 VC scheme shown in Fig. 1. Each pixel 'p' of the secret image is encrypted into a pair of sub pixels in each of the two shares. If 'p' is white, one of the two columns under the white pixels in Fig. 1 is selected. If 'p' is black, one of the two columns under the black pixels are selected. The first two pairs of sub pixels in the selected columns are assigned to share 1 and share 2 respectively. Since in each shares, p is encrypted into black and white or white and black pair of sub pixels, an individual share gives no clue about the secret image. Now consider the superposition of the two shares as shown in the last row of Fig. 1.

Secret image	Share1	Share2	Stacked image
□	■ □	■ □	■ □
	■ □	■ □	■ □
■	■ □	■ □	■ ■
	■ □	■ □	■ ■

Fig.1 Sharing and Stacking scheme of Black and White Pixel [2][3]

If 'p' is white it always output one black and one white sub pixel during encryption. If 'p' is black, it outputs two black sub pixels.

Fig. 2 shows an example of the application of the 2-out-of-2 VS scheme. Fig. 2(a) shows a secret binary image to be encoded. According to the encoding rule shown in Fig. 1, each pixel of image is split into two subpixels in each of the two shares, as shown in Fig. 2(b) and (c). Superimposing the two shares leads to the output secret image shown in Fig. 2(d). The decoded image is clearly identified, although some contrast loss occurs.

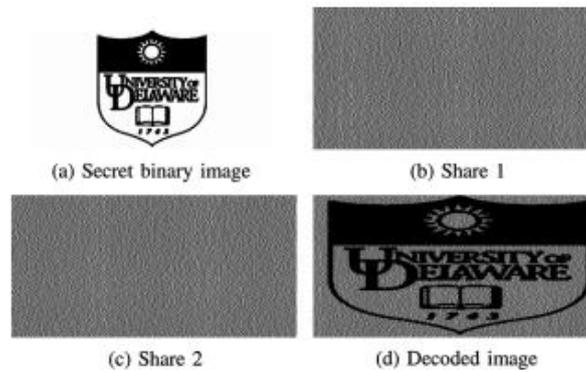


Fig. 2. Example of 2-out-of-2 scheme.

Based on the principle of, halftone visual cryptography has been proposed in void and cluster algorithm [3] to produce meaningful halftone image for the shares in the VC scheme. Halftone visual cryptography utilizes the void and cluster algorithm to encode a secret binary image into  $n$  halftone shares carrying significant visual information. Using the void and cluster algorithm to find positions for the secret pixels in the halftone cell, however, is computationally expensive. In this paper, we proposed a computationally efficient algorithm for halftone VC which relies on the simple operation of error diffusion [5]. Compared with the Floyd-Steinberg, Jarvis et al, and Stucki methods, our proposed method is more secure and requires less computation.

## II. HALFTONING VISUAL CRYPTOGRAPHY

Halftone VC was introduced in [1, 3] and is built upon the basis matrices and collections available in conventional VC. A secret binary pixel  $p$  in halftone VC is encoded into an array of  $Q_1 \times Q_2$  sub-pixels, referred to as a halftone cell, in each of the  $n$  shares. The pixel expansion in halftone VC is thus  $Q_1 \times Q_2$ . The secret pixel  $p$  in the reconstructed image can be visually decoded with contrast  $1/Q_1Q_2$  [1].

In a 2-out-of-2 halftone visual threshold scheme, a halftone image  $I$ , obtained from a grey level image  $GI$ , is assigned to participant 1. Its complementary image  $\bar{I}$ , obtained by reversing all black/white pixels of  $I$  to white/black pixels, is assigned to participant 2. To encode a secret pixel  $p$  into a

$Q_1 \times Q_2$  halftone cell in each of the two shares, only 2 pixels, referred to as the secret information pixels, in each halftone cell need to be modified. The two secret information pixels should be at the same positions in the two shares. If  $p$  is white, a matrix  $M$  is randomly selected from the collection of matrices  $C_0$ . If  $p$  is black,  $M$  is randomly selected from the collection of matrices  $C_1$ . The secret information pixels in the  $i$ th ( $i = 1, 2$ ) share are replaced with the two sub-pixels in the  $i$ th row of  $M$ . These modified pixels carry the secret information of the encoded image. The other pixels in the halftone cells that are not modified are ordinary pixels [1].

In the above procedure, the selection of the secret information pixels in a halftone cell is important as it affects the visual quality of the resultant halftone shares. To obtain better visual results, the void and cluster algorithm [4] which spreads the minority pixels as homogeneously as possible was used to achieve improved halftone image in each share. But using the void and cluster algorithm has two disadvantages. First, it is computationally expensive. Every binary pixel in the original halftone image has to go through a nonlinear low pass filter which needs intensive computation. Second, using the void and cluster algorithm to choose the positions of secret information pixels actually makes the positions dependent on the white/black pixel distribution on the original halftone image. The reconstructed image may reveal some trace of the original halftone image the secret image is encoded in.

## III. ERROR DIFFUSION FOR VISUAL CRYPTOGRAPHY

### 3.1. Basic Principles

The more popular technology of halftoning algorithms is error diffusion. This technology propagates quantization errors to unprocessed neighboring pixels according to some fixed ratios. The error diffusion preserves the average intensity level between the original input images and the binary output image.

Further, the error diffusion produces good halftone image despite relatively low cost.

Error diffusion was introduced in 1976 by Floyd and Steinberg [8]. It was a completely new method of image halftoning that produced much higher quality images. The algorithm relies on distributing the quantization error from thresholding to neighbors of current pixel. As the image is scanned (from left to right and top to bottom), the quantization error “diffuses” across and down the image, giving the algorithm its name. Error diffusion accurately reproduces the gray level in a local region by driving the average error to zero through the use of feedback.

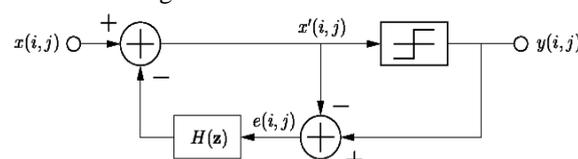


Fig. 3.1. Error Diffusion Algorithm.

Error diffusion algorithm is graphically illustrated in Fig.3.1. The process is described mathematically as follows. Assume an input image  $x(i, j)$  of size  $M \times N$  pixels, with pixel values ranging from 0 to 1. As the algorithm proceeds, each input pixel is effectively modified by the weighted errors diffused from previous pixels; this modified input is denoted  $x'(i, j)$ . For the first pixel in the image,  $x'(i, j) = x(i, j)$ . The modified input  $x'(i, j)$  is threshold to produce an output pixel  $y(i, j)$ :

$$y(i, j) = \begin{cases} 0, & x'(i, j) < 0.5 \\ 1, & x'(i, j) \geq 0.5 \end{cases}$$

The quantization error is given by  $e(i, j) = y(i, j) - x'(i, j)$ ,  $\begin{cases} 0 < k < M-1 \\ 0 < l < N-1 \end{cases} j$ ,

and is subtracted from neighboring pixels according to  $x'(k, l) = x(k, l) - h(k-i, l-j)e(i, j)$  where  $h(i, j)$  is known as the error filter.

### 3.2. Analysis of Error diffusion Halftoning Algorithms

In this paper, we have analyzed three error diffusion halftoning algorithm used in visual cryptography. First, the quantization error is scaled and added to the nearest gray scale pixels. The scaling factor for Floyd-Steinberg algorithm filter is given below.

		x	7/16
3/16	5/16	1/16	

The error filter proposed by Floyd-Steinberg algorithm [10] where  $x$  indicates the current pixel.

Second, Jarvis's halftoning algorithm the quantization error is scaled added to nearest gray scale pixels. The scaling factor is given below.

		X	7/48	5/48
3/48	5/48	7/48	5/48	3/48
1/48	3/48	5/48	3/48	1/48

The error filter proposed by Jarvis's algorithm [9]

and Third, Stucki halftoning algorithm the quantization error is scaled added to nearest gray scale pixels. The scaling factor is given below.

		x	8/42	4/42
2/42	4/42	8/42	4/42	2/42
1/42	2/42	4/42	2/42	1/42

The error filter proposed by Stucki algorithm. [9]

The effect of error diffusion with Floyd and Stenberg, Jarvis's and Stucki algorithm error filter for gray scale ramp, the test image is shown below.

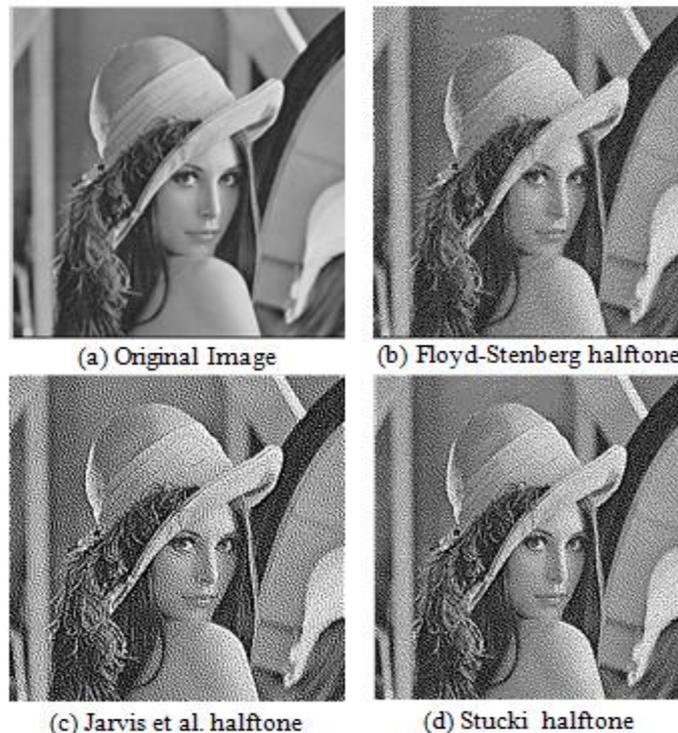


Fig. 3.2 Error Diffusion halftones

from the results of halftoned images we can conclude that the visual quality of halftone images depends on the algorithms employed. When different algorithms for error diffusion halftoning are compared, the comparison is done on the basis of contrast loss, perceived error between original image and halftoned image and the PSNR values. Following table define analysis of different algorithms [11].

Table1: PSNR value for all algorithms.

Types of Algorithm PSNR(db)	Floyd-Steinberg	Jarvis et al.	Stucki
Images			
Lena	6.75054	6.89729	6.8656
Peppers	6.9462	7.06942	7.04093
Barbara	7.16358	7.40814	7.36953
Tree	7.54767	7.77018	7.72993
Clock	8.429588	8.60261	8.56672

From the implementation of all the algorithms, it is observed that

- If the error is diffused in larger areas it gives sharper details and reduces some of the artifacts.
- This minimizes the low- frequency artifacts and makes it invisible for the eyes.
- This minimizes the low- frequency artifacts and makes it invisible for the eyes.
- As the number of elements of error filers increase, the algorithm becomes slower.
- Visual quality of halftone image is higher when Jarvis algorithm is used.
- Time required least when Floyd-Steinberg algorithm is used.

#### IV. SIMULATION RESULTS AND ANALYSIS

In this section, examples are provided to illustrate the high quality image and effectiveness of the proposed methods. In proposed algorithm, the image is scanned from top to bottom and left to right thus, we get higher PSNR value and image quality then previous algorithm. It is shown in Fig.4.

#### Proposed Algorithm:

The steps for proposed algorithm are:

1. Input gray scale image
2. Convert gray scale image into binary image
3. for  $j=1 \dots m$  do
4. for  $i=1 \dots n$  do
5. if  $J(i, j) < 128$  is found then  $c0$
6. else  $J(i, j) = 255$
7.  $error = J[i, j] - I[i, j]$
8. Distribute (7/16) errors to the right pixel
9. Distribute (1/16) errors to the right diagonal pixel
10. Distribute (5/16) errors to the bottom pixel
11. Distribute (3/16) errors to the left diagonal pixel
12. end for
13. end for
14. End

Here, I am giving the explanation of the proposed algorithm, First take gray scale image. Then, convert gray scale image into binary image. In third step, determine the pixel process. If there is any pixel to process, then start to scan image pixel from top to bottom then starting from left to right. After scanning the pixel, calculate error by subtracting binary pixel from original pixel. After finding error, distribute the error among its neighbor pixels. Then, go to step third and repeat the pixel processing until you complete. After successful processing of pixels, we would get the resulting halftone image.

Table 2: PSNR value all algorithms.

Types of Algorithm PSNR(db)	Floyd-Steinberg	Proposed Algorithm	Jarvis et al.	Stucki
Images				
Lena	6.75054	6.8125	6.89729	6.8656
Peppers	6.9462	7.0866	7.06942	7.04093
Barbara	7.16358	7.3095	7.40814	7.36953
Tree	7.54767	7.7664	7.77018	7.72993

We have made experiments for the various images to measure the performance of the proposed algorithm using MATLAB R2012a and analyzed performance of these algorithms and evaluated the result. The experiment results are shown in Table 2.

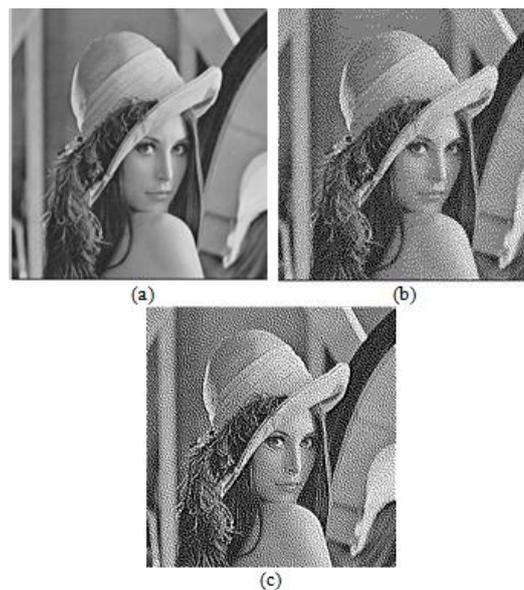


Fig 4: The result images of various methods (a) Original Image, (b) Floyd- Steinberg halftone and (c) Proposed halftone image

## V. CONCLUSION

From the implementation of the proposed algorithm, it is observed that, visual quality of halftone image is higher and also high peak signal-to-noise ratio (PSNR). The comparison is done on the basis of contract loss, perceived error between original and halftone image and the PSNR values.

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