Error Diffusion Using Band-based Peano Scan

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Abstract

The error diffusion method using band-based Peano scan is presented to improve the quality of the result image and reduce the wormy texture or the artifacts with low memory cost. The present technique divides the image data into 4-line bands. Each band is numbered downward from the first band to the last one.

The generalized Peano scan is employed for tracing pixels of each band. The band with odd number is scanned from left-top to right-bottom and the band with even number is scanned from right-top to left-bottom so that all pixels can be traced without the scanning gap.

In accordance with this scan, the error diffusion method is used for halftoning. The experimental results show that the present technique is an effective, practical and artifact-free way for halftoning using Peano scan with low memory cost.

Introduction

The halftoning technique is important for printing or displaying the continuous image with the device in which the direct rendition of the continuous tone is impossible.

While the error diffusion method[1] with the raster scan has been widely used as the effective halftoning technique, it may cause the wormy texture or the artifacts in the result image, especially in the region with the low luminance level or the constant luminance level.

The error diffusion method using the generalized Peano scan[2] has been proposed to improve the quality of the result image and reduce the wormy texture or the artifacts.

Peano scan is the discrete form of Hilbert curve, and the generalized Peano scan is a technique to scan an arbitrary rectangle region in the Peano scan scheme, while Peano scan can trace only the square region of $2^n \times 2^n$.

The error diffusion method using the generalized Peano scan is an excellent technique to reduce the wormy texture or the artifacts in the halftone image, but requires large amount of memory to trace the whole image.

In general, the whole image sized memory is required in Peano scan or the generalized Peano scan so that all the neighbor pixels can be referred from the current pixel in the scanning path.

The error diffusion technique using band-based Peano scan is presented to improve this drawback and generate the result image with the better quality.

Band-Based Peano Scan

The present technique divides the image data into *m*-line bands to reduce the memory cost.

To produce the image without the artifacts and the block distortion at the boundary of the bands, it is critical how many lines are clustered as a band.

We estimated the proper band size from the stochastic attribute of Peano scan as follows.

In general, Peano scan and the generalized Peano scan have Wiener process behavior that the scanning step between two points increases linearly with the square Euclidean distance of these points.

The adequate band size can be determined through the analysis of Wiener process behavior of the band-based Peano scan so that the band-based Peano scan has the similar stochastic behavior as that of the Peano scan or the generalized Peano scan.[3]

We obtained 4 lines as the best band size from our analysis results and use the fixed band size of 4 lines for the easy memory alignment.

In the band-based Peano scan, it is also important how the end point of the current band and the start point of the next band are connected at the boundary of the bands to reduce the block distortion.

The present method connects these points in the following manner.

First of all, each band is numbered downward from the first band to the last one.

Secondly, the generalized Peano scan is employed for tracing pixels in each band.

The band with odd number is scanned from left-top to right-bottom and the band with even number is scanned from right-top to left-bottom.

In general, the generalized Peano scan which starts at the left-top of the scanned region ends at the right-bottom of the region, and the generalized Peano scan which starts at the right-top of the scanned region ends at the left-bottom of the region.

The end point of the current band, therefore, is connected to the start point of the next band, thus generating the scanning path in which all pixels can be traced without the scanning gap.

The block distortion can be also suppressed at the boundary of the bands using this simple scanning scheme.

Error Diffusion using Band-based Peano Scan

In accordance with band-based Peano scan, the error diffusion method is used for halftoning.

The conventional error diffusion method using Peano scan or the generalized Peano scan may produce rough appearance in the result image.

To improve this drawback, the symmetric error matrix based on Jarvis matrix, the error handling in the cumulative manner and the edge enhancement technique are applied in the present method.

The error diffusion process in the present method takes the following steps.

In the first step, the previous errors $e_{x,y}$ of the neighbor pixels are lowpass filtered with the symmetric error matrix $W_{m,n}$ by Eq. (1).

$$E_{x,y} = \frac{\sum_{m,n} W_{m,n} B_{m,n} e_{x+m-3,y+n-3}}{\sum_{m,n} W_{m,n} B_{m,n}} \quad (1)$$

Note that $E_{x,y}$ denotes the lowpass filtered error and $B_{m,n}$ denotes the mask matrix with 1 indicating a binarized pixel and 0 indicating a non-binarized one.

Figure 1 shows the symmetric error matrix with the current pixel at its center.

1	3	5	3	1
3	5	7	5	3
5	7		7	5
3	5	7	5	3
1	3	5	3	1

Figure 1. The symmetric error matrix based on Jarvis matrix.

Secondly, the binarized output and the residual error of the current pixel is calculated by Eq.(2),(3),(4).

$$v'_{x,y} = v_{x,y} + k_e E_{x,y} \quad (2)$$

$$o_{x,y} = \begin{cases} 255 & \text{if } v'_{x,y} > th \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

$$e_{x,y} = v'_{x,y} - o_{x,y} \quad (4)$$

Note that $v_{x,y}$ denotes the value of the current pixel, $o_{x,y}$ denotes its binarized output value and th denotes the threshold value.

The residual errors are averaged for each color composition in the gray region of the RGB color image.

The contrast parameter k_e is used to eliminate the blurred appearance of the result image especially using Peano scan and calculated by Eq. (5).

$$k_e = \frac{k_{\max} - k_{ctrl} - G}{k_{\max}} \quad (5)$$

Note that G denotes the edge enhancement value estimated by the highpass filter such as Sobel filter, k_{max} denotes a positive constant that limits the maximum value of G, and k_{ctrl} denotes a positive constant for the contrast control.

The constant parameter k_e decreases in the edge region , or for the smaller k_{ctrl}.

Since $v'_{x,y}$ become asymptotically equal to $v_{x,y}$ for the smaller k_e, $o_{x,y}$ is calculated only by thresholding $v_{x,y}$ for the smaller contrast parameter, resulting in the high contrast effect in the edge region.

In the non-edge region, the contrast is adjusted depending on the control parameter k_{ctrl}.

The present technique mentioned above provides an error diffusion method using Peano scan on the 4-line band basis.

Table 1 shows the memory size required for each scanning technique using gray scale image of 2048 × 2560 (pixel) in size.

These required memory was calculated on the condition that one pixel occupies 1 byte and one error data occupies 2 bytes.

From Table 1, it's clear that the present method requires greatly less memory than the conventional method using Peano scan.

Table 1. Memory size required for each scanning method using 2048 × 2560 (pixel) image

Scanning Method	Required Memory Size
Raster scan (Jarvis matrix)	16Kbytes
Peano scan	20Mbytes
Present method	54Kbytes

Experimental Results

We estimated the quality of the binarized images through the experimental results to confirm the texture uniformity, the reduction of the artifacts, edge preservation, the tone rendition, and so on.

Figure 2 shows the original gray scale image of 1024 × 1024 (pixel) in size.

Figure 3, Figure 4, and Figure 5 show the result images for the original image using the error diffusion based on the raster scan, the generalized Peano scan, and the band-based Peano scan, respectively.

From the results of Figure 3 through Figure 5, the result image using the raster scan has some artifacts in the constant level region, and the result images using the generalized Peano scan and the present emthod has the texture uniformity and less artifacts

It can be found that the edges in the text region and the gradation were preserved in Figure 5.

We also estimated the graininess of the result images of the error diffusion using each scanning scheme as follows. We used the gray scale image with the constant 128 luminance level in the range between 0 and 255 as the estimation image.

The result images for the estimation image using the raster scan, the generalized Peano scan, and the present method are lowpass filtered with Gaussian filter to simulate the human visual system.

Table 2 illustrates the mean luminance of the Gaussian filtered result images using each method and Table 3 illustrates the standard deviation of the Gaussian filtered result images using each method.

Table 2. Mean luminance after Gaussian filtering

Method/r	0.4	0.5	0.6	0.7
Raster scan	150	131	128	128
Generalized Peano Scan	151	132	128	128
Present method	151	132	128	128

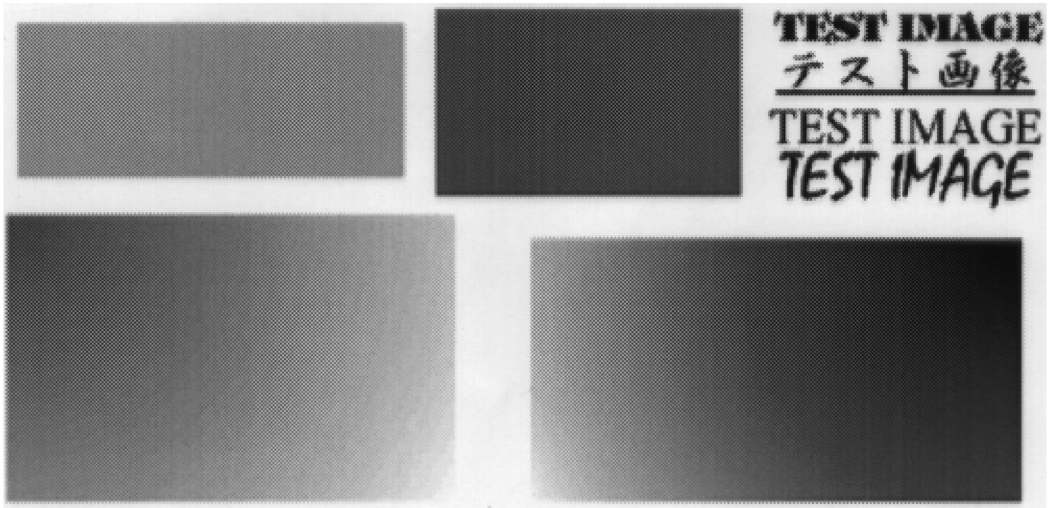

Figure 2. Original image

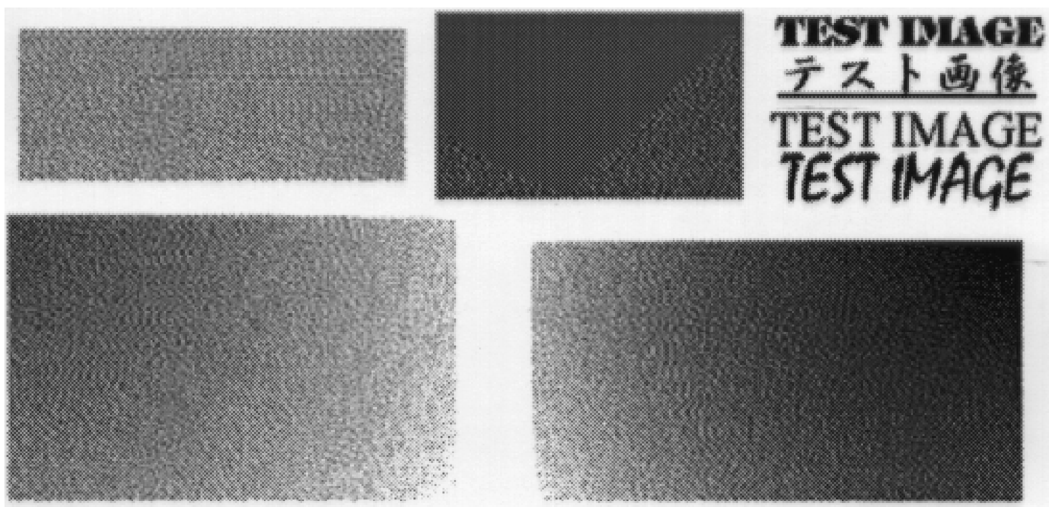

Figure 3. Result image using the raster scan

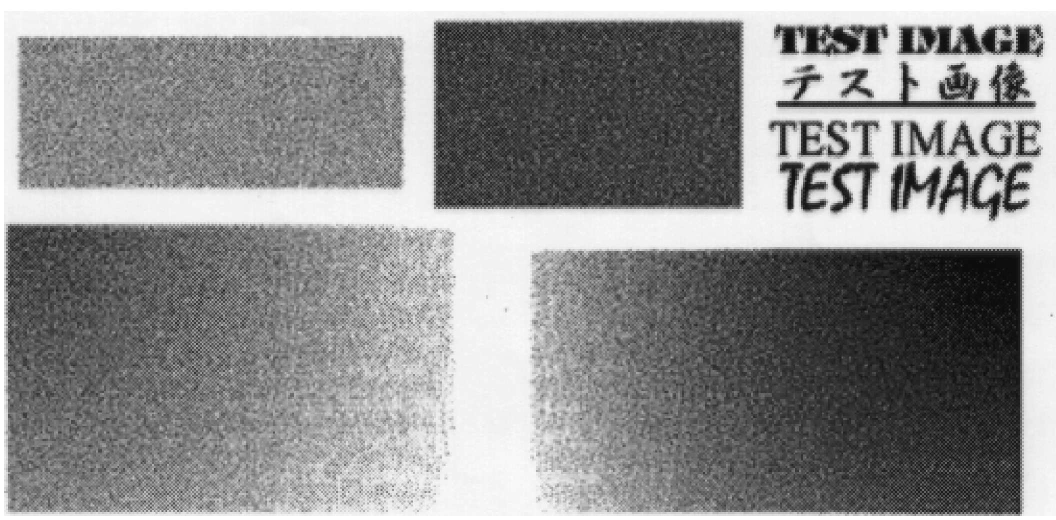

Figure 4. Result image using the generalized Peano scan

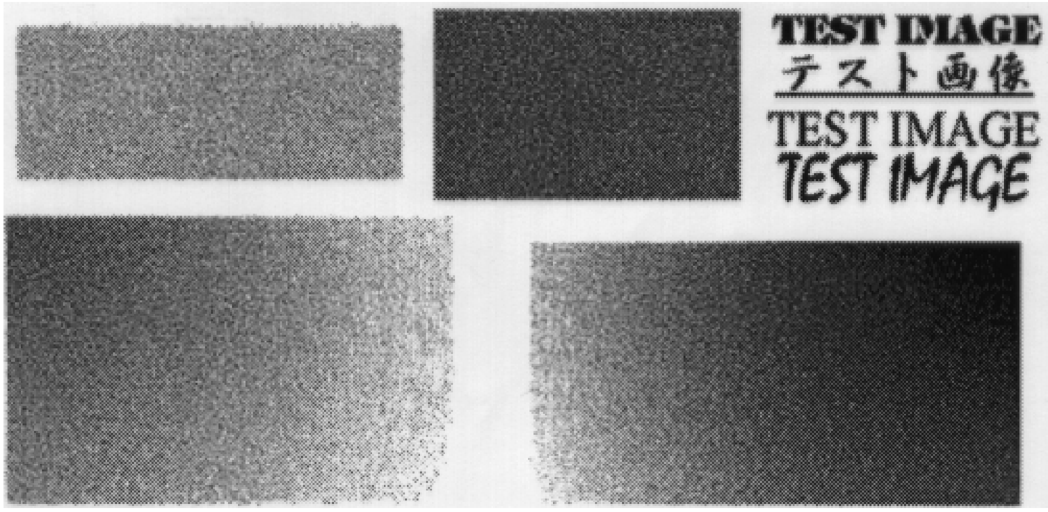

Figure 5. Result image using the present method

Table 3. Standard deviation after Gaussian filtering

Method/r	0.4	0.5	0.6	0.7
Raster scan	116	60	34	22
Generalized Peano Scan	123	71	45	31
Present method	123	70	44	30

Note that the Gaussian filtered result image has the luminance range between 0 and 255 and *r* denotes the point spread parameter of Gaussian filter. We simulated the different resolution using the different point spread parameter *r*.

In accordance with Table 2 and Table 3, the mean luminance decreases toward 128 and the standard deviation decreases with *r* increase.

In the result image using the raster scan, the standard deviation decreases more than the ones using the generalized Peano scan and the present method.

These indicates that the result image using Peano scan has the rough appearance rather than the one of the raster scan, although the present method made slightly less rough appearance than the generalized Peano scan in Table 3.

While the rough appearance may fade in the image with the high resolution,[4] the conventional method using Peano scan or the generalized Peano scan requires the large amount of memory to handle the high resolution image.

On the other hand, the error diffusion based on the raster scan causes the wormy texture or the artifacts even in the high resolution image.

Because the present method requires much less memory than the conventional method using Peano scan or the generalized Peano scan and can provide the artifact-free halftone image, it has great advantage especially for the high resolution image.

Conclusion

The error diffusion technique using band-based Peano scan was presented to improve the quality of the result image and reduce the wormy texture or the artifacts with low memory cost.

The experimental results show that the present technique is an effective, practical and artifact-free way for halftoning with less memory buffer than the conventional method using Peano scan or the generalized Peano scan.

We also estimated the rough appearance of the result images in several resolutions by changing the point spread parameter of Gaussian filter.

In general, high resolution image has large amount of pixel data especially in the case of the color image.

The present method, therefore, is more effective and practical in high quality halftoning of large sized color image than the conventional error diffusion method using Peano scan or the generalized Peano scan.

References

1. Robert W. Floyd and Louis Steinberg, *An Adaptive Algorithm for Spatial Greyscale, Proceedings of the S.I.D,* **17**, 2, pp.75–77 (1976).
2. T. Nagae, T. Agui, and H. Nagahashi, *A generalization of the Peano scan and its application to halftoning, ITEJ Technical Report*, **16**, 9, pp.25–30 (1992).
3. T. Agui, T. Nagae, and M. Nakajima, *Genralized Peano scans for arbitrarily-sized arrays, ITEJ Technical Report,* **14**, 37, pp.25–30 (1990).
4. K. Miyata, M. Saito, N. Tsumura, and Y. Miyake, Evaluation of image quality for high-quality digital halftoning: image analysis and evaluation of multi-level error diffusion, *IS&T/SPIE's 9th Annual Symposium,* **3016-21** (1997).

❋ Previously published in *IS&T's NIP13 Conference Proc.*, pp. 531–535, 1997.