Mol. Cryst. Liq. Cryst., Vol. 585: pp. 7–14, 2013

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2013.852768

Adaptive Three-Dimensional Error Diffusion Method for Improving Image Quality in Plasma Display Panel

SANG-CHUL KIM, HEUNG-SIK TAE, AND SUNG-IL CHIEN*

School of Electronics Engineering, Kyungpook National University, Daegu, 702-701, Korea

PDP often generates worm-like patterns on a displayed image because it employs an error diffusion method to maintain the quality of the input image by using limited number of gray-levels, which is quite essential for reducing dynamic false contours of PDP. To reduce worm-like patterns of PDP, an adaptive three-dimensional error diffusion method based on interrelation of neighboring frames is proposed. The interrelation of frames is estimated from the difference of adjacent frames, and the amount of quantization error for the spatial and temporal direction is adaptively changed depending on the magnitude of the frame difference.

Keywords Adaptive error filter; error diffusion method; frame difference; PDP; worm artifacts

Introduction

Plasma display panel (PDP) often suffers from motion artifacts called dynamic false contour (DFC) because of the address-display separated (ADS) subfield driving scheme. Thus, PDP represents a continuous tone image with a limited number of gray-levels for removing DFC [1]. In this case, degradation of the original image quality is inevitable and the error diffusion method (ED) is accordingly used to minimize this problem [2–4]. Generally, a typical ED consists of a feedback loop. A continuous-tone value reproduces a quantized value by comparing it with a threshold and quantization error is computed by subtracting the input value from the quantized value. The quantization error is distributed to the neighboring pixels by an error filter. Thus, an error diffusion method aims to reproduce the continuous-tone input value. However, typical ED produces many worm-like patterns called worm artifacts which are one of the main causes to deteriorate the image quality of PDP. Especially, the recent 3D PDPs express a stereoscopic image by splitting a set of subfields into two parts to represent right and left images, so the available expression for gray-levels becomes significantly reduced. Thus, limited gray scale expression and resulting worm artifacts are still serious problem in the PDP.

There have already been various attempts to reduce the worm artifacts [5]. Jarvis [6] and Stucki [7] propose a larger size error filter to spread a quantization error over a wider region.

*Address correspondence to Prof. Sung Il Chien, School of Electronics Engineering, Kyungpook National University, Sangyuk-dong, Buk-gu, Daegu 702-701, Korea (ROK). Tel.: (+82)53-950-5545; Fax: (+82)53-950-5505. E-mail: sichien@ee.knu.ac.kr

Although this method can somewhat reduce worm patterns, a large filter size requires more memory and processing time when compared with the Floyd-Steinberg method. To reduce the worm artifacts, Ulichney changes the scanning direction of conventional error diffusion by using serpentine scanning [8]. This approach does not require any memory increase over a conventional raster scanning, but sometimes vertical pattern is observable in the output image [9]. Error diffusion methods based on random effects such as stochastic diffusion weight method and threshold modulation method are also reported [10,11]. However, random effects tend to suppress the edges of halftone image. Many modified error diffusion methods, which distribute the error into the spatial direction only, are not best suited for the display devices. Recently, a three-dimensional error diffusion method (3DED) that propagates quantization error into both the spatial and temporal directions has been developed to reduce worm artifacts [12]. However, this 3DED generates another serious artifact, such as a line artifact, and too large error propagation into the temporal direction tends to generate so often spot noises around a moving object [13].

In this research, we have devised a new error diffusion method to solve the image quality problem of 3DED and reduce the worm artifacts at the same time. It has been analyzed that if gray-levels between two consecutive frames show much variation, the quantization error should not be dispersed to the next frame to remove the spot noises. For the areas whose gray-levels does not show abrupt change, large error needs to be dispersed to the next frame to reudce worm artifacts. To compensate for the transient state of the above two cases, the magnitude of the gray-level variation is used to determine how the amount of quantization error is adaptively divided between the neighboring spatial pixels and the pixel in the next frame. By using this type of the spatiotemporal filter, we are successful in reducing the worm artifacts without generating other types of artifacts.

Adaptive Three-Dimensional Error Diffusion Method

In the signal processing unit of PDP, an inverse gamma correction is applied to the input image to compensate between the input and output signals of the PDP, and inverse gamma corrected image is reproduced through the halftoning algorithm by using a limited number of gray-levels. After that, the number of sustain pulses for each subfield is determined by average picture level (APL) to satisfy the constraint of stable power consumption. Finally, the reproduced input image is displayed on the PDP via the sustain pulses of the each subfield. Figure 1 summarizes the block diagram of the signal processing unit in PDP.

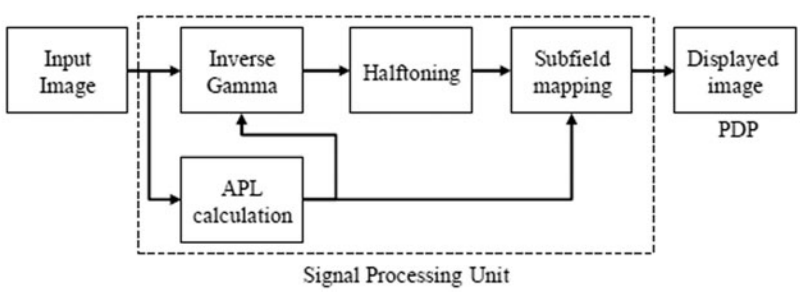


Figure 1. Block diagram of signal processing unit in PDP.

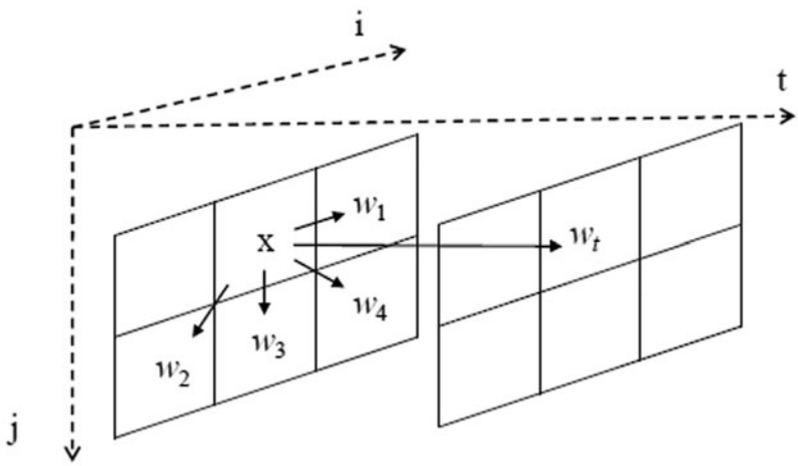


Figure 2. Concept of the proposed error filter.

As a halftoning method in Fig. 1, the Floyd-Steinberg error diffusion method (FSED) [2] is often used in PDP. However, FSED produces so often worm artifacts at certain gray-levels and its filter weights that determine the magnitudes of quantization error are always fixed. These artifacts aggravate the image quality of the PDP. The recently studied 3DED mainly focused on distributing part of the error to the temporal direction to suppress worm artifacts, but it often generates the line artifacts and spot noises into the next frame because dispersion errors to the temporal direction can disturb the quantization errors of the spatial direction in the next frame. Especially, image quality is seriously deteriorated when some video frames show a large motion or transition, such as fading and zooming. Thus, to minimize the image quality deterioration caused by a dispersal of inaccurate error from the neighbor frames, an appropriate criterion is required to determine the amount of error to the temporal direction.

To solve these problems, we adaptively adjust the dispersed quantization error to the next frame based on an interrelation or correlation between two consecutive frames. If the variation of the gray-level between two frames is large, small error is dispersed to the next frame to remove spot noises. Otherwise, relatively large error is diffused to the next frame to reduce the worm artifacts. As shown in Fig. 2, the spatiotemporal error filter of the proposed method is composed of two parts: temporal and spatial filter weights.

We first should find the interrelation of the two consecutive frames to decide the temporal filter weight. The motion information can reflect the interrlation between two neighbor frames, but obtaining the motion information is not easy task for a real time system. Here, we use the frame difference, as is calculated by an absolute gray-level difference between the current frame and next frame pixels. The frame difference for a pixel is obtained by

$$\Delta f = |f(x, y, n) - f(x, y, n + 1)| \tag{1}$$

where Δf is the magnitude of the frame difference. Here, $f(x,y,n)$ is input pixel gray-level value of *nth* frame at position (x, y). The temporal filter weight which is decided by amount

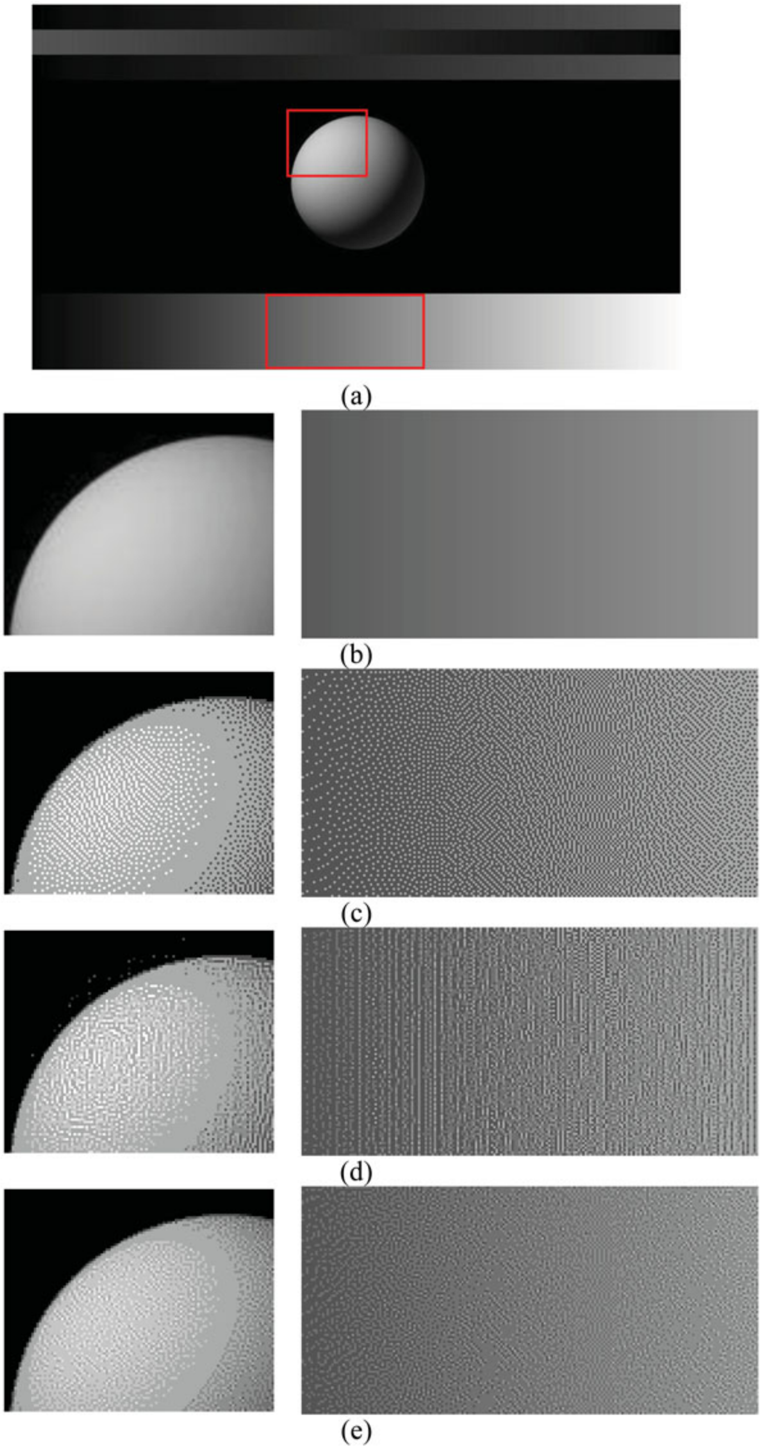


Figure 3. Simulation results of the error diffusion method (quantization level: 4), (a) Original video frame for gray image and four enlarged images for (b) original image, (c) FSED, (d) 3DED, and (e) proposed method.

of the frame difference is given as

$$w_t = \begin{cases} w_{t\_\max} e^{-\frac{\Delta f}{T}}, if\, \Delta f < \Delta f_{\max} \\ 0, otherwise \end{cases} \quad (2)$$

$\Delta f_{\max}$ is the maximum magnitude of the frame difference, w_t and w_{t_max} are temporal filter weight and its maximum value, respectively. And T is a constant that determines how fast w_t drops asΔfgets larger. We put a limit to the magnitude of quantization error to the temporal direction by using w_{t_max} and $\Delta f_{\max}$. The $\Delta f_{\max}$is experimentally set to be 0.15 when the full gray-level of a pixel is normalized to 1, and w_{t_max} is set to be 20 percent of a quantization error for the current pixel. Constant T is fixed at 0.22 experimentally. After the temporal filter weight is decided, the spatial filter weights modify the Floyd-Steinberg filter weights as follows:

$$w_p = (1 - w_t) \times w_p^{FS} \; p = 1, 2, 3, 4$$
$$w_1^{FS} = \frac{7}{16},\, w_2^{FS} = \frac{3}{16},\, w_3^{FS} = \frac{5}{16},\, w_4^{FS} = \frac{1}{16}, \quad (3)$$

where w_p is the *pth* spatial filter weight and w_p^{FS} is the corresponding Floyd-Steinberg filter weights [2]. In this way, the error filter is adaptively determined based on the frame difference of the two adjacent fames and is repeated for every pixel and every frame. In addition, the w_s which is sum of the spatial weight is expressed as

$$w_s = \sum_{p=1}^{4} w_p = 1 - w_t \quad (4)$$

By using the Eq. (4), we obtain the following equation.

$$w_s + w_t = 1 \quad (5)$$

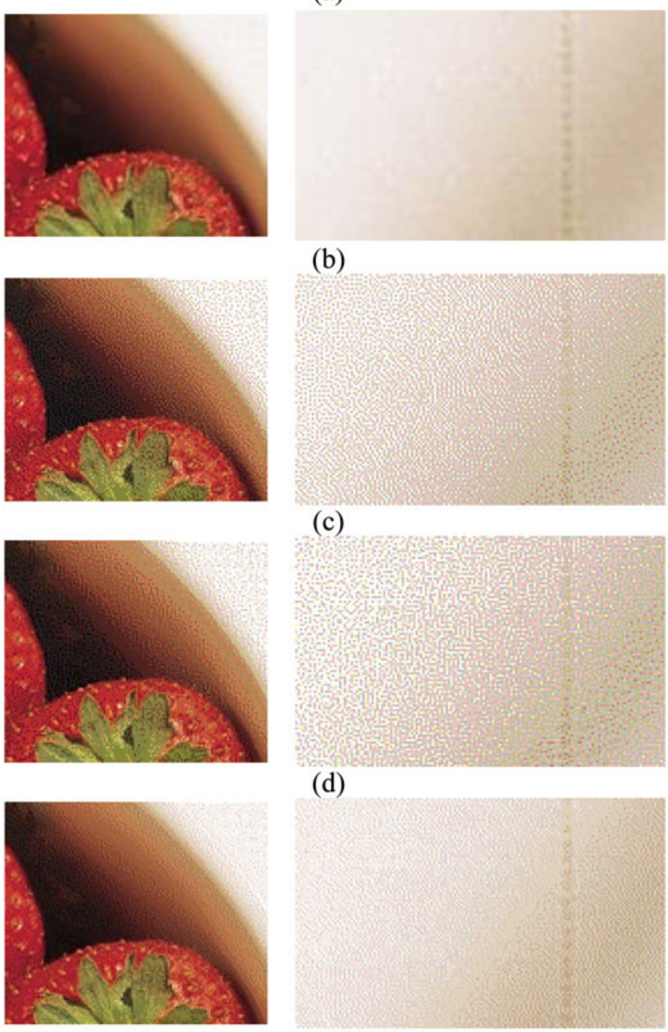
If sum of the weights is not 1, the error filter affects the average picture level.

Experimental Results and Discussion

The performance of the proposed method is evaluated by using the video simulation and the actual device experiment on a 42-inch PDP. We firstly discuss the perceived luminance of human visual system (HVS) for appropriate evaluation of the image quality. According to the research of the Luxenberg and Kuehn, the perceived luminance of HVS is obtained through the integration of the average luminance for 100ms when people are watching the video in the display [14]. This visual phenomenon means that HVS perceives the average luminance of three continuous frames in case of the standard video of 60 Hz and 30 frames per second. Therefore, when the video image quality needs to be printed for visual evaluation, we have averaged three continuous frames for the simulation results.

Figure 3 shows the simulation results among the conventional methods and proposed method by using four gray-levels on video image in which a sphere moves three pixels per frame from the left to the right between two static backgrounds of gradation. In the Fig. 3(a), we put two boxes to indicate regions where we can observe worm artifacts and spot noises. For a better assessment of the simulation results for each method, two boxes as in Fig. 3(a) are enlarged. In FSED, many worm artifacts are observable in the gradation area and the moving sphere, as shown in Fig. 3(c). Figure 3(d) shows that 3DED seems to suppress the

(a)



(b)

(c)

(d)

(e)

Figure 4. Simulation results of the error diffusion method (quantization level : 8 × 8 × 8), (a) Original video frame for color image and four enlarged images for (b) original image, (c) FSED, (d) 3DED, and (e) proposed method.

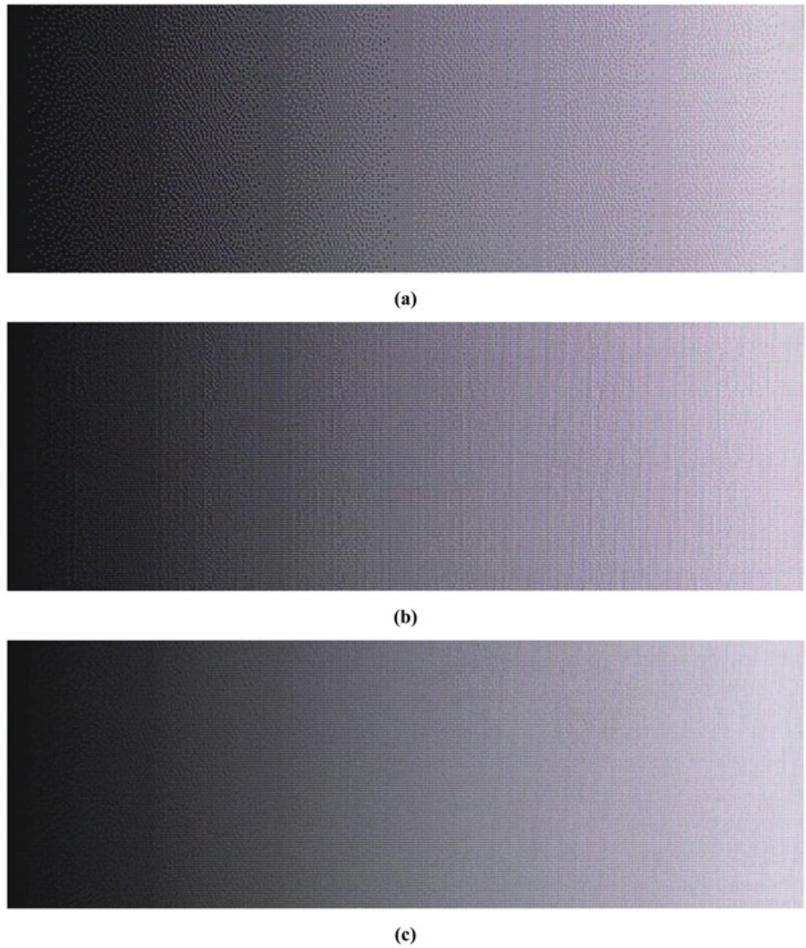


Figure 5. Experimental results on a 42-inch actual PDP about proposed method and conventional methods: (a) FSED, (b) 3DED and (c) proposed method.

worm artifacts, but this method produces strong line artifacts in the gradation image because the amount of dispersing quantization error is determined in proportion to the magnitude of the gradient and sometimes resulting spatial errors tend to accumulate only along the edge direction. Moreover, many spot noises are observable in the black background around the moving sphere. These spot noises occur because of the combination of the spatial error from the current frame and the relatively large temporal error of the previous frame around edges. In contrast, as shown in Fig. 3(e), the proposed method expresses the gradation image more smoothly and it also effectively reduces the worm artifacts and also spot noises appearing around the moving sphere.

Figure 4 shows the simulation result of a color video which has abundant gray-level expression. Like the case of the previous simulation result, the FSED generates some false contours into the boundary of the bowl, and many worm artifacts appear in the backgrounds which are shown in Fig. 4(c). Compared with FSED, 3DED somewhat reduces the worm artifacts in the background, but it still generates false contours around the boundary of the bowl. We also cannot observe the line artifacts because of abundant gray-level expression in the 512 colors, but 3DED does not remarkably improve the image quality compared with the FSED. As expected, the proposed method effectively reduces worm artifacts and false contours in the boundary area of the bowl while keeping a good gray-level expression and reducing false contours. Especially, a false contour is not visually noticeable in the bowl because worm artifacts have been reduced there and better gray-level expression has been achieved thereby.

For evaluating the real image quality of the proposed method, we perform the actual device simulation on a 42-inch PDP, which is especially built for the experiment of these kinds of image processing. We test the results of image quality against a gradation image with only 16 gray-levels of each color and in this case the worm artifacts are frequently observed. Figure 5 shows the captured image for a low gray-levels part of a gradation image in the PDP. Like the previous simulation results of FSED, worm artifacts are still observed throughout all areas, as shown in Fig. 5(a). The 3DED can somewhat reduce worm artifacts in comparison with the FSED, but this method produces many line artifacts, as shown in Fig. 5(b). In contrast, as shown in Fig. 5(c), the proposed method expresses the gradation image more smoothly and it also effectively reduces the worm artifacts. The experimental results are printed here and somewhat distorted during the process, but when we observe these images on a PDP, these artifacts are quite noticeable.

Conclusions

A new error diffusion method is proposed to improve image quality of PDP to reduce the worm artifacts. The proposed method first calculates the frame difference of two consecutive frames, which allows us to determine adaptively the error filter weights for the temporal and spatial directions at each pixel. Thus, we can adjust the ratio of quantization errors of the spatial and temporal directions according to the frame difference. Through the simulation results and actaul PDP experiments, we can verify that the proposed method reduces worm artifacts without generating other artifacts.

Acknowledgment

This research was supported by Kyungpook National University Research Fund, 2012.

References

[1] Thebult, C., Correa, C., & Weitburush, S. (2002). *European Patent 1 245*, 924.
[2] Floyd, R., & Steinberg, L. (1976). *Proc. Soc. Image Display*, *17*, 75–77.
[3] Yamaguchi, T., Masuda, T., Kohgami, A., & Mikoshiba, S. (1996). *SID*, *4*, 263–270.
[4] Kim, S. C., Kang, S. J., & Chien, S. I. (2009). *IEEE Trans. Consumer Electron.*, *55*, 622–627.
[5] Kang, H. R. (1999). *Digital Color Halftoning*. Chapter 16, pp. 357–395, SPIE Press: Washington.
[6] Jarvis, J. F., Judice, C. N., & Ninke, W. H. (1976). *Proc. Comp. Graph. Image.*, (5), 13–40.
[7] Stucki, P. (1981). Research report RZ1060, *IBM Research Lab*.
[8] Ulichney, R. (1987). *Digital Halftoning*. The MIT Publishing: Cambridge, MA.
[9] Knox, K. T. *Proc. SPIE*, (2179), 159–169.
[10] Tiecheng, L. (2007). *IEEE Trans. Consumer Electron.*, *53*, 528–534.
[11] Kim, S. C., Kim, H. M., & Chien, S. I. (2010). *Proc. Int. Conf. Machine Vision*, 324–338.
[12] Liu, Z. J., & Liang, Z. H. (2007). *IEEE Trans. Consumer Electron.*, *53*, 239–242.
[13] Hsu, C. Y., Lu, C. S., & Pei, S. C. (2007). *IEEE Int. Conf. Multimedia and Expo*, 1938–1941.
[14] Lloyd, J. M. (1975). Thermal Imaging Systems: Springer Publishing, Plenum Press, 131–133.