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Error Diffusion Using Half Toning in Color Images

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Abstract

In this paper, a new error diffusion method is proposed that provides high quality ED results. The goal of half-toning method is to quantize each pixel to one bit binary pixel. The proposed error diffusion method is based on half toning method, which is known as Floyd and Steinberg's filter. To expedite processing time, the denominator of the proposed method is chosen in 2^k *form, where k is integer number. Therefore, the method is faster than the previous methods, while preserving simplicity. Experimental results show that the obtained red, green, blue channels and color images look satisfactory for viewer.*

Keywords*: image processing, half-toning, residual diffusion*

1. Introduction

The error diffusion (ED) is a method of half-toning where the discrete values assignment is made and residual is allocated to adjacent pixels [1-5]. Here, non-processed pixels are referred as adjacent pixels [6]. The principal goal is to transform a diverse form of images into binary format. The ED is one of half-toning approaches, where ED is categorized as region operation (or pixel operation) [7-12]. Therefore, parallel processing is possible and buffer is needed for this process.

The ED operates by comparing the real intensity of a pixel against its adjacent intensity and obtaining the difference between both pixels [13,14]. The remainder is called a the residual or error. Portions of the residual are separated between adjacent pixels causing the residual to be spread and the name became ED [15]. One advantages of ED method is that, it provides effect of edge enhancement for images [16-20]. This is why half-toning method applied contents is more readable.

The Facsimile is one of well-known applications that ED has been adopted. To generate intensity, the pen located in lower or upper position [21-25]. For example, to make white area, pen moves over a piece of paper, while to make black area, pen is located at lower position. Similarly, we can make shade area by varying pen's position [24,25].

This paper proposed ED method, which is modified version of Floyd and Steinberg's filter. To expedite processing time, the denominator of the proposed method is 2^k. This paper proposes ED method for color images. This paper is arranged as follows. First part of Section 2 introduces related works in half-toning methods. The later part of Section 2 provides the proposed method. Section 3 shows objective and subjective performances of the proposed method and the benchmarks. Finally, Section 4 yields conclusion remarks.

2. Proposed Work

The ED model is an adjacent method that provides sharper images than point methods and creates subjectively pleasant textures. However, this model is very sensitive to dot-

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overlap printer due to deformity. Thus, it is required to combine a printer model in the algorithm. Moreover, adding HVS model in ED is helpful.

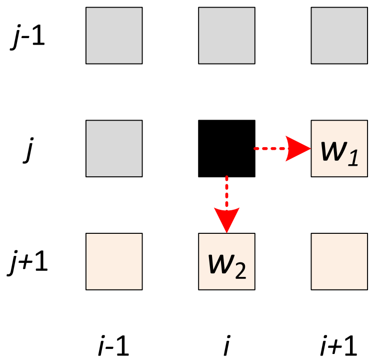


Figure 1. Simplest Example of ED with 3×3 Window Size. Parameters W_1 and W_2 Are Weights, which Meets W_1+W_2=1

Figure 1 indicates one of the simplest formats of ED, where parameters w_1 and w_2 are weight, and $w_1+w_2=1$. With the format of ED, w_1 portion of residual from the pixel (i+1,j) is diffused to the pixel on the right and w_2 portion to the pixel (i,j+1). In multi-channel (N channel) image case, the ED can be independently applied to the channel 1 to channel N, respectively. It is recalled that the total amount of spread residual is limited as 1. If the diffused residual is over 1, the result images become over brightened. On the other hand, if the diffused residual is less than 1, then effect becomes weaken. Therefore, in most cases, the total amount of spread residual is fixed as 1. Meanwhile, the portion of the residual is scattered to adjacent pixels, and it may result pixels bigger than 255 or smaller than 0. Therefore, cut off range is assigned, and intensity of result pixels is [0,255].

One of earliest ED methods was introduced by Floyd and Steinberg (T_{FS}), where an equation for achieving ED on images id depicted as follows:

$$T_{FS} = \frac{1}{16}\begin{bmatrix} X & Y & 7 \\ 3 & 5 & 1 \end{bmatrix}. \tag{1}$$

It is noted that symbol X denotes a pixel in the current row at the position of (i-1,j). Normally pixels X are previously treated and therefore processing symbols X is skipped. Symbol Y at the positon of (i,j) denotes the pixel currently being treated.

Some researchers improved Eq. (1) and achieved better ED methods. For example, Jarvis, Judice, and Ninke proposed bigger filter to minimize average error. The form is denoted as Eq. (2):

$$T_{JJN} = \frac{1}{48}\begin{bmatrix} X & X & Y & 7 & 5 \\ 3 & 5 & 7 & 5 & 3 \\ 1 & 3 & 5 & 3 & 1 \end{bmatrix}. \tag{2}$$

Again, it is noted that symbols X_1 and X_2 stand for pixels in the current row at the position of (i-2,j) and (i-1,j). Symbol Y at the positon of (i,j) denotes the pixel presently being processed. Finally, the Stucki filter is defined as,

$$T_{ST} = \frac{1}{42}\begin{bmatrix} X & X & Y & 8 & 4 \\ 2 & 4 & 8 & 4 & 2 \\ 1 & 2 & 4 & 2 & 1 \end{bmatrix}. \tag{3}$$

Let us assume one dimensional ED. If images have artifact, it is shown in particular direction. These directions can be horizontal, vertical, or diagonal direction. Our goal is to design an ED method which requires similar complexity of Floyd-Steinberg ED method. However, as filter size grows, complexity raises. Therefore, we use eight coefficients instead of ten coefficients. Equation (4) shows the proposed method.

$$\frac{1}{10N-12}\begin{bmatrix} X & X & Y & N & N-1 \\ N-2 & N-1 & N & N-1 & N-2 \\ 0 & N-2 & N-1 & N-2 & 0 \end{bmatrix}. \quad (4)$$

Here, N is arbitrary determined parameter. The Y represents the pixel currently being scanned. Adjacent numbers such as N, N-1 are weights. Note that all weights of equation should be 1. The pixel to the right obtains N/(10N-12) of the residual value, the pixel located in the diagonal direction obtains (N-1)/(10N-12). It is noted that pixels X are not considered because we follows traditional left-to-right scanning format. Therefore pixels X are already coded. For example, if N is 5, equation (4) becomes equation (5).

$$T_{38} = \frac{1}{38}\begin{bmatrix} X & X & Y & 5 & 4 \\ 3 & 4 & 5 & 4 & 3 \\ 0 & 3 & 4 & 3 & 0 \end{bmatrix}. \quad (5)$$

It is found that Eq. (5) gives better result than traditional Floyd-Steinberg. However, Eq. (5) shows slow implementation because denominator is 38, which cannot be represented as 2^k. In other words, bit shifting is not available for Eq. (5). To allow bit shifting property in Eq. (4), following equation should be met.

$$10N - 12 = 2^k.. \quad (6)$$

Here, integer N is represented as,

$$N = \frac{2^k + 12}{10}.. \quad (7)$$

Now, it is concluded that '2^k+12' should be dividable by 10. The smallest value that meets this property is k=3. In this case, N=2 and Eq. (4) becomes,

$$T_8 = \frac{1}{8}\begin{bmatrix} X & X & Y & 2 & 1 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}. \quad (8)$$

The next k that meets above property is k=7. In this case, N=14 and Eq. (4) becomes,

$$T_{128} = \frac{1}{128}\begin{bmatrix} X & X & Y & 14 & 13 \\ 12 & 13 & 14 & 13 & 12 \\ 0 & 12 & 13 & 12 & 0 \end{bmatrix}. \quad (9)$$

As denominators in Eqs. (7) and (8) are 2^k, bit shifting is available during the ED process. It is noted that Eq. (7) is simplified version of Eq. (8), with bottom row information were removed. For example, pixels (i-2,j+1), (i+2,j+1), (i-1,j+2), and (i+1,j+2) are now 0. This makes the system of Eq. (7) much faster than that of Eq. (8). Figure 2 shows comparison of different methods and Figure 3 shows the block diagram of the proposed method.

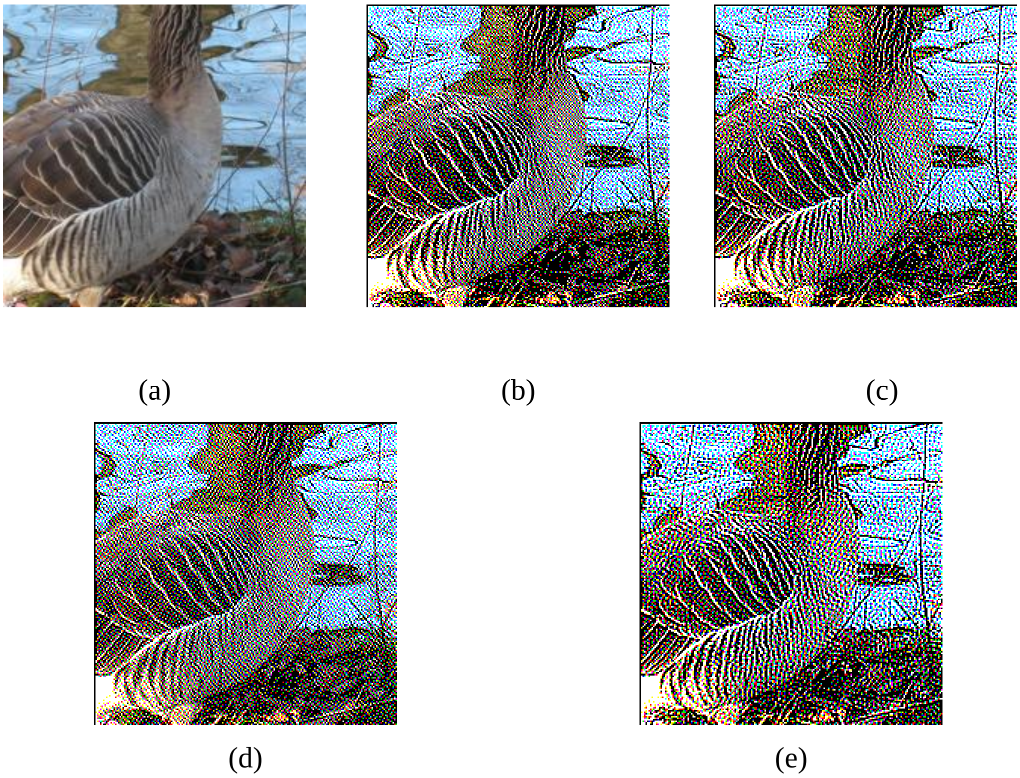


Figure 2. Result Images of Different Methods: (A) Original Image, (B) Floyd and Steinberg, (C) Jarvis, Judice, and Ninke, (D) T_8, and (E) T_{128}

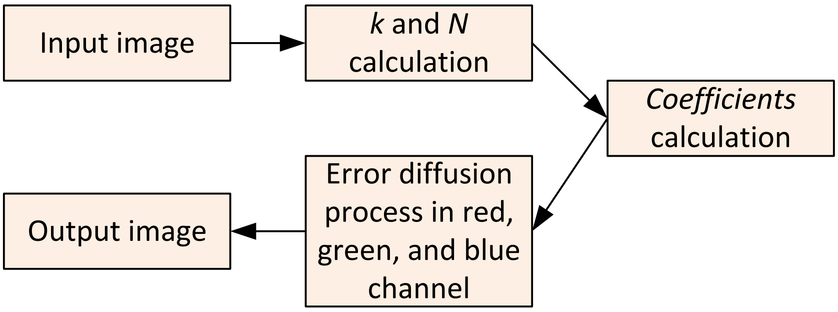
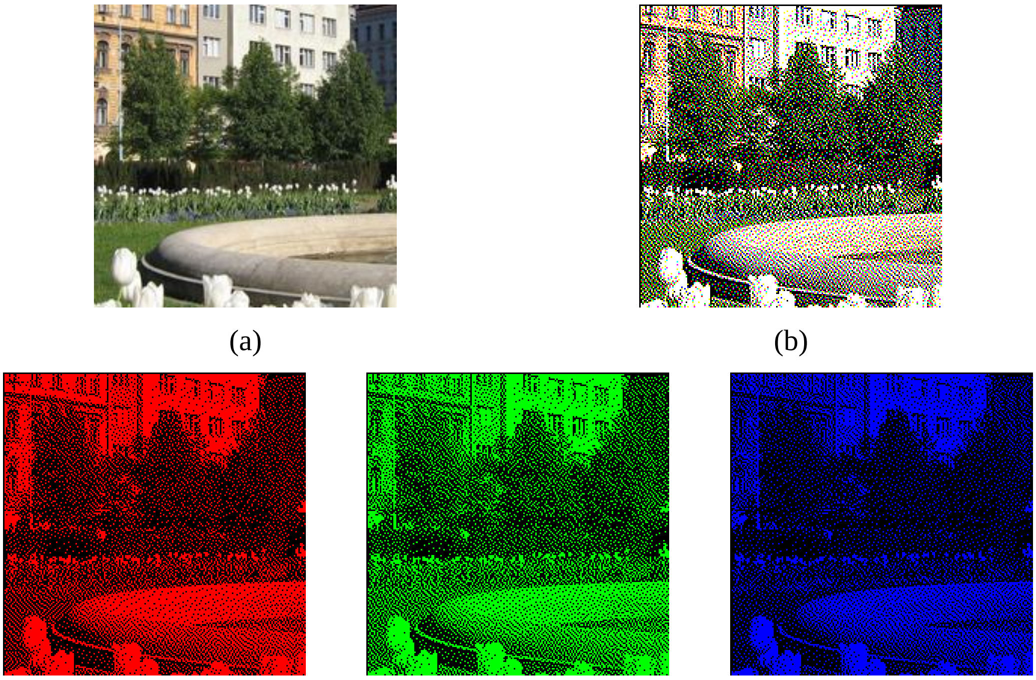


Figure 3. Block Diagram of the Proposed Method

3. Experimental Results

We provide the results for the different methods discussed above. Adopted methods in this simulation were T_{FS} (Floyd and Steinberg), T_{JJN} (Jarvis, Judice, and Ninke), T_{ST} (Stucki), T_8, and T_{128}. LC dataset was used for comparison, which are 540×720 size images. To evaluate the performance of the presented method, we used 10 color images from LC dataset. The images become 541×721 size after the processing, and horizontally (201 to 400) and vertically (201 to 400) cropped images were used for testing. Figure 4 shows an example of decomposition method. Figure 4(a) is the original image, and Figure 4(b) is its T_8 processed image. Figures 4(c,d,e) are red, green, and blue channel decomposed images.



(a) (b)

(c) (d) (e)

Figure 4. ED Image Decomposition: (A) Original Image, (B) T_8, (C) Red Channel of T_8, (D) Green Channel of T_8, and (E) Blue Channel of T_8

Table 1. MSE Comparison in Red Channel

Image number	T_{FS}	T_{JJN}	T_{ST}	T_8	T_{128}
1	11435.18	11594.76	10662.76	11774.96	11587.19
2	11569.08	11636.91	10808.68	11914.08	11650.05
3	13719.89	14954.91	14620.99	15010.11	15019.98
4	13296.63	13632.25	13176.61	13780.55	13662.2
5	13351.59	13473.22	12931.59	13669.87	13507.24
6	13732.71	14097.35	13709.34	14269.34	14135.16
7	12120.77	12589.95	11819.72	12665	12584.7
8	13030.74	13434.49	12912.69	13691.18	13448.47
9	12176.02	13099.2	12547.91	13392.2	13129.28
10	10253.5	11259.89	10345.28	11485.14	11296.18
Avg.	12468.61	12977.29	12353.55	13165.24	13002.04

To evaluate performance of each method, Tables 1 to 3 show MSE result comparison for red, green, and blue channels of conventional (T_{FS}, T_{JJN}, and T_{ST}) and proposed methods (T_8 and T_{128}). Table 4 shows FSIM results for color images.

Table 2. MSE Comparison in Green Channel

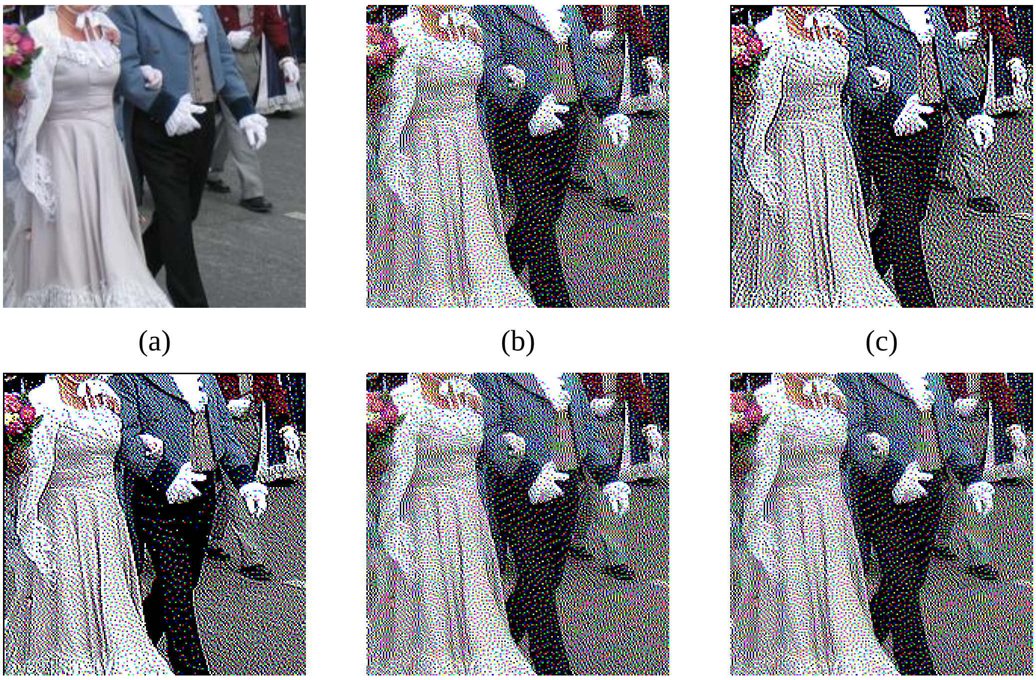
Image number	T_{FS}	T_{JJN}	T_{ST}	T_8	T_{128}
1	11656.87	11808.59	10946.24	12033.24	11838.94
2	12029.24	12262.66	11544.7	12544.48	12285.31
3	13174.03	14494.99	14036.57	14528.4	14480.74
4	13666.41	13876.75	13494.05	14017.68	13908.39
5	13903.9	14059.05	13604.19	14199.13	14076.98
6	14024.84	14398.42	14086.46	14550.06	14448.7
7	13036.51	13566.09	13028.71	13682.04	13592.15
8	13648.01	14149.98	13765.9	14322.5	14194.07
9	12184.94	13273.65	12693.98	13495.28	13238.97
10	11290.39	12348.3	11605.97	12517.14	12389.66
Avg.	12861.51	13423.85	12880.68	13588.99	13445.39

Table 3. MSE Comparison in Blue Channel

Image number	T_{FS}	T_{JJN}	T_{ST}	T_8	T_{128}
1	11318.14	11467.5	10556.91	11668.85	11466.25
2	12571.92	12779.43	12126.42	12953.07	12799.64
3	10978.7	12184.06	11338.87	12288	12216.48
4	12268.47	12585.1	11884.95	12674.51	12623.83
5	13380.65	13494.05	12949.4	13694.12	13515.86
6	13671.51	14042.97	13710.28	14277.07	14114.9
7	9833.176	10298.59	9078.816	10417.69	10313.78
8	14161.16	14562.66	14200.82	14690.03	14598.62
9	10819.54	11689.05	10871.89	11961.05	11684.83
10	10051.22	11082.22	10067.52	11280.41	11094.2
Avg.	11905.45	12418.56	11678.59	12590.48	12442.84

Table 4. FSIM Comparison for Color Images

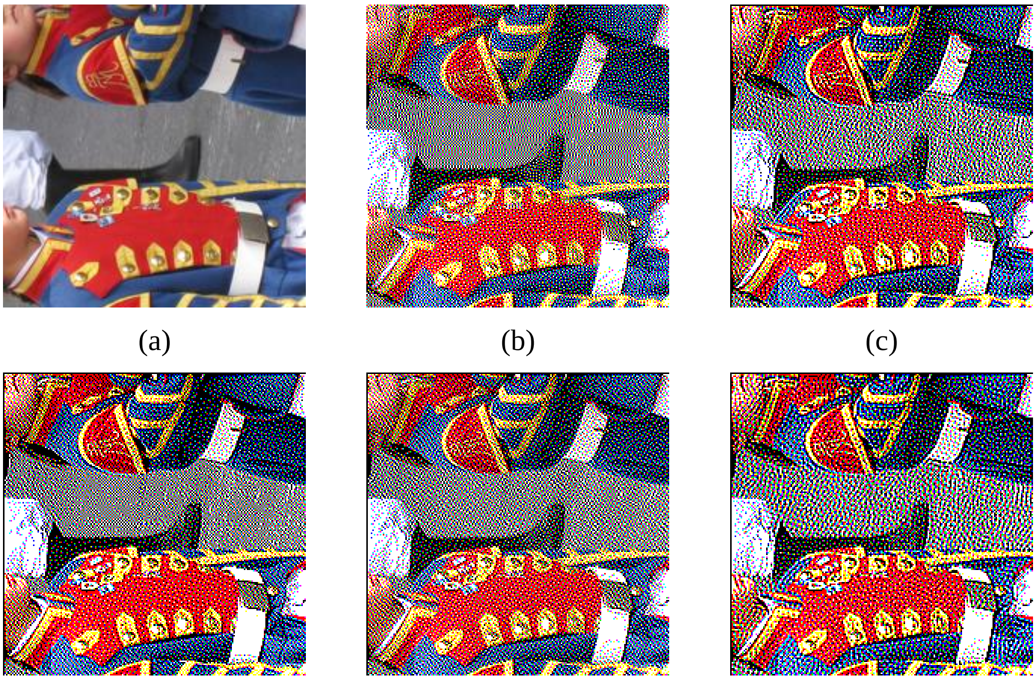
Image number	T_{FS}	T_{JJN}	T_{ST}	T_8	T_{128}
1	0.498462	0.393878	0.460483	0.436859	0.375632
2	0.528125	0.416618	0.466886	0.453404	0.397049
3	0.579738	0.43548	0.475038	0.491642	0.41405
4	0.477752	0.344264	0.388787	0.386682	0.320076
5	0.467398	0.333527	0.380061	0.390599	0.314332
6	0.534923	0.394897	0.446544	0.457618	0.370593
7	0.571179	0.429189	0.471414	0.483741	0.406148
8	0.51627	0.38762	0.460237	0.43682	0.367006
9	0.612377	0.507159	0.539475	0.538088	0.493285
10	0.598208	0.473916	0.518956	0.515396	0.459484
Avg.	0.538443	0.411655	0.460788	0.459085	0.391765



(a) (b) (c)

(d) (e) (f)

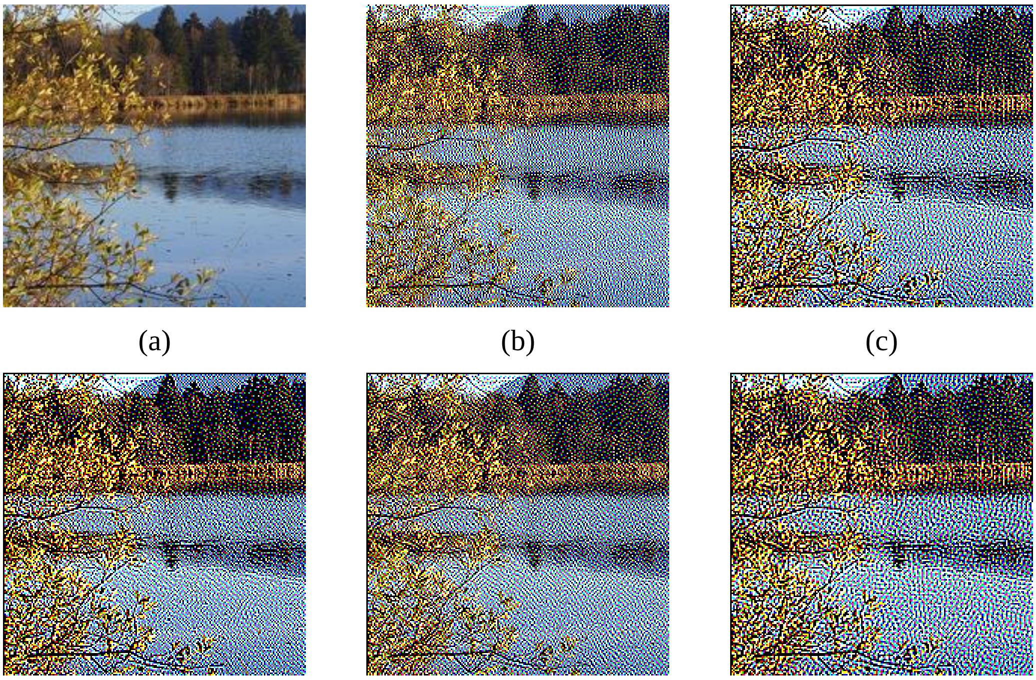
Figure 5. Performance Comparison for Different Methods on LC Image #1: (A) Original Image, (B) T_{FS}, (C) T_{JJN}, (D) T_{ST}, (E) T_8, And (F) T_{128}



(a) (b) (c)

(d) (e) (f)

Figure 6. Performance Comparison for Different Methods on LC Image #2: (A) Original Image, (B) T_{FS}, (C) T_{JJN}, (D) T_{ST}, (E) T_{8}, and (F) T_{128}



(a) (b) (c)

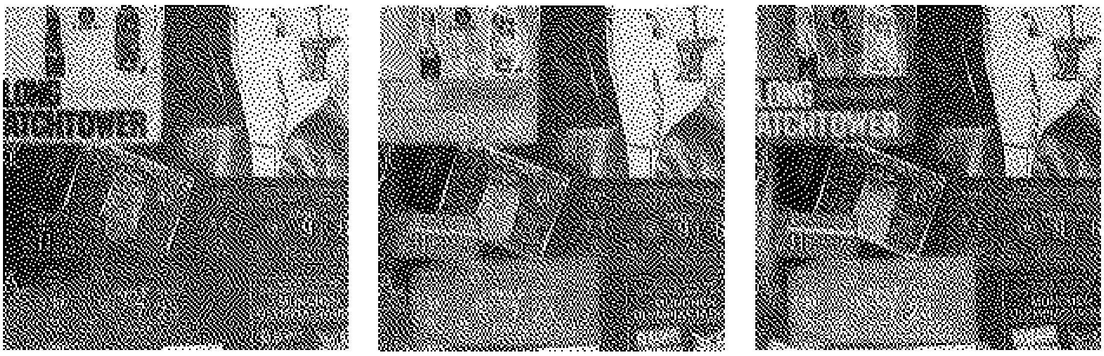
(d) (e) (f)

Figure 7. Performance Comparison for Different Methods on LC Image #3: (A) Original Image, (B) T_{FS}, (C) T_{JJN}, (D) T_{ST}, (E) T_{8}, And (F) T_{128}.

(a) (b) (c)

(d) (e) (f)

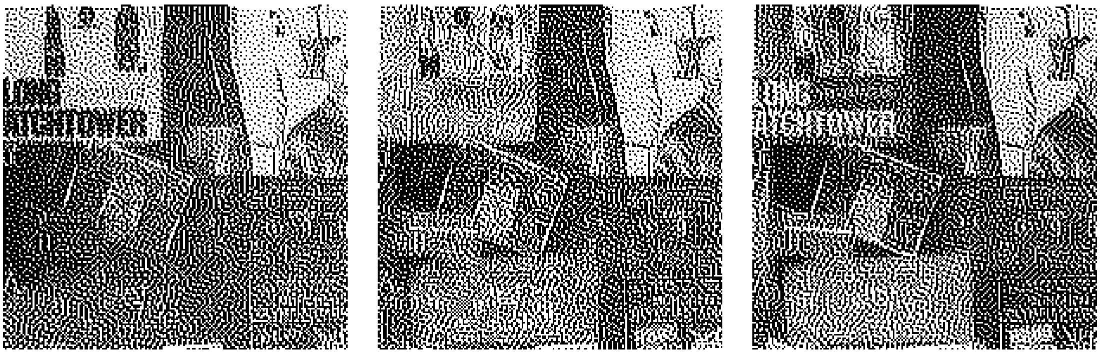
Figure 8. Performance Comparison for Different Methods on LC Image #5: (A) Original Image, (B) T_{FS}, (C) T_{JJN}, (D) T_{ST}, (E) T_8, And (F) T_{128}



(a) (b) (c)

Figure 9. Difference between Each Channel of Original Image and Each Channel of T_8 Image: (A) Red Channel, (B) Green Channel, and (C) Blue Channel

Visual performance comparison is provided in Figure 5 to 8. Images (a) in each figure are the original image, and (b) to (f) are ED processed images by T_{FS}, T_{JJN}, T_{TS}, T_8, and T_{128}. As one can see, the granules of the result images are crisper as the filter size grows. Figure 9 shows the difference between each channel of original image and each channel of T_8 image. Similarly, Figure 10 shows the difference between each channel of original image and each channel of T_{128} image.



(a) (b) (c)

Figure 10. Difference between Each Channel of Original Image and Each Channel of T_{128} Image: (A) Red Channel, (B) Green Channel, and (C) Blue Channel

4. Conclusions

This paper proposes a new error diffusion approach which is assumed to provide high quality ED. The proposed method quantizes each pixel to 1-bit binary one. To accelerate processing speed, the denominator of the proposed method is selected with the form of 2^k. Thus, the method is faster than the conventional methods, while preserving simplicity property. Simulation results indicate that the provided red, green, blue channels and color images are satisfactory for viewer.

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