New halftoning method using adaptive cell

Shin Aoki
R&D center, Ricoh Co., Ltd, Yokohama, Japan

Abstract

We developed a new halftoning method, adaptive cell, which generates unstructured dots as by error diffusion method, but the produced binary image is less granular and more stable than that of error diffusion. The basic idea is covering the input image with cells which vary in size and shape depending on the input image data. Then appropriate number of pixels at the center of each cell are set on, to preserve the local average of the input image. The characteristics of the generated binary image shows that this method is suitable for high density electro photographic binary printers.

1. Introduction

Many halftoning techniques have been developed[1]. Particularly, the error diffusion method and the blue noise mask method [2] are superior both in resolution and in tone reproduction, due to their unstructured dispersed dots characteristics.

However, Mitsa[3] stated that a binary image generated from a constant gray level image using blue noise mask is not optimal because the dot profile of a gray level depends on another gray level. The error diffusion method does not have such a dependency but it is also difficult to produce a low granular binary image in a hilight tone.

Moreover it is known that the dispersed dot is not suitable for printers which produces an unstable isolated dot such as electro-photographic printers.

Therefore, we aimed to develop a new halftoning method which satisfies the flowing properties.

- Low granularity in hilight tone
  In order to obtain low granularity in hilight tone, minimizing the variance of distances between neighboring dots is important. We use cells of constant size to achieve this property.

- Stability
  Clustered dot ordered dither are known to be stable. We tried to generate unstructured clustered dots to increase stability.

- High processing speed
  Other types of halftoning processes are reported which use an iterative optimization process to produce optimal dot profile [4], but their computing cost is expensive. We designed a straight forward algorithm to achieve high speed processing.

2. Method

2.1. Basic method

In this paper we assume the input image to be a 256 gray scale level image, and output as a bi-level image (ON or OFF). For a constant input image with a gray level of N/256, the halftoning process should produce one ON pixel and (256/N - 1) OFF pixels, to reserve the average density. Therefore the basic strategy of the proposed method is composing a cell of neighboring pixels of which the sum of the input value is approximately 256, then one pixel in the cell is set ON, and the rest of the pixels are set OFF.

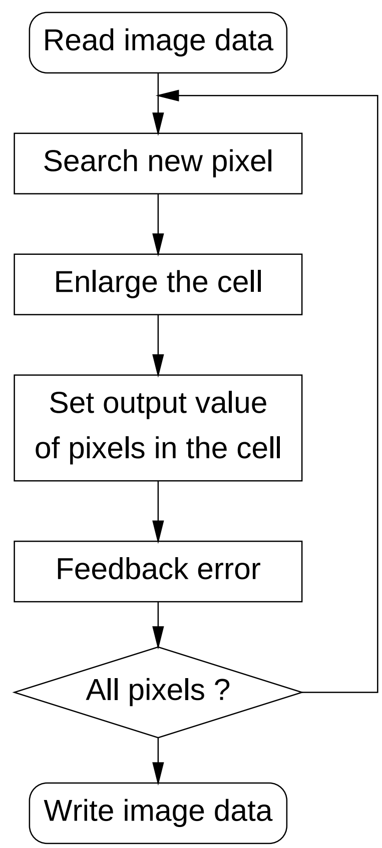


Figure 1: Flowchart of the proposed halftoning method.

This process proceeds cell by cell, not in scan line order, so that the positions of a pixel which has already been processed must be recorded in a special memory buffer, referred to as the "process marked buffers". Also this method uses error buffer memory which plays the same role as the error diffusion method.

Figure 1 shows the flow chart of the proposed process, and details of each step are described blow.

1. Search for an unprocessed pixel.
   Read processed mark buffer in scan line order until a pixel marked as unprocessed (0) is found. This is the first pixel of the current cell.

2. Enlarge the cell.
   Search next unprocessed pixel adjacent to the current cell, following a predefined search position order, adding each input and error value of the new pixel, until the sum becomes greater than 256. Examples of the search position order used in this step are shown in Figure 2. To ensure the randomness of the dot profile, plural number of order tables are prepared and one is selected randomly for each cell.

3. Set output value of pixels in the cell.
   The cell composed in the above step have more than 256 input (and error) values. Thus one pixel in the cell should be set as ON. The position of the ON pixel is determined as follows. Assume the x,y coordinate of the i-th pixel in the current cell as x_i, y_i, and the input pixel value as I_i. Then the coordinate of the weighted center is

   $$(\frac{\sum_i x_i I_i}{\sum_i I_i}, \frac{\sum_i y_i I_i}{\sum_i I_i})$$

   The pixel nearest from the weighted center of the cell is selected to be set ON. This calculation is to prevent blurring of the edge in the cell as shown in Figure 4. If the position of the weighted center is outside the cell, the nearest pixel inside the cell is selected.
   After that, the processed mark buffer at each position of the pixels inside the cell is marked as processed (1).

4. Feedback error value.
   The average value of each cell is a discrete value, i.e. 1/N. To decrease the tone gap, the error value in a cell is calculated by subtracting the output pixel value (255) from the sum of input and error values and recorded at the position of the unprocessed pixel nearest and right below the ON pixel (Figure 3).

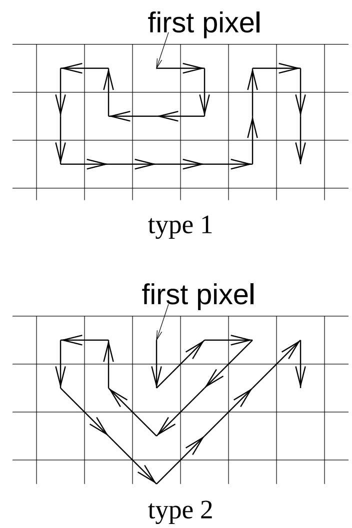


Figure 2: *Search order in the cell enlarging step*

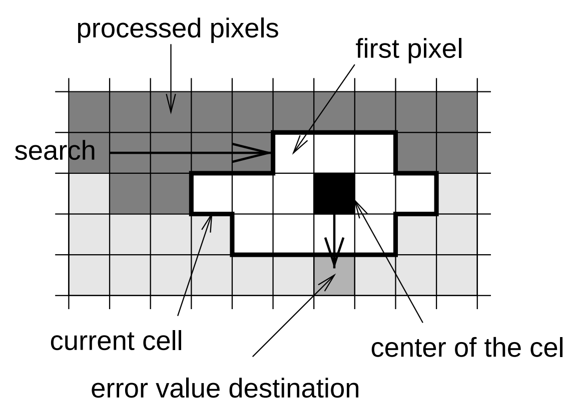


Figure 3: *Example of a cell*

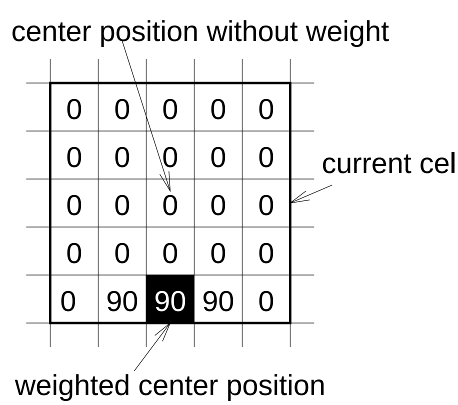


Figure 4: *Weighted center*

In this method, the larger a cell then the more operations are required but, at the same time, more pixels are processed. Pixels once assigned to a cell are never processed except for processed mark memory access. Here we can estimate the computation cost of this method by counting the required operations per one pixel. They are, two additions for input and error value in the cell enlarge step, and two additions and two multiplications in the calculation of center position. This cost is less or equal to the cost of most simple error diffusion methods.

2.2. Minimum cell size restriction

In the method described above, the position of the ON pixel is decided without information outside the cell. Thus the connection of an ON or OFF pixel makes clamps which increase the low frequency noise (Figure 5). In order to avoid the dot conjunction to neighboring cells, we can restrict the minimum cell size, and the appropriate number ($= int(\sum_i I_i/256)$) of pixels adjacent to the weighted center position are set ON.

This restricted method produces clustered dots which are larger than the single pixel dots. If the minimum cell size is restricted to 16 pixels the period of clustered dots is typically 4 pixels. With a 400dpi printer, these clustered dots make a 4/400 = 0.01 inch = 0.25mm period, which is visible and unpleasant. But with a 1200dpi printer, a 4/1200 = 0.003 inch = 0.08mm period may be invisible in ordinary viewing conditions. It should be stated that this period is the same as that of a conventional error diffusion with a 600dpi printer in middle tone, which is visually pleasant. On the other hand, in high density printers, stability of isolated dots may be a more important factor than the size of a clustered dot. Therefore, though it depends on actual printer characteristics such as dot size or noise level, it is likely that the minimum size restriction decreases the granularity.

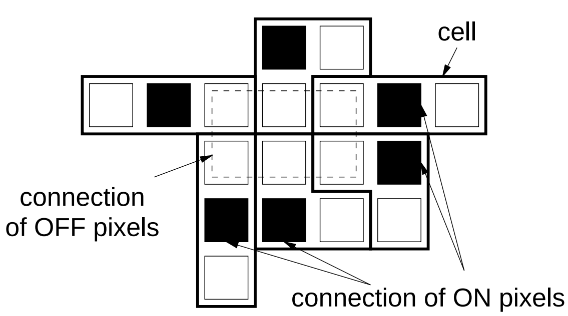


Figure 5: *Clamps due to the connection of ON or OFF pixels*

3. Result and discussion

Figure 6(a)-(d) shows the result of halftoning processes, error diffusion, blue noise mask, adaptive cell method, and adaptive cell method with minimum size restriction (minimum 16 pixels). The upper side of each sample is the full range (0-255), and the lower side is the hilight range (0-16) of gray scale ramp. As expected, we find the following characteristics in these samples.

(a) error diffusion Dots tend to align in lines in hilight tone, which increase low frequency noise and are visually annoying.

(b) blue noise mask Hilight tone is granular because the variance of the distances between neighboring dots is large.

(c) adaptive cell In the lower side the distances between neighboring dots are almost constant, so the image is less granular. But in middle tone in the upper side the connection of dots make it noisy.

(d) adaptive cell with minimum size restriction The lower side is the same as the result of adaptive cell(c). In the upper side, clustered dots are visible in middle tone because this sample is printed in 120 dpi. They are smaller and less visible if printed by higher density printers.

4. Conclusion

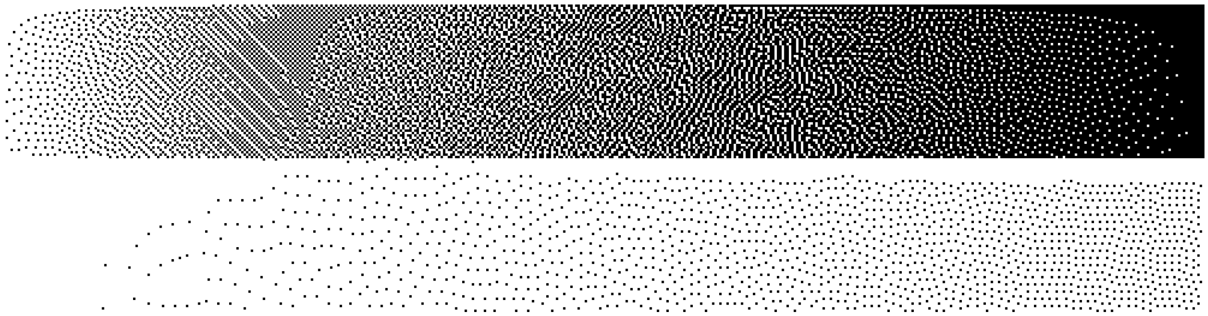
We developed a new halftoning method, which produces a low granularity hilight image. The produced images are stable because they are composed of clustered dots. The algorithm is straight forward and the computation cost is less or equal to most simple error diffusion methods. This halftoning method is suitable for high density electrophotographic printers.

References

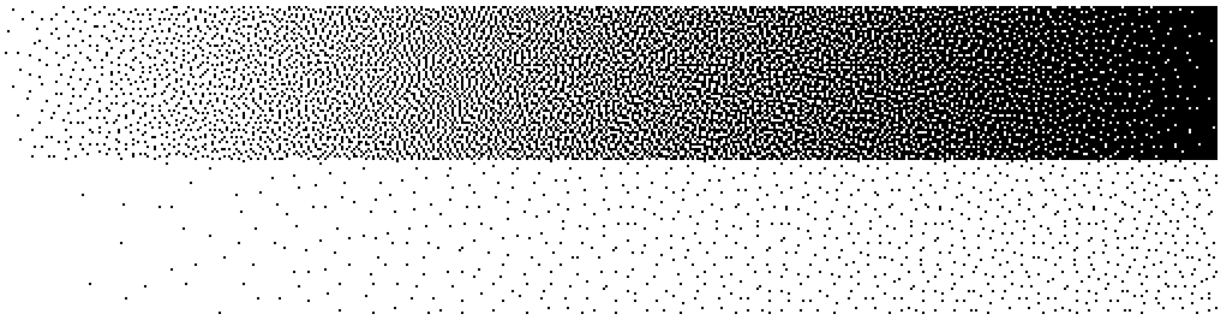
1. Robert Ulchney, “Digital Halftoning”, MIT Press (1987).
2. Theophane Mitsa and Kevin J. Parker, “Digital halftoning technique using a blue-noise mask”, J.Opt.Soc.Am. A, Vol.9, No.11, (1992).
3. Qing Yu, Kevin J.Parker, and Meng Yao, “Optimality of Blue Noise Mask Binary Patterns”, IS&T NIP12 (1996).
4. S. Gooran, M Österberg and B. Kruse, “Hybrid Halftoning – A Novel Algorithm for Using Multiple Halftoning Techniques.”, IS&T NIP12 (1996).

Biography

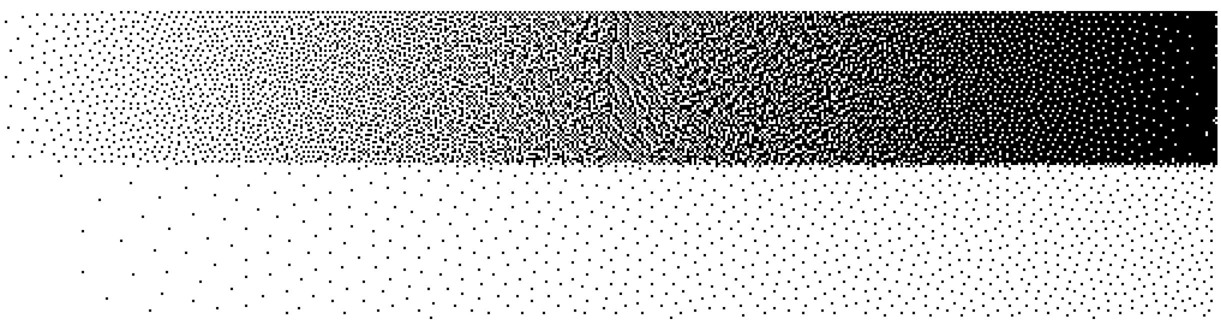
Shin Aoki was born in Tokyo, Japan in 1965. He received his M.E. degree from the University of Tokyo in 1990. Then, he joined R&D center of Ricoh Co.Ltd,. He is a researcher engaged in the development of digital image processing and color hard copy technologies.



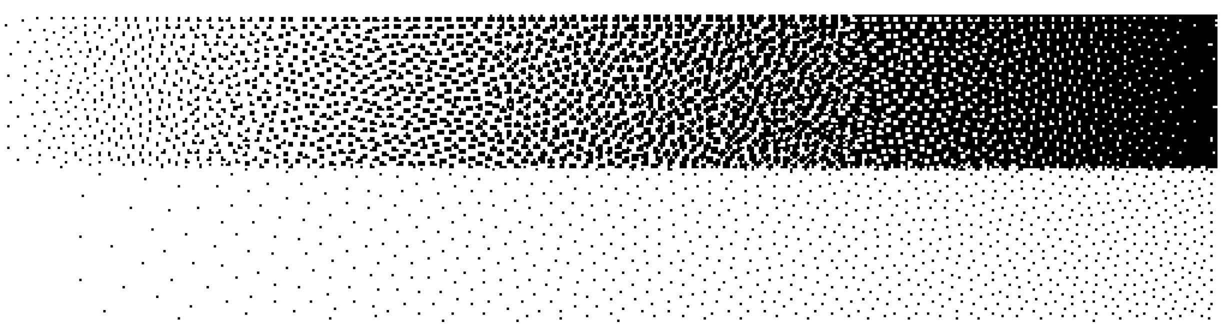
(a) Error diffusion.



(b) Blue noise mask.



(c) Basic adaptive cell method



(d) Adaptive cell method with minimum cell size restriction.

Figure 6: Result of halftoning processes.