Multi-Level Confined Error Diffusion Algorithm for Flat Panel Display

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SUMMARY The reduction of a structural pattern at specific gray levels or at the special condition of image data has mainly been discussed in digital halftone methods. This problem is more severe in some flat panel displays because their black levels typically are brighter than other displays blocks. The authors proposed an advanced confined error diffusion (ACED) algorithm which was a well-organized halftone algorithm for flat panel devices. In this paper, we extend the ACED algorithm to the multi-level systems, which are capable of displaying more than 2 levels. Our extension has two merits for the hardware implementation. First, it can be processed in real time using the look-up table based method. The second one is the flexibility of selecting the used gray level. This paper discusses the performance of the proposed algorithms with experimental results for natural test images.

**key words:** multilevel halftone, digital color image halftone, error diffusion, flat panel display

1. Introduction

The Plasma Display Panel (PDP) and Liquid Crystal Display (LCD) have recently entered the market as replacements for television and computer monitors based on Cathode Ray Tube (CRT). There are several factors such as the halftone method used, gray linearity, contrast ratio, color, and sharpness that affect their suitability in terms of image quality for these markets. The present paper focuses on effective digital color halftone algorithm for flat panel display. Many efficient digital halftone algorithms have been proposed [1]–[9]. However, these algorithms were mainly developed for digital printing, rather than digital display.

In this paper, we describe multi-level halftone algorithms for flat panel displays and the hardware implementation of the algorithms. As conventional works in printing side, H. Ochi, N. Suetake et al. and H. Hara et al. proposed multi-level error diffusion algorithms [11]–[14]. H. Hara et al. proposed the emphasized ordered dither algorithm for the middle gray level area. Especially, H. Ochi and N. Suetake et al. were focused on improving the vacant area (the banding problem) of conventional multi-level error diffusion. H. Ochi and N. Suetake et al. carried out the multiple quantization process for an image. They determined the error diffusion quantization value for increasing direction of dot-dispersibility. The vacant area was efficiently improved in their algorithms. However these algorithms have limitations to be applied for flat panel displays. To be applicable for flat panel displays, the real time processing is very important. However it may be not easy to be implemented for real time processing for these algorithms. The reason why is because the process is so complicated, requires multiple error diffusion calculation to generate the final error diffused image and requires more resources to be implemented. Additionally, these algorithms are not flexible for being expanded to use more output real gray level. These algorithms were focused on the only 3 level expansion of the conventional halftone except for the H. Ochi’s algorithm.

Each flat panel display device has a unique characteristic that depends upon how it is driven and upon how it produces the image. For instance, the plasma display is emissive and uses time division to produce their tone scale. Generally, the driving architecture of the plasma display is based on the passive matrix type that has subfield structure. Each subfield is composed of the reset period, the addressing period, the sustain period, and the erasing period. The combinations of the subfields that have a binary or weighted sustain periods (pulses) produce the tone scale. The smallest possible increment of light at a pixel location is therefore determined by the shortest subfield period. For a 1500 \( \text{cd/m}^2 \) peak white luminance, this suggests that the smallest white pulse of light will be approximately 0.8–2 \( \text{cd/m}^2 \). The halftone pattern is more visible in a moderate grayscale region because of this reason. Therefore, a specially organized halftone process is required to overcome this device-dependent limitation.

In order to solve this problem, the authors proposed a concept named Confined Error Diffusion (CED) and an advanced CED (ACED) algorithm. The CED and ACED algorithms were described with the concept of the bi-level halftone in [10]. However, most of the flat panel display devices are capable of displaying more than 2 levels. The present paper extends the ACED algorithm to the multi-level system based on a look-up table (LUT) method. Actually, various electro-optical characteristics of a display, such as gray linearity, efficiency, peak/black level luminance, and uniformity in mass production are a little different day by day, case by case which is manufactured. The gray linearity is one of the most important factors among these characteristics. The LUT based multi-level halftone algorithm is suited to the manufacturing circumstance, because the LUT can be easily implemented for each manufacturing status.

The paper is organized as follows. In Sect. 2, we explain the outline of the ACED algorithm. Section 3 develops a multi-level extension of the ACED algorithm. Sec-
tion 4 shows the results with the natural images and compare our algorithm with the conventional methods. In Sect. 5, the hardware implementation is discussed. The conclusion is given in Sect. 6.

2. Advanced Confined Error Diffusion

We describe the outline of the ACED algorithm [10] for improving the structural pattern induced by the dither pattern and the random error diffusion. Figure 1 shows the block diagram of the ACED algorithm. The algorithm is composed of two halftone processes as shown in the block diagram, the random error diffusion process for the lower bit packet and the ordered dither process for the higher bit packet. In the ACED algorithm, we separate the pixel data to an upper packet (higher bit packet, 3 bit from MSB) and lower packet (lower bit packet, 5 bit from LSB). The ordered dither process contributes to generate major rendering levels (ordered dither levels) while the random error diffusion process contributes to generate the intermediate (minor) rendering levels between the major rendering levels, which were determined by the ordered dither process. Figure 2 shows the concept of the ACED. The full pattern of one frame dither process is shown. The ACED carry is determined as follows:

\[
ACED(f, x, y) = d(f, x, y) \land r(f, x, y), \tag{1}
\]

\[
d(f, x, y) = 4\text{bit Dither}(f \mod 4, x \mod 4, y \mod 4), \tag{2}
\]

\[
r(f, x, y) = R.E.D(f, x, y), \tag{3}
\]

where \(f\) is frame count, \(x\) is pixel count, \(y\) is line count, \(d(f, x, y)\) is the ordered dither carry of the higher bit packet,
More carefully, we assume that the dither mask in the Fig. 2 is in memory. We need a 4 bit address to address the mask data in the memory. At first, we calculate the lower bit packet error carry, \( r(f, x, y) \), with the specially organized random error diffusion process for each pixel. After that, the carry is attached with the higher bit packet to produce 4 bit address data. Next, the ordered dither process (thresholding), which is dependent on the frame/line/pixel position, is carried out with the 4 bit address data including the higher bit packet (3 bit) and the result (1 bit) of random error diffusion. Finally, the local AND operation between the 4 bit dither carry, \( d(f, x, y) \), and random error diffusion carry, \( r(f, x, y) \), is carried out. If the result of random error diffusion is 0 at any pixel, the even mask is selected. If the result of random error diffusion is 1 at any pixel, the odd mask is selected. Consequently, the upper level dither mask confines the random error diffusion-carry.

The results of various kinds of halftone, Shiau Fan error diffusion [8], 6 bit ordered dither, the ACED algorithm, and 4 frame averaged ACED algorithm, with the source of "Eagle" image are shown in Fig. 3. The conventional halftone algorithms were focused on the digital printing, so neither the temporal problem, nor the display visibility was considered. The conventional error diffusion algorithm has a structural pattern, and this pattern can be more visible in flat panel displays like a plasma display panel, because of the heavy intensity of minimum unit luminance. The ACED algorithm can improve the gray level expression using the concept of confining error-carry within the dither mask and reduce the flicker problem by using a time-spatially well-balanced dither mask.

The ACED algorithm was constructed as a 1 bpp (bit/pixel) system in [10]. However, most of the current flat panel displays are capable of displaying more than 2 levels, typically 8 bpp system or 10 bpp. In the next section, we propose a multi-level ACED system.

### 3. Extension to Multi-Level System

Figure 4 shows the typical system block diagram of flat panel devices. Most of the flat panel displays are required pre-processing to process the gamma correction, because its display characteristics are not equal to that of CRT display. The color correction is required for the user requirements. The RGB gain control is also required for the white balance, brightness control. Although most of the flat panel displays have a capability of displaying over 255 gray levels for each RGB channel, the gamma correction causes to cover the wide range gray level area using the same light of a display, especially for the low gray area. For this reason, the digital halftone block is required. The halftone application is different depending on the driving scheme such as active/passive matrix driving, emissive/non-emissive driving. The data conversion and arrangement which is dependent on the driving methods are also required. The processed data must be rearranged to be displayed in each geometric RGB cell position of panel. Generally, an internal look-up table, a hardware memory, or a special data arrangement processor is used for the arrangement of data.

In the following we discuss the extension to multi-level systems. Our extension has two merits for the hardware implementation. First, it can be processed in real time using the look-up table method. The second one is the flexibility of selecting the gray level. The processing speed is very important for the mass production of flat panel displays, because the processing speed, which is related to the hardware resources, has an influence on the cost of manufacturing in usual. The flexibility of selecting the used gray levels will play important roles in developing new mass production devices. Figure 5 shows the concept of the proposed multi-level extension. We assume that a display device has a maximum ability of displaying \( m \) gray levels, and the device displays the source image using \( n \) gray levels within the \( m \) gray levels. In the view of \( g_{n-1} \) and \( g_n \), the bi-level halftone is applied. The \( g_n \) is the \( n \)-th real gray level that can be displayed by the device. Generally, the number and the value of \( g_n \) vary with various kinds of reason, such as the gamma correction, the driving method, the used materials, and hardware limits of the display device. Therefore, we require the flexible data conversion system. In this paper, we used the look-up table for converting the gamma corrected data to the halftone data. This look-up table can be constructed in accordance with the system gray levels and the values. The details of generating the look-up table are as follows.

![Fig. 4 Typical block diagram of flat panel display devices.](image-url)
\[ \text{Target\_Gamma}(x) = \text{Max\_Gray} \cdot \left( \frac{x}{\text{Max\_Gray}} \right)^\gamma \] (4)

The \text{Target\_Gamma}(x) is the transfer function of the display system, \( x \) is the input gray level, \( \gamma \) is the gamma value, and \( \text{Max\_Gray} \) is the maximum gray level of the display device. The final transfer function will be adjusted as shown in Fig. 4.

\[ \text{Float}(n-1, x) = \frac{\text{Target\_Gamma}(x) - g_{n-1}}{g_n - g_{n-1}} \] (5)

\[ \text{Integer}(n, x) = n \cdot \text{Float}(n, x) \] (6)

\[ \text{LUT}(x) = \text{Integer}(x) + \text{Float}(x) \] (7)

The \( \text{LUT}(x) \), which is the look-up table for the halftone process, is generated in accordance with the \text{Target\_Gamma}(x), the number and the value of \( g_n \). The \( \text{LUT\_RealGray}(n) \) is the look-up table for the real gray levels, in which the used real gray levels are stored. In the main process of the Fig. 4, the input images are gamma corrected in the “Gamma Correction” block with the Eq. (4). Next, the color correction is carried out. The color corrected image data are converted to the halftone data with looking the \( \text{LUT}(x) \) in the “Pre-Data Conversion” block. The \( \text{LUT}(x) \) is composed of \text{Float()} part and \text{Integer()} part as like Eq. (5) and Eq. (6), respectively. And the halftone process is carried out with the multi-level ACED algorithm.

\[ \text{Display\_Data}(x) = \text{LUT\_RealGray}(\text{Halftone}(\text{LUT}(x))) \] (8)

The \( \text{Display\_Data}(x) \), which are displayed through the display devices, are calculated like Eq. (8) in the “Post-Data Conversion” block. Finally, the \( \text{Display\_Data}(x) \) are arranged to be displayed using the hardware memory treatment or the arrangement processor depends upon the driving scheme.

In Fig. 6, there are an example plots of the \text{Target\_Gamma}(x), \( \text{LUT}(x) \), \text{Integer}(n, x), and \text{Float}(n - 1, x). The set of the \( \text{LUT\_RealGray}(n) \) is \( \{0, 31, 63, 95, 127, 159, 191, 223, 255\} \), in which we assume that a display device has an ability of displaying 9 real gray levels with requiring the \text{gamma\_value} = 2.2, \text{Max\_Gray} = 255.
4. Experimental Results

The proposed ACED can contribute to reducing the vacant area, the banding problem of conventional error diffusion, which is indicated by the arrow sign in the middle of gradation in Fig. 7 (b). To improve this vacant area, several algorithms were proposed in printing side [11]–[14]. The gradation ramp result of the H. Ochi’s is shown in Fig. 7 (c), the N. Suetake’s is in Fig. 7 (d) and the H. Hara’s is in Fig. 7 (e). The vacant area (the banding problem) was efficiently improved using these conventional multi-level error diffusion algorithms, especially H. Ochi’s and N. Suetake et al.’s algorithm. The vacant area caused by the accumulation delay of
the error diffusion is also effectively reduced in the result of the proposed algorithm as shown in Fig. 7 (e). As a natural image test, we compared the proposed multi-level halftone with the conventional multi-level halftone algorithms [11]–[14] using the condition of $\text{gamma}_\text{value} = 1$ and the tri-level (0, 127, 255) in Fig. 8. The size of the source image, “Fruits”, is 128 x 128 pixels. The proposed 1 frame result and 4 frames averaged result shows the outstanding gray level expression, color visibility compared with the conventional multi-level halftone in Fig. 8.

In Fig. 9, the natural image results of the multi-level ACED algorithm for the several cases of $\text{LUT}_\text{RealGray}(n)$ are shown. Actually, even though a display device has capability of displaying the 8 bpp, the halftone technology is required to express the non-linear gray level expression caused by inverse gamma correction as mentioned in Sect. 3. Additionally, there is a case that the output real gray levels are not 256 real gray levels. For example, the plasma display is capable of displaying the 8 bpp images in general, but the used output real gray levels are not 256 gray levels for most manufacturer. This is mainly because the false contour, which is fundamental problem of plasma display caused by its driving scheme, can be replaced by the artificial halftone pattern using reduced real gray levels. Liquid Crystal display has similar problems caused by its driving scheme. In this reason, we carried out the experiments for the various cases. We assume that the source image is displayed by the various kinds of display capabilities. The size of the source image, “balls”, is 128 x 128 pixels. Figure 9 (a), $\text{LUT}_\text{RealGray}(n) = [0, 255]$, is the result of the bi-level halftone. Figure 9 (b) is the result of the system which is capable of displaying 3 levels, $\text{LUT}_\text{RealGray}(n) = [0, 127, 255]$. Figure 9 (c) is the result of the system which is capable of displaying 5 levels, $\text{LUT}_\text{RealGray}(n) = [0, 63, 127, 191, 255]$. Figure 9 (d) is for 9 levels, $\text{LUT}_\text{RealGray}(n) = [0, 31, 63, 95, 127, 159, 191, 223, 255]$, Fig. 9 (e) is for 17 levels, $\text{LUT}_\text{RealGray}(n) = [0, 15, 31, 47, 63, 79, 95, 111, 127, 143, 159, 175, 191, 207, 223, 239, 255]$, and Fig. 9 (f) is for 33 levels, $\text{LUT}_\text{RealGray}(n) = [0, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 95, 103, 111, 119, 127, 135, 143, 151, 159, 167, 175, 183, 191, 199, 207, 215, 223, 231, 239, 247, 255]$. The $\text{gamma}_\text{value}$ is 1 and the $\text{Max}_\text{Gray}$ is 255.

From the results of the natural image, the ACED algorithm is effectively extended to the various kinds of multi-level system. The proposed multi-level halftone can be applied to the flat panel display devices.

5. Hardware Implementation

One important issue is the hardware implementation of the multi-level ACED algorithm. In Fig. 10, the hardware implementation of the multi-level CED and the multi-level ACED algorithm is given. The inputs of the halftone system are the RGB 8 bit signal, the vertical sync signal, the horizontal sync signal, and so on. The halftone system is operated with the time sequentially. All signals are synced by external clock signal (generally, pixel clock is used) and the vertical sync signal and the horizontal sync signal are the indicator of processing the source images. For the real time processing, almost...
of the internal block has a structure based on the look-up table (LUT). All LUT data are stored in the external "Flash ROM". During the time of starting the hardware system, the data are downloaded to the internal RAM automatically. In addition, the dither table and the random error diffusion seed are also downloaded to the internal Random Access Memory (RAM). The internal RAM block of "Line memory", of which the size is pixel number of 1 line × 5 bit, is prepared to treat the accumulated error data of the random error diffusion. The accumulated errors of the previous line are temporally stored to the "Line Memory". This is because the random error diffusion can be processed in real time. The internal RAM block of "Dither Table", of which the size is 256 bit × 4 frame, is to store the 4 frame dither table. We emerge the inverse gamma correction block and the pre-linear transform block of the multi-level ACED. The "Gamma + Pre Data LUT" data are calculated using the external data processing and are stored to the internal LUT RAM.

In this way, the same hardware structure with that of the multi-level CED algorithm can be applied to the multi-level ACED algorithm. The random number generator requires the random seeds, which are downloaded from the external "Flash ROM". The generated random numbers for each pixel are transferred to the "Random Error Diffusion" block, which carries out the well-organized random error diffusion. Next, the 4 bit dither table address is made with the MSB 3 bits from Floating data and the random error diffusion carry data. The 1 bit dither carry is determined by this 4 bit dither table address. The 4 bit dither table address is transferred to the internal RAM, "Dither Table", which has all dither table value like the Fig. 2. Finally, the 1 bit carry data is added to the "Integer 8 bits". The "Post Data Conversion LUT" is required for converting the halftoned data to the display data which is dependent on the display devices.

The other implementation issue for the look-up table based multi-level halftone extension is the determination of the Target.Gamma(x). In this paper, we assume that the Target.Gamma(x) curve is simply determined by the Eq. (4). Actually, Target.Gamma(x) should be determined using the real display characteristics by measuring the display output throughout the gray level 0 to maximum gray level for each color RGB channels. If this step were added to the proposed look-up table method, the gradation characteristics will be more improved.

6. Conclusion

The ordered dither has spatially well-distributed characteristics. The error diffusion has good characteristics for rendering the gray level. The ACED algorithm has both advantages of the dither and error diffusion algorithms for rendering the gray level. However, the previous ACED algorithm was constructed as a 1 bpp (bit/pixel) system. This paper has given an extension to multi-level system of the ACED algorithm. The effectiveness was evaluated by the natural image test. The proposed method has the flexibility of constructing the look-up table in accordance with the number and the value of the real gray level which is used in display device. The look-up table based method can offer the capability of real-time processing and provide a way to use the same hardware structure in both the multi-level CED and the multi-level ACED. As a future work, we will apply the ACED algorithm to the Plasma Display.

References


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