Computational experiment of error diffusion dithering for depth reduction in images

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Reception date of the manuscript: 02/06/2020
Acceptance date of the manuscript: 08/06/2020
Publication date: 12/06/2020

Abstract—The halftone technique is a process that employs patterns formed by black and white dots to reduce the number of gray levels in an image. Due to the tendency of the human visual system to soften the distinction between points with different shades, the patterns of black and white dots produce a visual effect as if the image were composed of shades of gray and dark. This technique is quite old and is widely used in printing images in newspapers and magazines, in which only black (ink) and white (paper) levels are needed. There are several methods for generating halftone images. In this article we explore dithering with error diffusion and an analysis of different halftone techniques is presented using error diffusion to change the depth of the image. The results showed that the depth of the image changes 1/8 per channel, this halftone technique can be used to reduce an image weight, losing information but achieving good results, depending on the context.

Keywords—Error Diffusion Dithering, Processing Image, Depth Reduction

I. Introduction

According to [1], error diffusion is a method for generating high quality halftones that are particularly suitable for low to medium resolution devices. The image resolution for halftones is determined by the screen ruling. The term screen ruling is used to describe the frequency of dots in a given area of image. For conventional screening (amplitude modulated screening or AM), the halftone dots are arranged in a grid structure termed the screen [2].

Also according to [1], to apply the error diffusion algorithm in producing a halftone $b(n_1,n_2)$, we need to scan the input image $f(n_1,n_2)$ in some manner. One of the most popular strategies is raster scanning, where we scan the image row by row from the top to the bottom, and within each row from the left to the right. At each pixel location, we perform the operations

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$$u(n_1,n_2) = f(n_1,n_2) - \sum_{m_1,m_2} h(m_1,m_2)e(n_1-m_1,n_2-m_2) \tag{1}$$

$$b(n_1,n_2) = Q(u(n_1,n_2)) = \begin{cases} 1 & \text{if } u(n_1,n_2) \geq 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$e(n_1,n_2) = b(n_1,n_2) - u(n_1,n_2) = Q(u(n_1,n_2)) - u(n_1,n_2) \tag{3}$$

The filter $h(m_1,m_2)$ generally has a low pass characteristic, and the coefficients often satisfy

$$\sum_{m_1,m_2} h(m_1,m_2) = 1 \tag{4}$$

Many research use error diffusion in wade of applications. Just to cite some of them: [3] employ a high speed ordered dithering and high quality error diffusion to simultaneously solve the problems we described above. As the experimental results demonstrate, this technique is able to enlarge the dynamic range of the histogram and improve the execution efficiency to around 15%-47% with the tested images.

Akarun, Ozdemir & Alpaydin presented in [4] an improvement on error diffusion dithering through a fuzzy error diffusion algorithm. In this method, the amount of error to be diffused is determined by considering the relative location of the pixel not only to the closest codebook vector, but also to the color cluster it belongs to. The goal is to hide the quantization errors by error diffusion, while preventing the excess accumulation of errors. This is achieved through an attraction-repulsion schema according to a fuzzy membership function.

In [5], Lee, Horiuchi & Saito proposed an algorithm named “confined error diffusion (CED)" which has a well organized architecture between random error diffusion and ordered dither method to improve the image quality and gray level expression for the flat panel display.

A halftone watermarking technique of high watermark rate, robustness, and watermark-rate flexibility is presented in [6]. This technique, namely the parity-matched error diffusion (PMEDF) method, is capable of achieving an embedded watermark rate as high as 6.25–25% with good image quality and without the need for the original image as the reference for decoding.

In [7] is reported a new strategy to increase the speed of Fourier single-pixel imaging by two orders of magnitude. In this strategy, we binarize the Fourier basis patterns based on up sampling and error diffusion dithering. The results demonstrate a 20,000 Hz projection rate using a DMD and capture 256-by-256-pixel dynamic scenes at a speed of 10 frames per second.

In [8], Ozaki, Sako, Harada & Takasaki developed an error-diffusion dithering method for a reflective Memory-In-Pixel LCD to provide a high-quality moving image. In [9], error diffusion halftoning has been used to achieve image dithering based on complex wavelets. Similar to the wavelet-based dithering, Floyd-Steinberg error diffusion has been incorporated, but in addition a new set of sub band amplification factors is coined in the proposed method to further enhance the contrast in a dithered image. Experimental results show that the proposed method is superior to state-of-the-art methods in terms of subjective and objective assessments.

Thus, this paper describes a practical experiment of an error diffusion dithering algorithm, based on the following classical dithering methods, applied to reduce image depth. The methods are: Floyd–Steinberg[10], Stevenson-Arce[11], Burkes[12], Stucki[13] and Jarvis-Judice-Ninke [14].

II. Implementation

This section describes the computational implementation of the descibre algorithm.

a. Diffusion error approach

This approach aims to change the intensity to 0 (minimum) or 1 (maximum) and then propagate the difference from the original value to the neighbors of the pixel. This way, a region with more 0 pixels will be perceived by human eye as a dark region; a region with more 1 pixels will be perceived as a brighter region; a region with the same amount of black and white pixels distributed equally will be perceived as gray, and this logic continues for the proportion between black and white in the image’s regions.

b. Algorithm

The methods can be described as kernels and the operation may seem like a convolution. The difference between

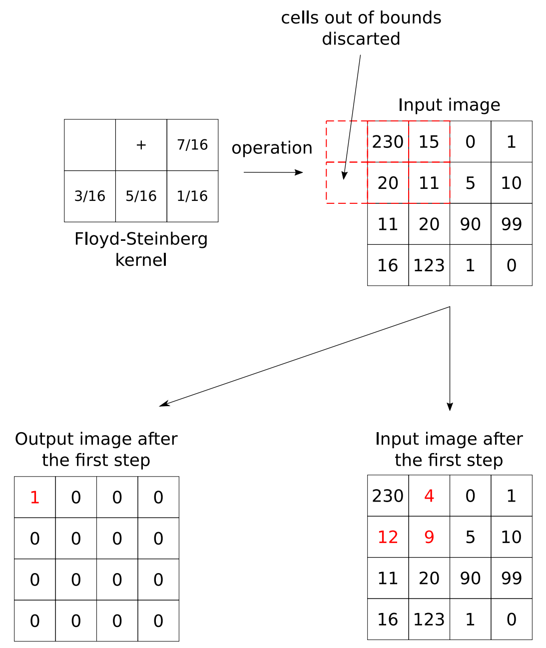


Fig. 1: The first step of a dithering operation with a Floyd-Steinberg kernel. Three pixels got updated in the first step. The red numbers indicates the changes made.

a dithering operation and a convolution is that the dithering updates the input image in order to propagate the error to the neighbours of the current pixel. With this principle, a generic function was developed to receive a dithering kernel, calculate the pixel value on the output image as

$$O[i,j] = round(\frac{I[i,j]}{255}) \tag{5}$$

where O is the output image and I is the input image. Then, the error is calculated as

$$error = I[i,j] - O[i,j] * 255 \tag{6}$$

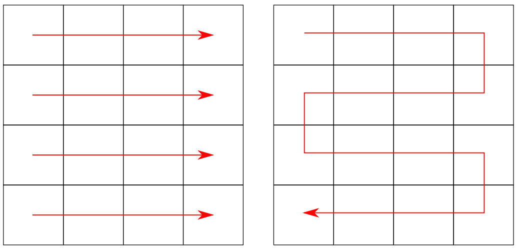
and the pixels around the original pixel are updated as

$$I[i+y, j+x] = I[i+y, j+x] + error * K[y,x] \tag{7}$$

where the K is the dithering kernel, and the y and x are the position of the proportion of error diffused to the neighbour on that position. If a cell on the kernel is positioned out of the image, it’s ignored in the current step. Also, the updated value always respect the pixel range of $[0,255]$. The design of the kernels varies between the techniques listed on Section I. Fig.1 shows an example of the first step of a dithering operation.

c. Image scanning approaches

The two approaches chosen to scan the image was **left to right** and **zigzag**, illustrated in the Fig.2. For this, a parameter called *alternate* is passed to the method, and when it is true, the horizontal range changes to right-left in the odd rows. Additionally, the kernel is flipped horizontally to propagate the errors in the scanning direction, never changing a pixel that already exists in the output image.



(a) Left to right **(b)** Zigzag

Fig. 2: Two different scan approaches used on the tests.

d. Colored images

To process RGB (Red, Green, Blue) images, each channel was dithered separately, and then mounted as a 3D-array again. Fig.3 illustrates the steps followed by the algorithm for the Stucki's dithering method using the left-to-right approach.

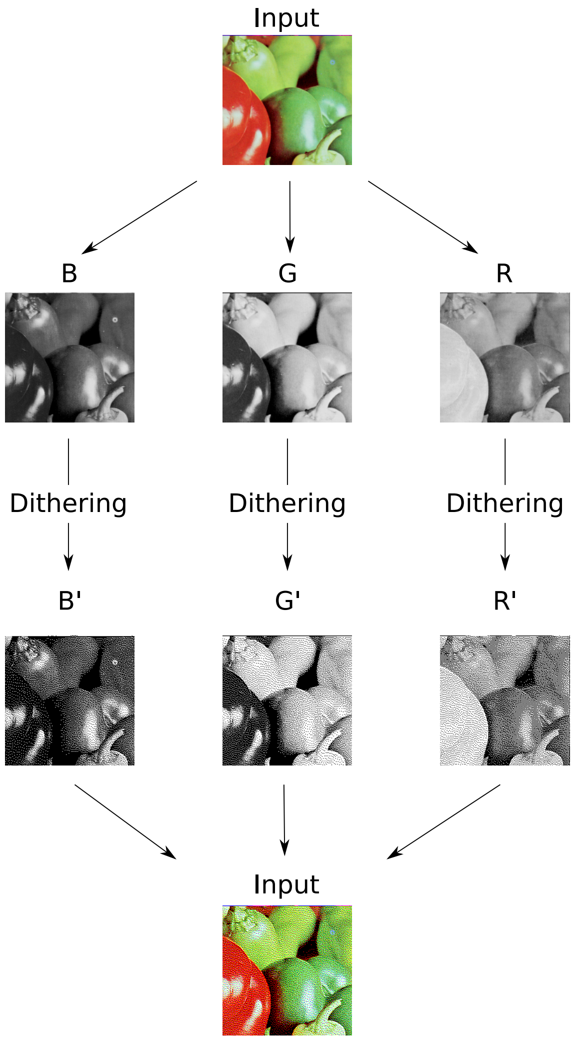


Fig. 3: Sequence of steps in the algorithm when performing dithering in a RGB image using Stucki's method and lef-to-right approach.

III. Experiment and Results

For each of the approaches, the images *baboon*, *monalisa*, *peppers* and *watch*, represented on Fig.4 was used as input. As the approaches have different shapes, the pattern in the result changes along the tests. In Fig.5 it can be seen the difference between **Stevenson-Arce** [11] and **Floyd-Steinberg** results at the same location of the same input.

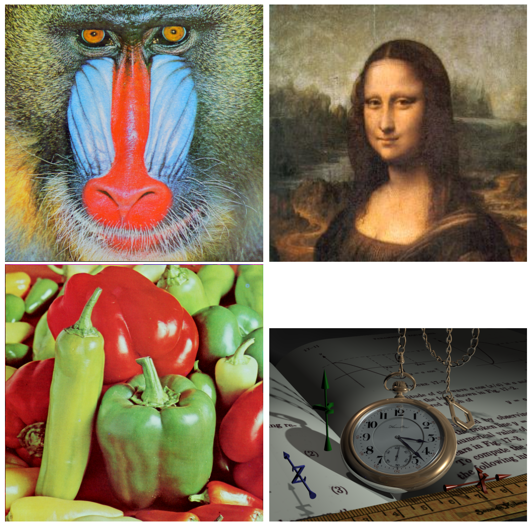


Fig. 4: Original images used as input.

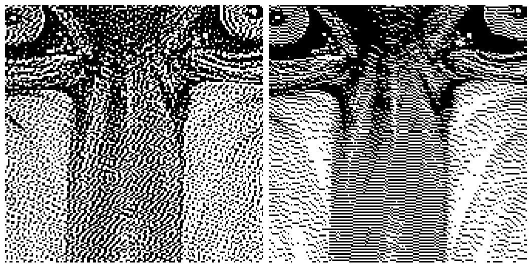


Fig. 5: Difference between patterns generated with different approaches. In the left, Stevenson-Arce. In the right, Floyd-Steinberg.

Fig. 6 shows the difference between the two scan approaches using Floyd-Steinberg kernel. As the mask reaches just some of 8-neighbors pixels and the weight is higher at the right side, when a pixel has an intensity near to the threshold, it propagates too much error to the right neighbor, creating a result with more horizontal lines. When the zigzag approach is used, this horizontal line is replaced by a pattern with more dots. This difference is less evident in the other approaches with a bigger mask, as the pixels are more influenced by more distant pixels that have different intensities and that distributes complementary errors.

Fig.7 shows the result of Burkes approach with zigzag scan in the *peppers* input. As each channel is converted to

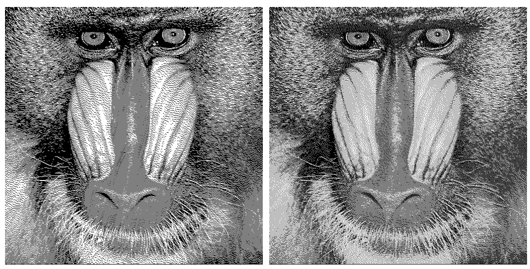


Fig. 6: Difference between left-to-right approach (left image) and zigzag approach (right image).

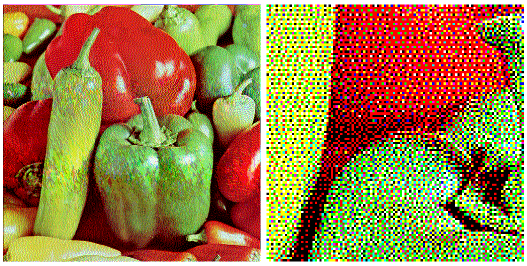
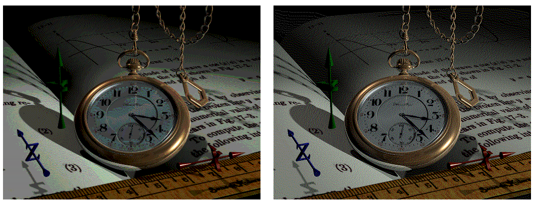


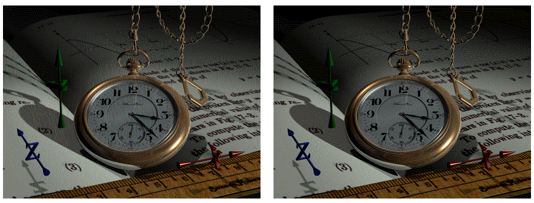
Fig. 7: Result from Burkes applied to *peppers* using the zigzag approach.

a binary image, the combination of the three channels result on colors: **red**, **green**, **blue**, **cyan**, **magenta**, **yellow**, **white** and **black**.

On Fig.8 and Fig.9 it can be seen the result of all approaches for *watch* and *monalisa* inputs using zigzag method. All images seams like the input when plotted with a small size. The difference is more evident on *monalisa*, especially because it's resolution is smaller than *watch*. But with a zoom in (as showed in Fig.7) the absolute pixel values and the difference between the approaches can be seen in all tests. Fig.10 highlights the dark region of **Jarvis, Judice and Ninke** and **Floyd-Steinberg** results. On the right one, almost all texture around the arrow was lost and became pure black. The left one shows that more pixels of the paper at the back of the clock appear after dithering, but when it's looked closer, it seams like noise.



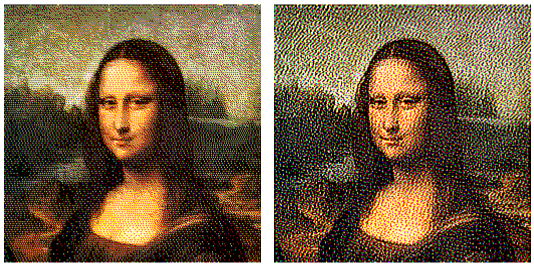
(a) Floyd-Steinberg **(b)** Steverson-Arce



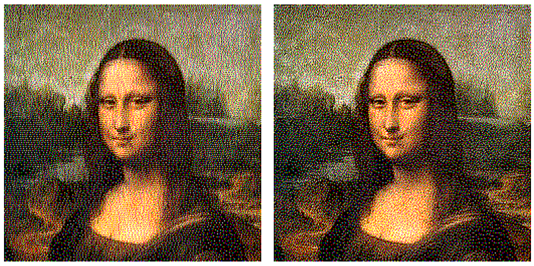
(c) Burkes **(d)** Stucki

(e) Jarvis, Judice and Ninke

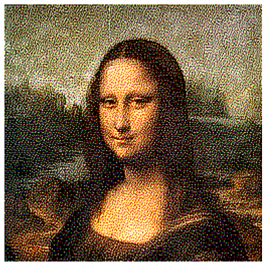
Fig. 8: Results for all methods using a zigzag approach on *Watch* input.



(a) Floyd-Steinberg **(b)** Steverson-Arce



(c) Burkes **(d)** Stucki



(e) Jarvis, Judice and Ninke

Fig. 9: Results for all methods using a zigzag approach on *Monalisa* input.

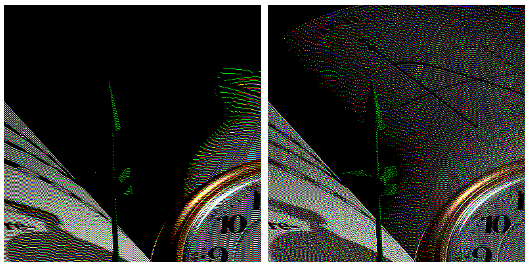


Fig. 10: Difference between **Jarvis, Judice and Ninke** and **Floyd-Steinberg** results from *watch* input using left-to-right approach.

IV. Conclusion

The main purpose of dithering is to plot high resolution (high dimension in a small area) in context with low resource, like old newspaper printing (with monochrome images) or low cost magazine printing (with colorful images), so the result achieve the proposed goals. Another interest detail is that, as the depth of the image changes 1/8 per channel, this halftone technique can be used to reduce an image weight, losing information but achieving good results, depending on the context.

Another use of this technique is in led panels, that mix dithering with a blink technique, so more frames can be processed at time and less micro-controller could be used to print something on the screen.

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