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Parameter Evaluation and Review of Various Error-Diffusion Half toning algorithms used in Color Visual Cryptography

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Abstract*— Color visual cryptography (VC) encrypts a color secret image into n halftoned image shares. The secret image can be recovered simply by stacking these shares together without any complex computations involved. The shares are very safe because separately they reveal nothing about the secret image. Half toning is the key feature of visual cryptography which provides security at the early stage of cryptography. A particular half toning method that has been used extensively in VC scheme is so called error diffusion method. This method provides a simple and efficient algorithm for half toning. Error diffusion (E-D) algorithm has attracted much attention in the graphics community. In this paper we will make a review of error-diffusion half toning techniques that are used in VC scheme and compare the respective algorithms for parameters such as PSNR and perceived error.

Index Terms— **Digital Half Toning, Error Diffusion, PSNR, Perceived Error.**

I. INTRODUCTION

In 1994, Naor and Shamir proposed a cryptography scheme called the "k-out-of-n visual secret sharing scheme," and the idea they raised has been referred to as "visual cryptography" [1]. The major feature of their scheme is that the secret image can be decrypted simply by the human visual system without any complex computations. Naor and Shamir's scheme can hide the secret image in *n* distinct images called shares. The secret image can be revealed by simply stacking together as many as *k* of the shares. Each of the shares looks like a collection of random pixels and of course appears meaningless by itself. Naturally, any single share, before being stacked up with the others, reveals nothing about the secret image. This way, the security level of the secret image when transmitted via the Internet can be effectively lifted up. VC scheme proposed by Naor and Shamir [1] serves as a basic model and has been applied to many applications. Aside from the obvious applications to information hiding, there are many applications of VC, which include general access structures [2], copyright protection [3], watermarking [4], [5], visual authentication and identification [6], print and scan applications [7], etc. To illustrate the basic principles of VC scheme, consider a simple (2, 2)-VC scheme in Fig. 1. Each pixel from a secret binary image is encoded into black and white sub pixels in each share. If *p* is a white (black) pixel, one of the six columns is selected randomly with equal probability, to replace *p*. Regardless of the value of the pixel *p*, it is replaced by a set of four sub pixels, two of them are black and two white. Thus, the sub pixel set gives no clue as to the original value of *p*. When two sub pixels originating from two white *p* are superimposed, the decrypted sub pixels have two white and two black pixels. On the other hand, a decrypted sub pixel having four black pixels indicates that the sub pixel came from two black *p* pixels. Fig. 2 shows an example of a simple (2, 2)-VC scheme with a set of sub pixels shown in Fig. 1. Fig. 2(a) shows a secret binary message, Fig. 2(b) and (c) depicts encrypted shares for two participants. Superimposing these two shares leads to the output secret message as shown in Fig. 2(d). The decoded image is clearly identified, although some contrast loss is observed. Several new methods for VC have been introduced recently in the literature. In 1996, Ateniese [2] proposed a more general method for VC scheme based upon general access structure. This paper provided a more efficient construction of threshold schemes. The VC scheme concept has been extended to grayscale share images by L. A. MacPherson [8]–[11]. Blundo [9] in 2000 proposed VC schemes with general access structures for grayscale share images. In this paper, it is assumed that the secret image consists of a collection of pixels, where to each pixel is associated a grey level ranging from white to black and each pixel is handled separately. Hou [12] transformed a gray-level image into halftone images and then applied binary VC schemes to generate grayscale shares. Although the secret image is grayscale, shares are still constructed by random binary patterns carrying visual information which may lead to suspicion of secret encryption. Ateniese [13] developed a method of extended visual cryptography (EVC) in which shares contain not only the secret information but are also meaningful images. Zhou *et al.* [14] used half toning methods to produce good quality halftone shares in VC. Visual secret sharing for color images was introduced by Naor and Shamir [15] based upon cover semi groups. Hou [12] in 2003 proposed schemes for color shares by applying halftone methods and color decomposition. Hou decomposed the secret color image into three (yellow, magenta and cyan) halftone images. In 2011, Gonzalo R. Arce [16] proposed a new scheme for color visual cryptography which introduces Visual Information Pixel (VIP) synchronization to generate high quality shares. This paper has also introduced an error diffusion technique for generating halftoned shares which are more pleasant to human eyes. From the review of Color visual cryptography schemes, it is seen that half toning of images is achieved by various methods in different schemes. In this paper, we will take a review of all these methods. At the same time we will compare all these methods and will

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adopt the one which will give us the best result with respect to color visual cryptography.

II. HALFTONING

Halftoning is an intentionally applied form of noise called as 'blue noise' used to randomize quantization error. It prevents large-scale patterns such as color banding in images. It is often used in digital printing, where it is applied to bit-depth transitions. Halftoning is analogous to the dithering technique used in digital audio and digital video data processing such as digital photography, seismology, RADAR, weather forecasting systems and many more. It is often one of the last stages of audio production to compact disc. In the applications mentioned above, the quantization and re-quantization of digital data results into error. If this error is repeating and correlated to the signal, it results into a cyclical and mathematically determinable form. In some fields, especially where the receptor is sensitive to such artifacts, cyclical errors yield undesirable artifacts. To overcome this drawback a new technique was proposed by Zhou et al [14] called as 'Halftoning'. Halftoning results in less determinable artifacts. In image processing it is always required to print various images with a limited color palette (color quantization). This results into loss of details of an image. In a halftoned image, colors not available in the palette are approximated by a diffusion of colored pixels from within the available palette. The human eye perceives this diffusion as a mixture of the colors within it. Halftoning introduces a pattern into the image which is not perceived by human eye. Unfortunately this is not typically the case and often the patterning is visible. In these circumstances it has been shown that a blue noise halftone pattern is the least unsightly and distracting pattern [17]. Error diffusion techniques were some of the first methods to generate blue noise dithering patterns; however, other techniques such as ordered dithering can also generate blue noise dithering without the tendency to degenerate into areas with artifacts. Halftoned images, particularly those with relatively few colors, can often be distinguished by a characteristic graininess, or speckled appearance [18].

A. Need for half toning

We know that if the original image is a photograph, it has thousands, or even millions of colors. If we want this image to get printed with a printer having a specific color palette, there will be a loss of details of an image. For example, let us consider an original image (Fig 3(a)). If this image is to be printed by a printer having 216-color "web-safe" color palette, it should be reduced to the respective form. This is done by simply translating the original color pixels into the closest available color from the palette, where no half toning occurs (Fig 3(b)). This often results into significant visual side-effects. This approach results in flat areas (contours) and a loss of details, and may produce patches of color that are significantly different from the original. The application of half toning can help to minimize such visual artifacts, and usually results in a better representation of the original (Fig 3 (c)). It helps to reduce color banding and flatness. The result of printing a halftoned image is often much closer to the original (Fig 3(d)) [19].

B. Types of half toning

There are several types of half toning. We will discuss only the types that are most commonly used in color visual cryptography.

a) Ordered half toning

In this method, for every pixel in the image the value of the pattern at the corresponding location is used as a threshold. The neighboring pixels do not affect each other. This makes it suitable for use in animations. Ordered half toning uses carefully chosen square grids of binary pixels to represent different gray scale ranges. A particular square grid is chosen so that its pattern corresponds to the appropriate gray level. The correspondence is established by its proximity to the average grayscale level. This technique can be parallelized, since each grid is calculated independently of the surrounding ones. The final outcome is likely to contain some characteristic diagonal artifacts which reduce the quality of the final halftoned image Different patterns can generate completely different halftoning effects. Though simple to implement, this halftoning algorithm is not easily changed to work with free-form, arbitrary palettes. [20].

b) Error-Diffusion Halftoning

Error diffusion is a simple but efficient way to halftone a grayscale image. The quantization error at each pixel is filtered and fed into a set of future inputs. The quantization error depends upon not only the current input and output but also the entire past history. The error filter is designed in such a way that the low frequency difference between the input and output image is minimized. The error that is diffused away by the error filter is high frequency or "blue noise." These features of error diffusion produce halftone images that are pleasant to human eyes with high visual quality [21].

III. ALGORITHMS FOR ERROR DIFFUSION HALFTONING

There are several error diffusion algorithms to perform halftoning on color images.

A. Floyd-Steinberg halftoning algorithm

This error-diffusion algorithm is proposed by Floyd and Steinberg [17]. It raised the idea to keep track of the error. Figure 4(a) shows the process of Floyd-Steinberg algorithm. Algorithm-1 implements the error-diffusion halftoning of an n by m grayscale image. The boundary conditions are ignored. It is convenient to compute the output pixels in scan line order from upper left to lower right. At every step, the algorithm compares the grayscale value of the current pixel J (i, j) which is represented by an integer between 0 and 255, to some threshold value (typically 128). If the grayscale value is greater than the threshold, the output pixel I (i, j) is considered black (value 0), else it is considered white (value 1). The difference between the pixel's original grayscale

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value and the threshold is considered as an error. Because we don't want to alter the already computed pixels, we spread this error intensity only to the pixels on the right, the right diagonal, the left diagonal and the bottom. The amount of error which is spread to each neighbor may be varied, but sending 3/8 of the error to the right and lower pixels and 1/8 to the two diagonal neighbors gives good results. The matrix shown graphically in Figure 4(b) is an error-diffusion matrix proposed by Floyd and Steinberg [17], [18].

Algorithm 1.

```
Procedure HALFTONING AN IMAGE
for i = 1,……,n do
  for j = 1,…..,m do
    if  J(i, j) < 128 is found then J(i, j) = 0
    else J(i, j) = 1
    error = J[i, j] - I[i, j]*255
    Distribute (3/8) error to the right pixel
    Distribute (1/8) error to the right diagonal pixel
    Distribute (1/8) error to the bottom pixel
    Distribute (3/8) error to the left diagonal pixel
  end for
end for
```

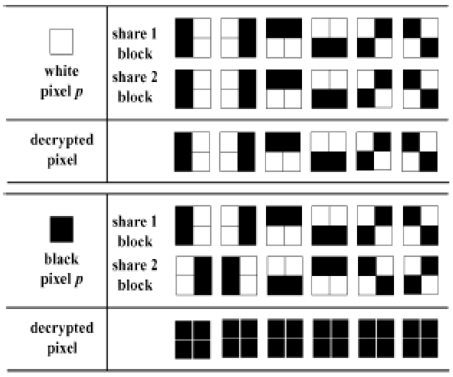


Fig.1. Construction Of (2, 2) VC Scheme: A Secret Pixel Is Encoded Into Four Sub pixels in Each of Two Shares. The Decrypted Pixel is Obtained By Superimposing the Blocks in Shares One and Two.

As observed from figure 4(b), halftoning is a very time consuming process. In fact, it requires four floating-point multiplication operations and six memory accesses to process each pixel of the image. For an image with dimensions *n* by *m* it takes *10·n·m* such operations, and is therefore computationally quite expensive [22].

B. Modified Floyd-Steinberg halftoning algorithm

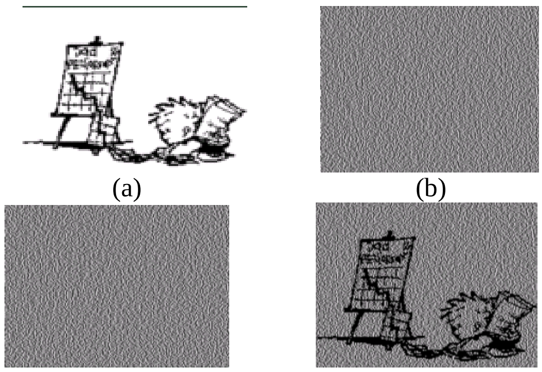
In the modified Floyd-Steinberg algorithm the number of elements to which error is diffused remains the same. The only difference is in the fraction of error which is distributed among these elements. In this algorithm, the amount of error which is spread to each neighbor is 7/16 of the error to the right pixel, 5/16 to the lower pixel, 3/16 to the diagonal left pixel and 1/16 to the diagonal right pixel. Figure 4(b) shows the diffusion matrix of distributing modified error fractions to four neighboring pixels. Comparing the simulation results of both the algorithms of Floyd-Steinberg halftoning, we can observe that by increasing the coefficients which are distributed to the neighboring pixels the contrast loss can be reduced [22].

C. Jarvis halftoning algorithm

Another error diffusion algorithm has been proposed by Jarvis, Judice and Ninke. It diffuses the error in the 12 neighboring cells instead of 4 cells as in the Floyd-Steinberg algorithm. As a result, this algorithm is even slower, requiring at least *24·n·m* floating point and memory access operations. Further, when printing color images, the running time increases by a factor of four. A diffusion matrix of Jarvis algorithm is shown in figure 4(c) [23].

D. Stucki halftoning algorithm

Stucki diffused the error in the 12 neighboring cells as shown in figure 4(d). The only difference between Jarvis algorithm and Stucki algorithm is the fraction which is added to the neighboring pixels [24].



(a) (b) (c) (d)

Fig.2. (a) Binary secret image (b) Encrypted share 1. (c) Encrypted share 2. (d) Decrypted secret message.

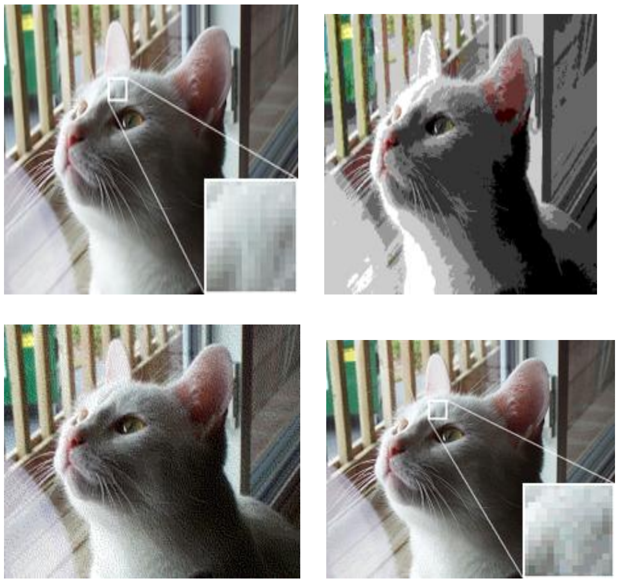


Fig 3. a) Original image, b) Original image with no halftoning applied, c) Original image with Floyd-Steinberg halftoning, d) Original halftoned image with color details

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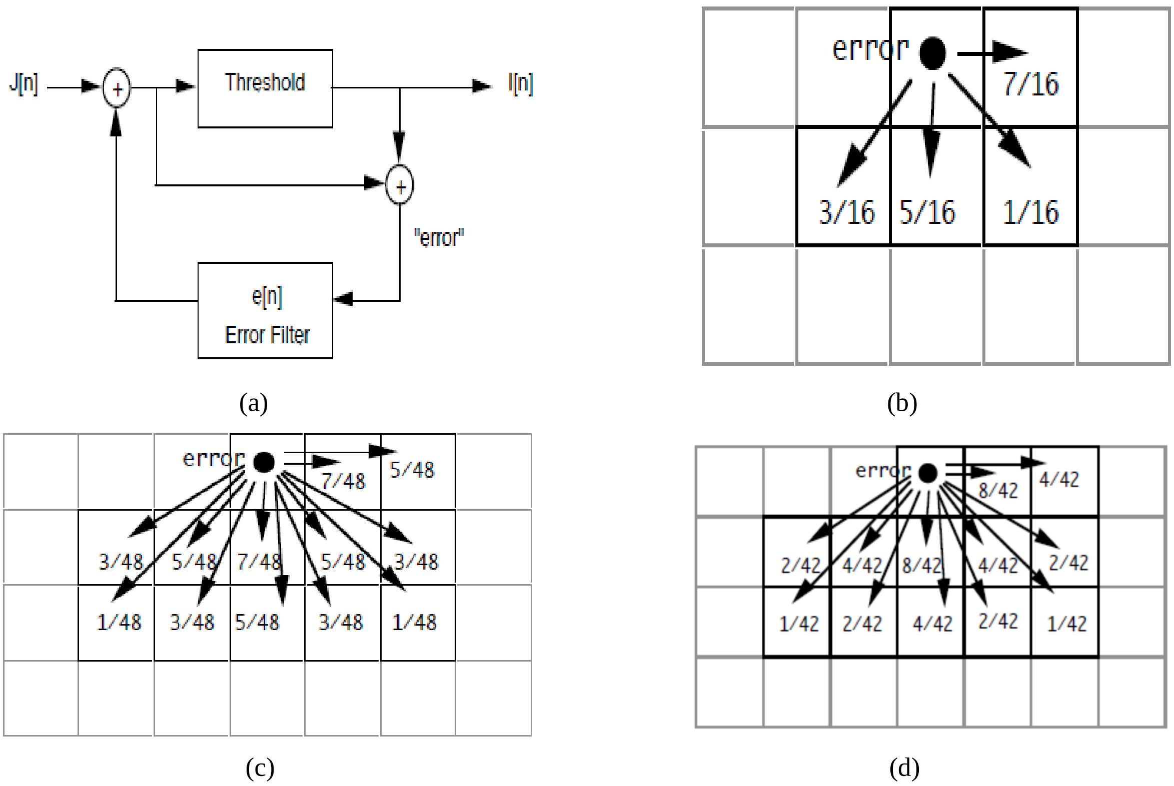

Fig 4. A) The Floyd-Steinberg Half toning, B) Floyd-Steinberg Error-Diffusion Matrix, C) Jarvis Error-Diffusion Matrix, D) Stucki Error-Diffusion Matrix

IV. SIMULATION RESULTS

In this section, we will discuss the experimental results of the entire error-diffusion halftoning algorithms used in color visual cryptography. Figure 5 shows the resultant halftoned images, where we can observe the visual quality of all the images. From figure 5, we can conclude that the visual quality of halftoned images depends on the algorithm employed. Floyd and Steinberg's algorithm was the first halftoning algorithm. Figure 5(b) shows the halftoned image using original Floyd-Steinberg algorithm. A typical problem that is seen in this halftoning technique is spectral whitening where the variation in average separation distance between minority pixels becomes so great that the pattern starts to resemble the halftone pattern created by white noise. In order to reduce these artifacts the modifications to the original error diffusion algorithm has been introduced. Figure 5(c) shows the halftoned image using a modified Floyd-Steinberg algorithm. Comparing the simulation results of both the algorithms of Floyd-Steinberg halftoning, we can observe that increasing the coefficients that are distributed to the neighboring pixels; the contrast loss can be reduced. In an effort to break up worm patterns in error diffusion, Jarvis and Stucki introduced 12-element error filters and it is apparent that both filters break up worms at extreme gray levels. Figure 5(c) and (e) shows the halftoned images using Jarvis and Stucki algorithms respectively. Table 1 shows the

V. CONCLUSION

In this paper, different algorithms for error diffusion halftoning are compared. The comparison is done on the basis of contrast loss, perceived error between original and halftoned image and the PSNR values. From the implementation of all the algorithms, it is observed that

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

Color Visual cryptography requires halftoned images with minimum contrast loss and minimum time. Though the visual quality of halftoned images using error-diffusion methods is good but they are too computationally costly to be implemented in simple and fast visualization software. One of the solutions to this is, to use an algorithm which performs parallel operations on the pixels of an image. In future we will try to implement the faster algorithms with high visual quality.

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(a)


(b)


(c)


(d)


(e)

Fig 5. Halftone shares using error diffusion algorithms (a) Original image (b) Halftone image using Original Floyd and Steinberg algorithm (c) Halftone image using Modified Floyd and Steinberg algorithm (d) Halftone image using Jarvis algorithm (e) Halftone image using Stucki algorithm

TABLE 1: Perceived error and PSNR for all the algorithms

Type of halftoning Algorithm	Perceived Error	PSNR
Original Floyd-Steinberg algorithm	4213223	18.2995
Modified Floyd-Steinberg algorithm	4.2132e+006	18.2995
Jarvis algorithm	4206273	18.2975
Stucki algorithm	4.2019e+006	18.3104

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