An Integrated Color Halftone Method for Noise Reduction

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Abstract

Color halftoning is a method for representing continuous tone color images with limited colors. To implement halftone, error diffusion is one of the most popular algorithms due to its high-performance results. In the conventional error diffusion, the fixed thresholds and filter weights are used. In the process, many artifacts are introduced in the halftone images as side effects. With the color aspect, each of the three color planes is independently calculated during the process of traditional error diffusion. However, the pattern of dots formed independently by combining the dots of each of color planes is often not visually pleasing because no effort is made to insure that the dots of each of the different color planes are ideally distributed relative to the dots of the other color planes. In this paper, we present an integrated error diffusion algorithm in which variable filter weights, threshold matrix, serpentine scan path and multi-color halftoning are used to reduce the noises generated during the halftone process. Our experimental results showed that worm-like artifacts, structural artifacts and start-up artifacts are successfully decreased and the color halftoned images are more comfortable to the human visual system.

Introduction

Digital halftoning is the process of transforming a continuous-tone image to a binary image. It is commonly used to render a color or grayscale image for output device such as printers or display equipments. There are many methods to perform digital halftoning, and commonly used methods are dithering and error diffusion. The dithering techniques are attractive in sense that they are very simple to implement, and they are computationally inexpensive. However, their performance is poor when compared to the error diffusion technique. The error diffusion algorithm introduced by Floyd and Steinberg[1] is a very efficient halftoning algorithm that produced halftone image with a high-performance results. However, the conventional error diffusion also generates worm-like artifacts, structural artifacts and start-up artifacts. With the color aspect, each of the three color planes is independently calculated during the process of traditional error diffusion. However, the pattern of dots formed independently by combining the dots of each of color planes is often not visually pleasing. In order to cope with the drawbacks mentioned above, many efforts have been made to improve the output quality of error diffusion algorithm.

Deterministic Changes of the Error Filter

Eschbach[2] proposed an interesting application by using multiple deterministic error filters. Based on the gray level, a larger error filter is used in highlighted and shadowed regions, while a small error filter is used in the midtone region.

Modification of Scan Direction

The scan orders of the conventional error diffusion are processed from left to right and top to bottom. A scan line is processed from left to right until the end is reached; then the pointer is returned to the leftmost position for processing the next scan line. In the process of serpentine scan,[3] a scan line is first processed from one direction, say left to right using a standard error filter. When the end of the line is reached, instead of going back to the leftmost position of the next line, the process of the next line is from right to left using the mirror of error filter.

Threshold Modification

In generic error diffusion a constant threshold value that is usually set at midpoint is used. Rodney L.[4] presented a image processor with error diffusion where the modulated threshold matrix is applied. Bingfeng Zhou[5] used threshold modulation to remove the visual artifacts.

Tone-Dependent Error Diffusion

Victor Ostromoukhov[6,7] presented an halftoning method implemented by the algorithm of error diffusion for which the weights of the filter and the thresholds of the quantizer are varied depending on input pixel value to reduce worm-like artifacts.

Color Error Diffusion

Allan Chiwan Cheung[8] proposed color-related error diffusion by considering the combined number of dots from the color planes. The dots for each color plane are determined locations of to be visually pleasing for human eyes.

In this paper, we present an integrated error diffusion algorithm in which the tone-dependent filter, varied threshold matrix, serpentine scan path and color-related halftoning are used to reduce the noises generated during the halftone process.

Error Diffusion Algorithm

In the algorithm of error diffusion the error feedback after quantized is used to modify input pixel. It is schematically showed in Fig. 1 and works as follows.

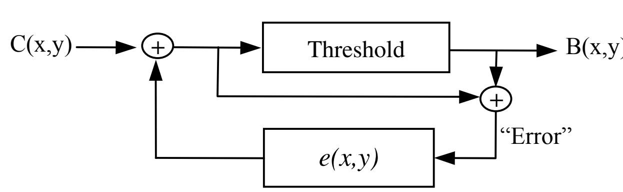
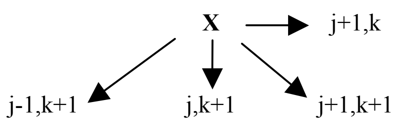


Figure 1. The error diffusion algorithm

Input continuous-tone image C(x,y) is modified by previous quantized error then it is compared to the threshold. If the value is greater than the threshold, the pixel is considered as black, and its output value B(x,y) is set to 255. Otherwise, it is considered as white, and B(x,y) is set to 0. The different between output value and original value is considered as “Error”. There are two methods to achieve this error diffusion.

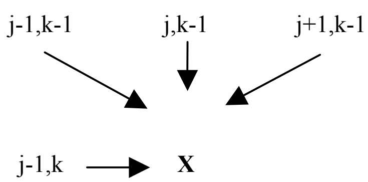
Standard Error Diffusion

This algorithm calculates the error from pixel X and diffusion this error to neighboring dots.



Systematic Error Diffusion

In this algorithm, a pixel X is received the errors from neighboring dots and the output of the pixel is modified according to error diffusion filter. In this paper, we integrate this algorithm and the tone-dependent error diffusion filter in our simulation method.



Color Error Diffusion

Color digital images are represented by one byte (8 bits) in each color plane so about 16.77 million colors can be shown in a color image. For example, an inkjet printer produces the color space by cyan, magenta and yellow. Each of the three color planes is independently calculated during the process of traditional error diffusion. Dots of a specific colorant can even be located at same position with others. This produces a pattern that may be highly visible to human vision. To avoid such pattern, the printing rule as follow is proposed.

```
if( C + M <= 255 )
{
    if( C > Threshold )
    {
        Print Cyan dot only
    }
    else if (C + M > Threshold )
    {
        Print Magenta dot only
    }
}
else
{
    if( C + M -255 > Threshold )
    {
        Print Cyan and Magenta dots
    }
    else if( C > Threshold )
    {
        Print Magenta dot only
    }
}
```

In this method, the relation between cyan and magenta planes during the color printing process is considered. After systematic error diffusion processes, if the sum of pixel values of cyan and magenta plane is less than 255 at the specific location, only one of the planes with maximum value is to be printed. If cyan is greater than the threshold value, a cyan dot is to be printed. Otherwise, if the sum of pixel values is grater than the threshold value, a magenta dot is to be printed.

If the sum of pixel values is greater than 255 at a specific location, at least one of the dots, cyan or magenta, is to be printed. If the sum of pixel values is greater than the threshold value plus 255, both the cyan and magenta dots are to be printed. Otherwise, if cyan is greater than the threshold value, a cyan dot is to be printed. If magenta is greater than the threshold value, a magenta dot is to be printed.

Simulation Results

In this paper, tone-dependent error diffusion method using the Ostromousukhov’s variable coefficient algorithm is introduced into our simulation result. The test image Fig. 2(a) is used to produce Figs. 2(b)-(d), which is a gray-scale ramp of 32 levels where highlight and shadow region are shown. Figure 2(b) was obtained by using the traditional systematic error diffusion. Figure 2(c) was obtained by using the tone- dependent systematic error diffusion. Figure 2(d) was obtained by using the tone dependent systematic error diffusion with serpentine scanning method. It is interesting to see the differences among Figs. 2(b)-(d). By comparing Figs. 2(b) and (c) we can see that the worm-like pattern are produced in both of the traditional systematic error diffusion and the tone-dependent systematic error diffusion. Such worm-like artifacts have a prevailing angle respect to the base line of the image. Figure 2(b) shows one kind of worm-like patterns with horizontal waveforms. Figure 2(c) shows the other kind of worm-like patterns with a 45^{o} angle. Figure 2(d) shows that worm-like patterns are successfully reduced by the tone-dependent systematic error diffusion with serpentine scan path method.

The color diffusion method described in previous section is used to simulate color image is shown in Fig. 3 and Fig. 4. In Fig. 3(b), a halftone image generated by applying traditional systematic error diffusion. The black dots on the highlight background are easily visible. Figure 3(c) shows a halftone image generated by applying the systematic color–related error diffusion with tone-dependent error filters. The black dots are reduced from highlight background so a image looked comfortable for human vision is produced.

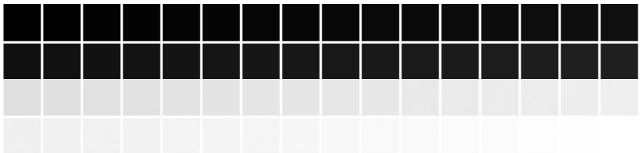


Figure 2(a) Original gray image

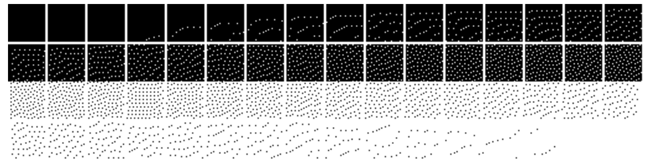


Figure 2(b) Traditional systematic error diffusion

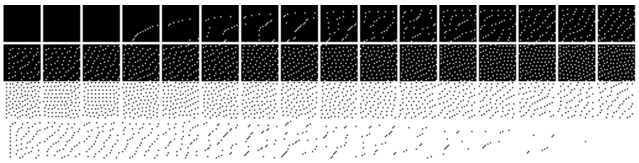


Figure 2(c) Tone-dependent systematic error diffusion

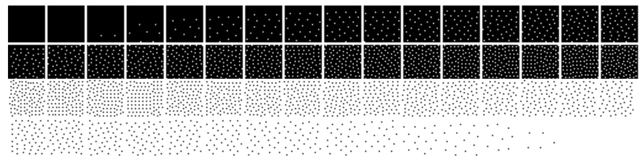


Figure 2(d) Tone-dependent systematic error diffusion with serpentine scan path

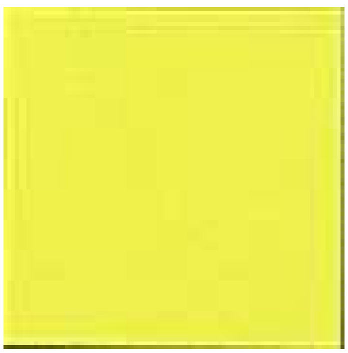


Figure 3(a). Color original image

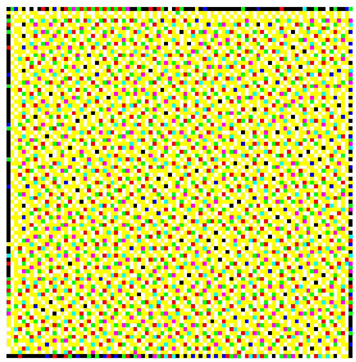


Figure 3(b). Traditional systematic error diffusion

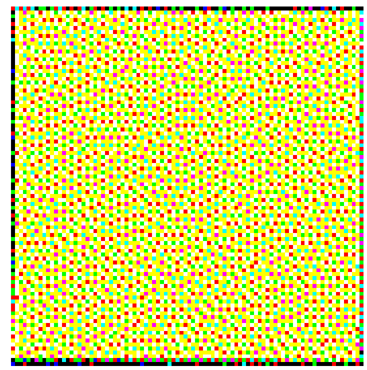


Figure 3(c). Tone-dependent systematic color error diffusion

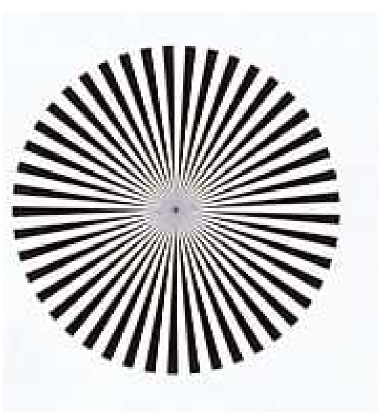


Figure 4(a). Color original image

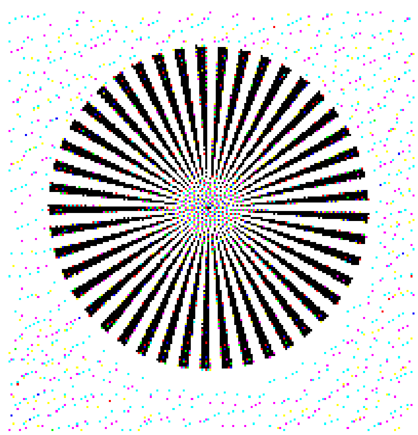


Figure 4(b). Traditional systematic error diffusion

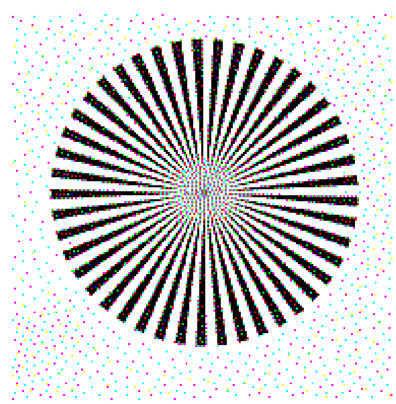


Figure 4(c). Tone-dependent systematic color error diffusion with serpentine scan path

Figure 4(b) shows a halftone image generated by applying the traditional systematic error diffusion. There are some artifacts such as the start-up delay at the bottom of the black circle. Figure 4(c) shows a halftone image generated by applying the systematic color-related error diffusion with tone-dependent error filters and serpentine scan path. The start-up artifacts at the bottom of the black circle are reduced in this method.

Conclusion

As simulated above, the tone-dependent systematic error diffusion with serpentine scan path effects worm-like pattern distribution. Tone-depend systematic color error diffusion with serpentine scan path that reduces most of the visual artifacts of traditional error diffusion is achieved. In our experimental results, worm-like artifacts, structural artifacts and start-up artifacts are successfully reduced and the color halftoned images are more comfortable to the human visual system.

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