

## Watermark Embedding for Direct Binary Searched Halftone Images by Adopting Visual Cryptography

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**Abstract:** In this paper, two methods are proposed to embed visual watermark into direct binary search (DBS) halftone images, which are called Adjusted Direct Binary Search (ADBS) and Dual Adjusted Direct Binary Search (DADBS). DADBS is an improved version of ADBS. By using the proposed methods, the visual watermark will be embedded into two halftone images separately, thus, the watermark can be revealed when these two halftone images are overlaid. Experimental results show that both methods can achieve excellent image visual quality and decoded visual patterns.

**Keywords:** Data hiding, halftone, direct binary search, visual watermark.

### 1 Introduction

With the development of computer science and internet technology, more and more multimedia contents such as images are shared on the internet. But there are still many materials need to be printed in our daily life. However, many materials are being copied or modified illegally. Therefore, the protection of printed materials becomes more and more significant.

Printed images are also called halftone images [Bayer (1973)]. Due to the limitation of printers, the printed images can only use two tones (ink for black and no ink for white) to simulate the multitone grayscale images. To transform grayscale images into halftone images, many different halftone methods have been developed, including Direct Binary Search (DBS) [Analoui and Allebach (1992)], Ordered Dithering (OD) [Ulichney (1993)], and Error Diffusion (ED) [Floyd and Steinberg (1976)]. Among these methods, the halftone images generated by DBS gain much higher visual quality than others.

Since the halftone images only use two tones, the traditional digital watermark methods cannot be applied to halftone images directly, such as methods that are introduced in Keissarian et al. [Keissarian (2009); Cao, Zhou, Sun et al. (2018)]. Therefore, two kinds of methods to embed watermark into halftone images have been developed in recent years.

The methods in the first category are proposed to embed a secret binary stream into the cover halftone images. Then these methods retrieve the watermark from the stego halftone image by applying the corresponding extraction algorithms. In Fu et al. [Fu and

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Au (2000); Pei and Guo (2006); Guo (2007); Bulan, Sharma and Monga (2010); Guo and Liu (2011)], they proposed methods to embed watermark by modifying the pixel values in spatial domain. A method by changing the coefficient values in the wavelet transform domain to embed watermark was proposed in Luo et al. [Luo, Zhao, Huang et al. (2007)]. In Amini et al. [Amini, Yaghmaie and Sadreazami (2010)], the watermark was embedded by merging the singular values of the selected frequency band of the cover image and the watermark. By changing the point spread function, a secret binary stream was able to embed into the DBS halftone images in Guo et al. [Guo, Su, Liu et al. (2012)].

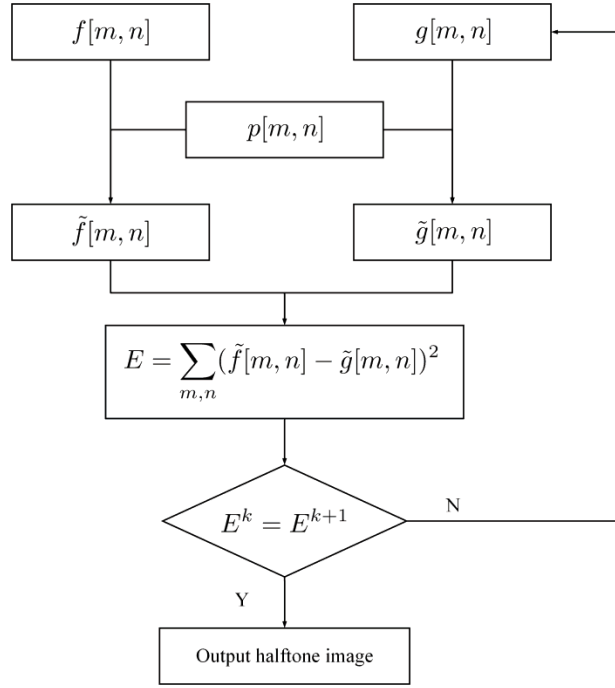
The methods in the second category are proposed to embed watermark into multiple halftone images. In general, two halftone images are used to carry watermark in these methods. When the two halftone images are overlaid, the watermark is appearing. The first method of this category was proposed in Fu et al. [Fu and Au (2001)]. After that, a method named DHCED was proposed in Fu et al. [Fu and Au (2003)] which improved the performance. Pei et al. [Pei and Guo (2003)] used Noise-Balanced Error Diffusion to embed watermark, and gained the similar performance with [Fu and Au (2003)]. Guo et al. [Guo, Au, Fang et al. (2011)] embedded the watermark into both of the two cover halftone images. In Sanchez et al. [Sanchez, Nayak and Pradhan (2014)], the watermark was embedded into Multiscale Error Diffusion halftone images. Guo et al. [Guo and Liu (2011)] embed watermark into halftone images, which were generated by the least-mean-square (LMS) method. The methods in the second category can be applied in some special halftone methods such as error diffusion. But these methods cannot be applied into the halftone images generated by the efficient Direct Binary Search halftone.

In this paper, due to the perfect performance of efficient DBS, we propose two methods to embed watermark into efficient DBS halftone images. The first method which is called Adjusted Direct Binary Search (ADBS) can only embed watermark into one halftone image. Considering the improvement of the visual quality, the second method called Dual Adjusted Direct Binary Search is proposed, which is capable to embed watermark into both of the two cover halftone images.

The rest of the paper is organized as follows. Section 2 reviews the Efficient Direct Binary Search. Section 3 introduces the first method, Adjusted Direct Binary Search. Section 4 introduces the second method, Dual Adjusted Direct Binary Search. The experimental results are given in Section 5. And Section 6 draws the conclusion.

## **2 Review of efficient direct binary search**

The DBS is used to make the halftone image looks more similar with the grayscale image by minimizing difference between them on human visual system. The method has two steps. The first step is calculating the difference of grayscale image and halftone image in human visual system. The second step is trying to toggle or swap pixels in halftone image to reduce the total difference of them on human visual system. But calculating the total error costs a lot. So, Analoui et al. [Analoui and Allebach (1992)] proposed a method, called efficient Direct Binary Search, to solve this problem. The efficient DBS is then deduced as below.



**Figure 1:** Flowchart of Direct Binary Search

Assuming  $f(u, v)$  and  $g(u, v)$  are the grayscale and halftone image, respectively.  $p(u, v)$  denotes the Point Spread Function. Then, the corresponding images on human visual system are represented as  $\tilde{f}(x, y)$  and  $\tilde{g}(x, y)$ , which can be calculated by the following formulas.

$$\tilde{f}(x, y) = \iint f(u, v)p(x-v, y-v)dudv, \tag{1}$$

$$\tilde{g}(x, y) = \iint g(u, v)p(x-u, y-v)dudv. \tag{2}$$

So the difference between the grayscale and halftone images on the human visual system can be calculated as

$$\tilde{e}(x, y) = \tilde{f}(x, y) - \tilde{g}(x, y). \tag{3}$$

Then the total square error is used as the measure of the differences between the grayscale image and the halftone image can be calculated as

$$E = \iint (\tilde{e}(x, y))^2 dx dy. \tag{4}$$

As for the discretized images, the total square error can be transformed as

$$E = \sum_{i,j} \sum_{m,n} e[i, j]e[m, n]c_{pp}[m-i, n-j], \tag{5}$$

where  $[m, n]$  is a sample of  $(x, y)$  and  $c_{pp}[m, n]$  is the convolution of the Point Spread Function, which can be obtained by

$$c_{pp}[m, n] = \iint \tilde{p}(x, y)\tilde{p}(x-mX, y-nX)dx dy, \tag{6}$$

and

$$e[m,n] = f[m,n] - g[m,n] \quad (7)$$

is the difference between the grayscale image and halftone image.

The iterative method of efficient DBS is applied to minimize the total square error of the grayscale image and halftone image on the Human Visual System. In every iteration of the efficient DBS, it tries to toggle a pixel or swap a pair of pixels and calculates the incremental error. Then the manipulation that corresponding to the minimum incremental error is chosen. The incremental error of toggle manipulation at  $[m_0, n_0]$  is

$$\Delta E = a_0^2 c_{pp}[0,0] + 2a_0 c_{pe}[m_0, n_0], \quad (8)$$

where

$$a_0 = \begin{cases} -1 & \text{if } g[m_0, n_0] \text{ is toggled from 1 to 0,} \\ 1 & \text{if } g[m_0, n_0] \text{ is toggled from 0 to 1,} \end{cases} \quad (9)$$

and

$$c_{pe}[m,n] = \sum_{i,j} e[i,j] c_{pp}[i-m, j-n]. \quad (10)$$

And  $c_{pe}$  is used to save intermediate results and reduce the amount of calculation. The incremental error of swap manipulation between  $[m_0, n_0]$  and  $[m_1, n_1]$  is

$$\begin{aligned} \Delta E = & (a_0^2 + a_1^2) c_{pp}[0,0] \\ & + 2a_0 c_{pe}[m_0, n_0] + 2a_1 c_{pe}[m_1, n_1] \\ & + 2a_0 a_1 c_{pp}[m_1 - m_0, n_1 - n_0], \end{aligned} \quad (11)$$

where  $a_0, a_1$  are calculated as Eq. (9). According to the Eq. (10),  $c_{pe}$  is influenced by the  $e[m,n]$ , which is associated with  $g[m,n]$ . So during the iteration process,  $c_{pe}$  should be updated. For pixel  $[m_0, n_0]$ , if the toggle manipulation is selected

$$c'_{pe}[m,n] = c_{pe}[m,n] + a_0 c_{pp}[m_0, n_0], \quad (12)$$

if the swap manipulation is selected,

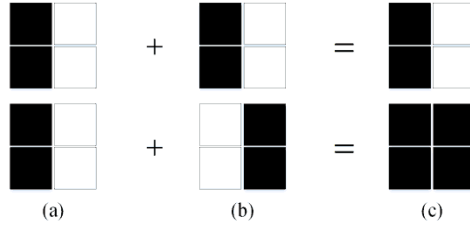
$$\begin{aligned} c'_{pe}[m,n] = & c_{pe}[m,n] + a_0 c_{pp}[m - m_0, n - n_0] \\ & + c_{pp}[m - m_1, n - n_1]. \end{aligned} \quad (13)$$

In summary, the procedure of the efficient Direct Binary Search will follow the steps below.

1. Initialize the halftone image  $g[m,n]$  with any halftone method.
2. Initialize  $c_{pp}[m,n]$  and  $c_{pe}[m,n]$  with the grayscale image  $f[m,n]$ , the initial halftone image  $g[m,n]$ , and the Point Spread Function  $p(x,y)$ .
3. In the halftone image  $g[m,n]$ , for each pixel, calculate the incremental error  $\Delta E$  by Eqs. (8) and (11), to determine to toggle, swap or do nothing. And if toggle manipulation or swap manipulation is selected, the  $c_{pe}$  should be updated by Eq. (12) or Eq. (13).
4. Repeat 3 until  $g[m,n]$  does not change.
5. Output the halftone image  $g[m,n]$

### 3 Data hiding by adjusted direct binary search

In visual cryptography, the goal of the data hiding method in halftone images is that the watermark can be displayed when the two halftone images are overlaid. Fig. 2 gives some example to help understand this. In Fig. 2, (a) and (b) represent the two halftone images, and (c) represents the overlaid result. In the first row, (a) and (b) are in the same tone, the result looks relatively white. And in the second row, (a) and (b) are in the opposite tones, the result looks relatively dark. To achieve this goal, if the pixel of the watermark image is white, the two halftone images are better to be in the same tone, if it is black, the two halftone images are better to be in the opposite tones.



**Figure 2:** Example of two halftone images are overlaid

Let  $f_1[m,n]$  and  $f_2[m,n]$  denote the first and second grayscale images. Let  $g_1[m,n]$  and  $g_2[m,n]$  denote the watermark image. The values of  $g_1[m,n]$ ,  $g_2[m,n]$ , and  $w[m,n]$  are 1 (for black) or 0 (for white). Therefore,

$$b[m,n] = 1 - (g_1[m,n] \oplus g_2[m,n] \oplus w[m,n]) \quad (14)$$

could be used to represent if the watermark has been successfully embedded at position  $[m,n]$ , where  $\oplus$  mean XOR. In watermark image, for white pixels, the  $w[m,n]$  is 0 and  $b[m,n]$  should be contrast to  $g_1[m,n] \oplus g_2[m,n]$ . So that if  $g_1[m_0,n_0] \oplus g_2[m_0,n_0]$  is 0,  $b[m_0,n_0]$  should be 1, it means the watermark has been successfully embedded at pixel  $[m_0,n_0]$ . On the other hand, if  $g_1[m,n] \oplus g_2[m,n]$  is 1,  $b[m_0,n_0]$  is 0, that means the watermark has not been embedded at pixel  $[m_0,n_0]$ . Therefore, the total number of the pixels which have been successfully embedded is

$$D = \sum_{m,n} b[m,n]. \quad (15)$$

In our first data hiding method, called Adjusted Direct Binary Search (ADBS), we fix the first halftone image and adjust the second halftone image to successfully embed watermark as well as achieve the high visual quality. So in ADBS, the optimization goal can be wrote as

$$J = E - \alpha D. \quad (16)$$

$E$  is the square error of the second grayscale image and the second halftone image in the Human Visual System.  $D$  represents the total number of the successful embedding pixels.  $\alpha$  is used to control the embedding rate. Finding the optimal solution of Eq. (16) is an NP-hard problem. So, by using the same process as efficient DBS to modify the second

half-tone image and the embedded half-tone images can be obtained. Therefore as the same as the efficient DBS,  $\Delta J$  can be rewrote as

$$\Delta J = \Delta E - \alpha \Delta D, \quad (17)$$

thus, for toggle manipulation at position  $[m_0, n_0]$

$$\Delta J = a_0^2 c_{pp}[0,0] + 2a_0 c_{pe}[m_0, n_0] + \alpha(2b[m_0, n_0] - 1), \quad (18)$$

and for swap manipulation at position  $[m_0, n_0]$  and  $[m_1, n_1]$

$$\begin{aligned} \Delta J = & (a_0^2 + a_1^2)c_{pp}[0,0] \\ & + 2a_0 c_{pe}[m_0, n_0] + 2a_1 c_{pe}[m_1, n_1] \\ & + 2a_0 a_1 c_{pp}[m_1 - m_0, n_1 - n_0] \\ & + 2\alpha(b[m_0, n_0] + b[m_1, n_1] - 1). \end{aligned} \quad (19)$$

But in Eqs. (18) and (19),  $\alpha$  is not easy to choose. Since  $\Delta E$  is easy to be affected by the Point Spread Function according to Eqs. (8) and (11). For different parameters Point Spread Function the  $c_{pp}$  and  $c_{pe}$  is different. Therefore, to solve the problem, we use

$$\alpha = \beta c_{pp}[0,0] \quad (20)$$

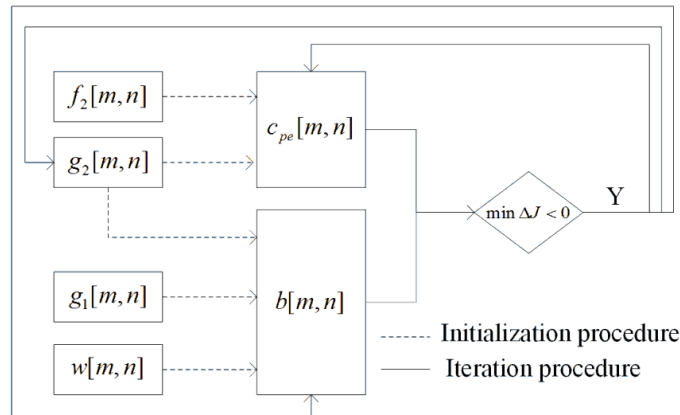
to represent the  $\alpha$ , and use  $\beta$  to control the embedding rate and reduce the effect of the Point Spread Function. Eqs. (18) and (19) can be rewrote as

$$\Delta J = a_0^2 c_{pp}[0,0] + 2a_0 c_{pe}[m_0, n_0] + \beta c_{pp}[0,0](2b[m_0, n_0] - 1), \quad (21)$$

and

$$\begin{aligned} \Delta J = & (a_0^2 + a_1^2)c_{pp}[0,0] \\ & + 2a_0 c_{pe}[m_0, n_0] + 2a_1 c_{pe}[m_1, n_1] \\ & + 2a_0 a_1 c_{pp}[m_1 - m_0, n_1 - n_0] \\ & + 2\beta c_{pp}[0,0](b[m_0, n_0] + b[m_1, n_1] - 1). \end{aligned} \quad (22)$$

After changing the pixels, not only the  $c_{pe}[m, n]$  should be updated, but also the  $b[m, n]$ . So, after the pixel has been changed at  $[m_0, n_0]$ ,  $b'[m_0, n_0] = 1 - b[m_0, n_0]$ .



**Figure 3:** Procedure of ADDBS

In summary, the procedure of the Adjusted Direct Binary Search in the Fig. 3 follows the steps below.

1. Initialize  $g_1[m, n]$  and  $g_2[m, n]$  with  $f_1[m, n]$  and  $f_2[m, n]$  by efficient DBS.
2. Initialize  $c_{pp}[m, n]$ ,  $c_{pe2}[m, n]$  and  $b[m, n]$  with the grayscale image  $f[m, n]$ , the initial halftone image  $g_2[m, n]$ , and Point Spread Function  $p(x, y)$ .
3. Search all pixels on  $g_2[m, n]$ , for each pixel calculate the incremental error  $\Delta J$  by Eqs. (21) and (22), to determine to toggle, swap or do nothing. And if toggle, swap happened, update the  $c_{pe2}[m, n]$  by Eqs. (12) and (13), then update  $b[m, n]$ .
4. Repeat 3 until  $g_2[m, n]$  does not change.

#### 4 Data hiding by dual adjusted direct binary search

Since the ADBS fixed the first halftone image and only embed watermark into the second halftone image, the second halftone image's visual quality will be more poorer than the first one. So, we propose a method, called Dual Adaptive Direct Binary Search (DADBS), to embed watermark into both of the two halftone images.

In DADBS, since both of the two halftone images need to be modified to embed the watermark, the visual quality of both of the two halftone images should be considered. Therefore, in DADBS, the optimization goal can be rewrote as

$$J = E_1 + E_2 - \alpha D, \quad (23)$$

where  $E_1$  and  $E_2$  are the square error of the two grayscale images with the two halftone images on the Human Visual System.  $D$  represent the total number of the successfully embedded pixels.  $\alpha$  is used to control the embedding rate. With the similar process as efficient DBS, in DADBS, the incremental  $J$ ,

$$\Delta J = \Delta E_1 + \Delta E_2 + \beta c_{pp}[0, 0] \Delta D, \quad (24)$$

is used to determine which manipulation should be accepted. Where  $\Delta E_1$  and  $\Delta E_2$  are calculated by Eq. (8) or Eq. (11). And for toggle manipulation at position  $[m_0, n_0]$

$$\Delta D = b[m_0, n_0], \quad (25)$$

for swap manipulation at position  $[m_0, n_0]$  and  $[m_1, n_1]$

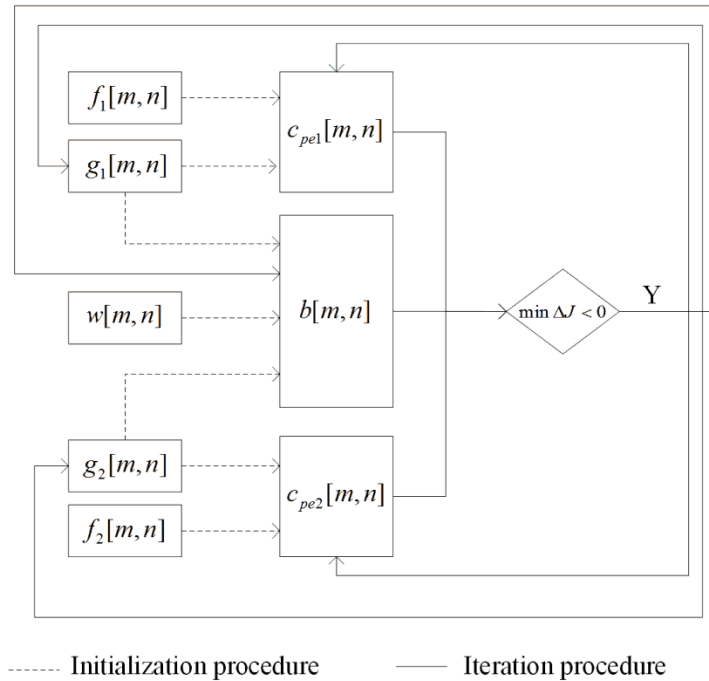
$$\Delta D = b[m_0, n_0] + b[m_1, n_1]. \quad (26)$$

To modify both of the two halftone images, in DADBS, we alternately fixed one of them and modify another for each pixel. So the procedure of DADBS the Fig. 4 will follow the steps as below.

1. Initialize  $g_1[m, n]$  and  $g_2[m, n]$  with the grayscale images  $f_1[m, n]$  and  $f_2[m, n]$  by the efficient DBS.
2. Initialize  $c_{pp}[m, n]$ ,  $c_{pe1}[m, n]$ ,  $c_{pe2}[m, n]$ ,  $b[m, n]$  with the grayscale image  $f_1[m, n]$ ,  $f_2[m, n]$ , the initial halftone image  $g_1[m, n]$ ,  $g_2[m, n]$ , and the Point Spread Function  $p(x, y)$ .
3. Alternately fixed one of them and modify another. For modified halftone

image, calculate the  $\Delta J$  by Eq. (24), to determine to toggle, swap or do nothing. And if toggle or swap happened, update the  $c_{pe1}[m,n]$ ,  $c_{pe2}[m,n]$  and  $b[m,n]$ .

4. Repeat 3 until  $g_1[m,n]$  and  $g_2[m,n]$  do not change.



**Figure 4:** Procedure of ADBS

## 5 Experimental results

In this section, the result for ADBS and DADBS are presented. Because the DBS methods will produce the most good visual quality in all halftone methods, so in this paper we compared the visual quality of the halftone image generated by the proposed methods with the Error Diffusion method not the Error Diffusion based visual watermark method. In the experiments, the size of all images are  $512 \times 512$ . We use the visual error between the halftone and grayscale image to measure the visual quality of the halftone image. It can be calculate by Eq. (6), and the visual quality will be more worse with higher error. The watermark embedding rate is calculate as

$$r = \frac{\sum_{m,n} b[m,n]}{512 \times 512} \quad (27)$$

the embedding rate is more higher, the watermark is more clear when the two halftone images are overlaid.

Fig. 5 shows an example of ADBS. That we use the native DBS method to generate the first halftone image, and the ADBS method (here  $\alpha = 0.24$ , search width  $n = 3$ ) to generate the second halftone image. When the two halftone images are overlaid a logo of visual studio is appeared.



Fig. 6 shows the results of visual error and the embedding rate results of the two methods. To compare the results of ADBS and DADBS, we only plot the second image’s visual error of both the two methods. It’s easy to find out the visual error is becoming more and more higher as the embedding rate increased. As for in the same embedding rate, the DADBS will get a more slower visual error.

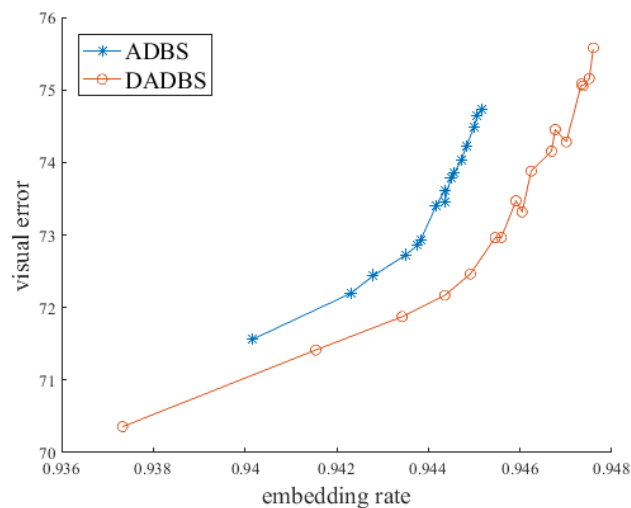
Tab. 1 shows the visual error of some typical Error Diffusion and Ordered Dithering halftone images. It’s easy to find out the halftone image with the smallest visual error is generated by the Floyd Kernel based Error Diffusion method. But it is visual error is still bigger than the visual error of the halftone image that generated by ADBS of DADBS (less than 76).



**Figure 5:** From topleft to buttomright is the orginal image, the first halftone image generated by DBS, the second halftone image generated by ADBS, the overlay of the two halftone image

**Table 1:** The visual error of different error diffusion methods

Error Diffusion Kernel	Burkes	Floyd	Jarries	Stucki
Visual Error	156	93	356	275



**Figure 6:** The visual error embedding rate results of ADBS and DADBS. The original images are both lena

## 6 Conclusion

This work presents two halftone watermarking methods, ADBS and DADBS. ADBS and DADBS can both embed a visual watermark into two efficient DBS generated halftone images. When the two halftone images are overlaid, the watermark will be appeared. According the experimental results, the proposed methods not only provide the methods to embed watermark, but also generate a good visual quality than the Error Diffusion based watermark methods, and the halftone images' visual quality even better than the halftone image which generated by Error Diffusion.

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