Dispersed Micro-Cluster Halftoning

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Abstract

A new class of halftone screens is proposed. This approach integrates the frequency modulation, multi-center dot, and super cell to create micro-cluster dots having high screen frequency and high tone level. A general multi-center dot scheme and a technique for optimally dispersing pixels in an N × N array are developed. The stochastic randomization can be introduced to perturb the rigid structure of the subcell nuclei. Once the nuclei are established, the clustered-dot order dither is used for further dot growth. Subcells can grow in any pattern and in any direction. The purpose is to give a pleasing pixel distribution (e.g. blue noise). A high precision for 15° and 75° screen angles is achieved. In addition, this class of halftone screens can be described by the Holladay algorithm to have a very low implementation cost, low computation cost, and fast processing speed. Outputs of dispersed microcluster screens give an appearance of high frequency, high tone level, and smooth transition of gray ramps. It produces good images for text, graphics, and pictorials.

Introduction

In halftone printing, there is a tradeoff in the screen frequency and tone level. It requires high frequency screens to reproduce image details. For printing devices with middle and low resolutions, a high frequency screen means a small cell size. The smaller the cell size, the less tone levels it can render. Thus, false contouring appears. If one wants to remove contouring by increasing the cell size, the dot becomes coarse and the details will be lost. Many techniques, such as the multi-center dot, dispersed dot, super cell, and frequency modulation, have been developed to overcome this problem. In this paper, we present a new approach, called the micro-cluster dot, for dealing with this tradeoff problem.

Algorithm

The micro-cluster halftoning is based on the frequency modulation, super cell, and multi-center dot approaches. We integrate these methods and apply them in stages as shown in Figure 1. This method can be applied to any N × N screens and any screen angles allowed in a two-dimensional digital grid. First, a halftone cell is divided into small subcells using a general multi-center dot scheme developed herein. The frequency modulation is used to disperse pixels among subcells. An algorithm is invented to optimally disperse pixels in N × N arrays. If rigid structures occur during the distribution of nuclei, a stochastic randomization can be introduced to perturb the rigid structures. Once the nuclei are established, the classical clustered-dot order dither is used for further dot growth. This dispersed micro-cluster halftoning is illustrated by using a 75°, 241-level screen. The cell is divided into 25 small subcells (see Figure 2); each has nine or ten pixels. This subdivision increases the apparent screen frequency by fivefold. The preferred subcell size is from 6 to 32 pixels depending on the printer resolution. The lower limit can go as low as one pixel; in that case, it is a pure dispersed dot. For medium to high resolution printers (600 dpi and above), a larger subcell can be obtained. The key is to keep the screen frequency high, greater than 150 lpi if possible. For N × N division, each side of the halftone cell is equally divided by N, then lines are drawn to connect the corresponding division points. Note that the size and shape of subcells are not the same as shown in the heavy dashed lines of Figure 2. The rule is that a pixel with a half or more of its area inside the subcell boundary is included in the subcell.

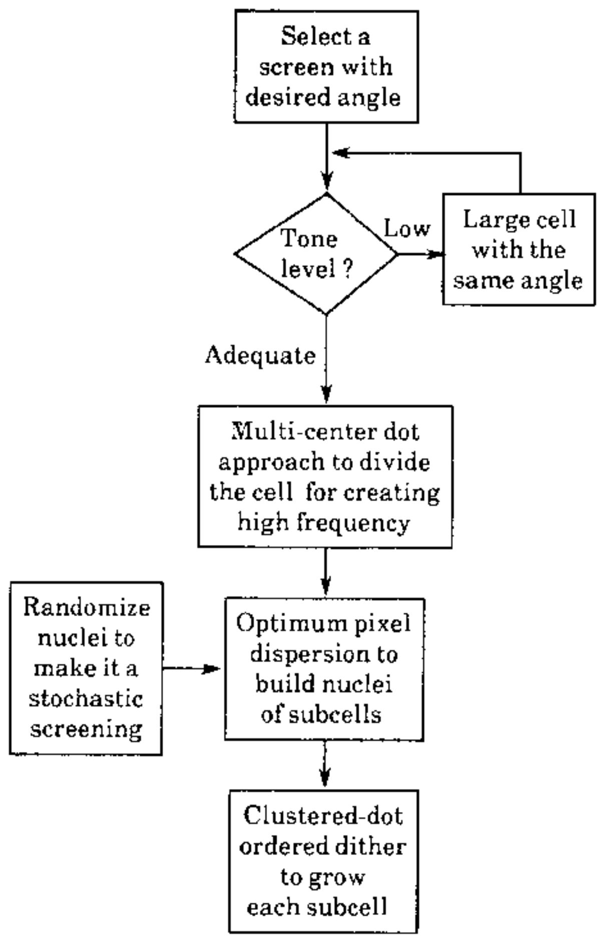

Figure 1. The schematic diagram of the micro-cluster halftoning.

The next step is to assign dot pattern to the screen. Any dot patterns, either a spiral, a classical, or a line pattern in any direction (clockwise or counterclockwise) can be used. To make a screen even more irregular, a mix of several patterns (one for each subcell, for example) may be attempted. Whatever pattern is chosen, the pixel will be turned "on" in a rotating order among all subcells according to a selected sequence. Figure 2 depicts the first 25 levels using an optimum 5 × 5 dot sequence. After nuclei are established, each subcell is grown into a conventional clustered-dot. The order of increment is the same as in the first 25 pixels. Two examples of the micro-cluster dot growth, microdots #1 and #10, are shown in Figure 2.

The nuclei within an N × N array are arranged by using an optimum pixel dispersion scheme. It is based on the assumption that an additional pixel is put in a place where the average distance from neighboring pixels is the highest and the variance is the lowest, to maintain as far as possible an approximately equal distance to all nearest neighbors. In view of this criterion, we design a measure Λ for optimizing dispersion.

$$\Lambda = \sum_{i}^{k} \left| d_{\mathrm{i}} - d_{ave} \right| / d_{ave}$$

where d_i is the distance between the added pixel and one of the nearest pixels, and d_{ave} is the average distance of d_i with i from 1 to k. The smaller the Λ the better a pixel is dispersed. The k value is usually chosen as a 4 to have one pixel in each direction, or the added pixel is in the convex hull enclosed by 4 nearest pixels. This approach is illustrated by a 3 × 3 array in Figure 3.

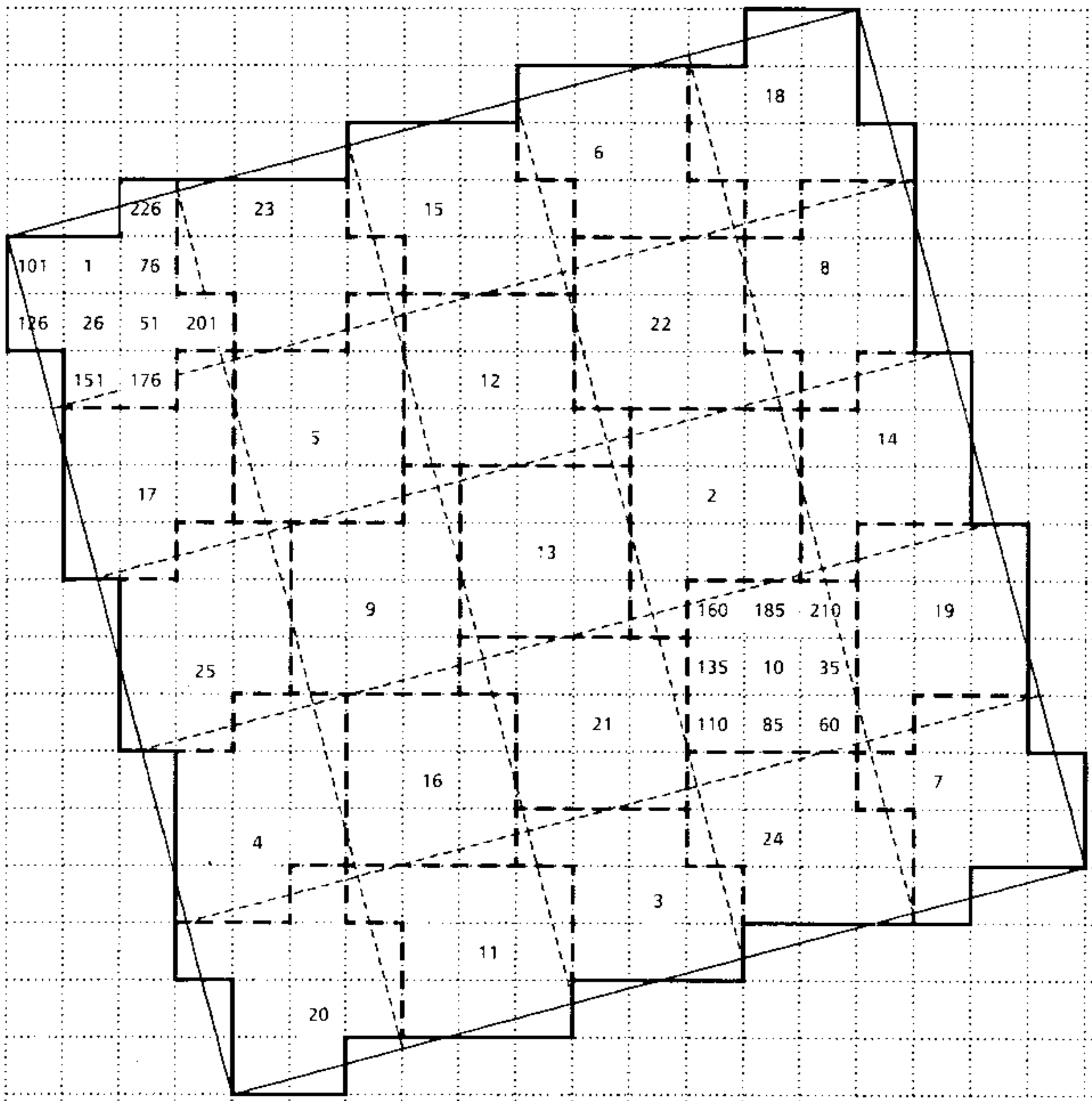

Figure 2. An example of the dispersed micro-cluster dot using a 75°, 241-level screen.

1. The Position of the First Pixel in the 3 × 3 Array is Arbitrary

In this example, we put the first one in the upper-left position p(1,1). To place the second pixel, positions p(2,1), p(3,1), p(1,2), and p(1,3) have the same arrangement with its nearest neighbors. The remaining positions are the same also. Thus, there are only two choices to place the second pixel either p(2,1) or p(3,2), designated as x and y, respectively, in Figure 3a.

2. Compute the Distances to the Nearest Pixels

For p(2,1), the distances to four neighbors are 1, 2, $\sqrt{10}$, and $\sqrt{10}$, respectively. The average distance is 2.33 and Λ is 0 113. For p(3,2), the distances are $\sqrt{2}$, $\sqrt{5}$, $\sqrt{5}$, and $\sqrt{8}$. The average is 2.17 and Λ is 0.07. From this computation, we choose p(3,2) for the second pixel because the measure Λ is smaller.

3. Continue this Computation for the Third Pixel

From the symmetry, P(2,1), P(2,2), P(1,3), and P(3,3) are the same (see Figure 3b); their distances to the nearest four neighbors are 1, $\sqrt{2}$, 2, and $\sqrt{5}$. The average is 1.66 and Λ is 0.241. Positions P(3,1) and P(1,2) are the same; their distances are 1, 1, 2, and 2. The average is 1.5 and the Λ is 0.395. The last one p(2,3) has a Λ of 0.148. Therefore, the third pixel is placed in position p(2,3) as shown in Figure 3c.

4. Continue this computation until there are only single pixel holes.

5. Fill the hole that has the shortest distance between holes and smallest Λ.

Continue the same computation as Step 2 until all holes are assigned a value.

The resulting optimum pattern for 3 × 3 array is:

1	4	6
7	9	2
5	3	8

It is interesting to point out that the Bayer dot sequence is the output of this technique when applies to the 4 × 4 pixel array.

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

Using this algorithm, we determine an optimum dot sequence for the 5 × 5 array which is used for setting up the nuclei in Figure 2.

1	15	23	6	17
24	5	12	21	8
16	9	25	2	13
4	18	14	10	22
20	11	3	19	7

This general dot dispersion scheme, in fact, is not limited to N × N arrays; it can be stretched to derive the optimum dot sequence for N × M arrays. The measure Λ and computations remain the same as in the case of N × N.

Several images are printed using a xerographic printer. The resulting prints show sharp text, low noise in flat areas, smooth gray ramps, and no moiré patterns. The dispersed micro-cluster halftoning seems to have the best of both worlds.

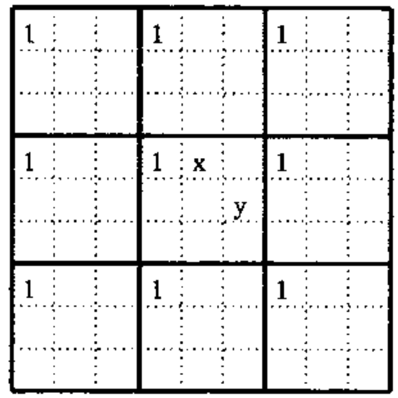

Figure 3a. One pixel in a 3×3 array

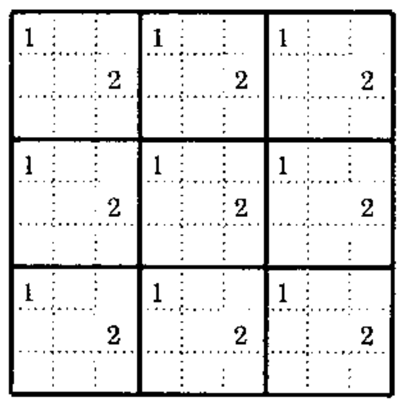

Figure 3b. Two pixels is dispersed in a 3×3 array

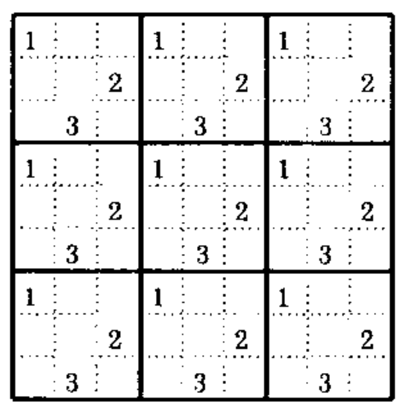

Figure 3c. Three pixels is dispersed in a 3×3 array

Summary and Conclusion

The dispersed micro-cluster halftoning provides many advantages, the important ones are:

- It can apply to any digital halftone cells.
- It provides both high frequency and high tone level screens.

- It gives smooth transition of gray levels.
- It introduces irregularity into often rigid halftone patterns.
- It adds many more angle-frequency-level combinations that are unattainable by the rational tangent screens.
- It provides a variety of ways for arranging the dot size, dot shape, and dot pattern.
- It uses threshold array approach; therefore, it can be implemented in a two-dimensional look up table using Holladay's algorithm which is the most efficient way of implementing halftone screens. It is very easy to implement.
- The memory requirement and computation cost are very low.
- The processing speed is fast.
- It can achieve a high precision for 15° and 75° s creens by increasing the cell size. A super cell can be used, if a high precision is required.

References

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