Color Stochastic Screening with Smoothness Enhancement

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Abstract

This paper describes a novel color stochastic screening with smoothness enhancement to achieve high quality, high resolution color halftones. Stochastic screening is an im-proved dither halftoning process to produce halftones close to error diffusion quality but much faster in performance. Our technique first applies Voronoi tessellation and its region areas to determine the locations of largest voids or tightest clusters, then applies a void-and-cluster algorithm to redistribute the dots in the screen to achieve homogeneous dot distribution for all tonal levels. We then adaptively adjusts CMY(K) color screens to minimize the interference between colors by optimizing halftone frequency to achieve overall smoothness and high quality halftones.

Experimental results are presented to show the effectiveness of the presented technique.

Introduction

Digital halftoning is essential for printing applications. It converts a continuous-tone image (e.g., a scanned photo-graph) into a halftone image which is in binary format printable by normal digital printers. Although a halftone image is a binary image whose pixel value is either 1 or 0 corresponding to a color or white, the image looks, from a distance, as though it has intermediate tones ranging from color to white due to varying halftone dot sizes or densities by the halftoning process. For color halftoning, 24 bit/pixel continuous tone images may be converted into 3 or 4 bit/pixel for CMY or CMYK (i.e., Cyan, Magenta, Yellow, blacK) colors (1 bit/pixel per color). Halftoning has been widely used for ink jet printing, laser printing, and printing press. Many techniques were developed [1-3].

Among the techniques, error diffusion approach usually produces better halftone quality than dithering but slower in performance.

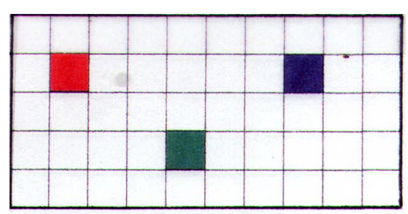
Stochastic Screening

Stochastic screening [4-8] is an improved dither method in order to produce halftone quality close to error diffusion but much faster in performance. Stochastic screening applies dither matrices which usually have much larger size than conventional dither matrix size. Enlarged dither matrix size is no longer designed by hands but by computer programs of stochastic procedures in either spatial domain [4,5,7,8] or frequency domain [6]. Larger dither matrix size increases freedom of manipulating halftone dot distribution to achieve higher quality halftones.

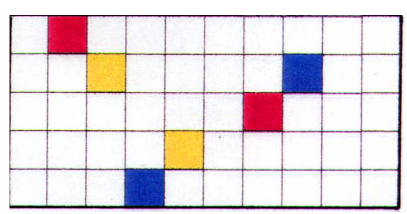
There are various ways to construct a good stochastic screen for a single color. However, stochastic screening for multiple colors (e.g., CMYK colors), color interference (i.e., visible noises) between colors is a common artifact which degrades color halftone smoothness. It was the objective of this research to develop an improved color stochastic screening technique to solve the problem to achieve minimized color interference noise and maximized smooth fidelity.

CMYK Color Printing

For a CMYK (i.e., Cyan, Magenta, Yellow and blacK) color printer (e.g., a color ink jet printer), the printer is capable of printing only eight possible colors: CMYK and RGBW (Red, Green, Blue and White). R color is printed by M+Y, G is printed by C+Y, and B is printed by C+M. The C, M, or Y are printed by a single C, M, or Y ink. White means no ink is printed. In light tone area, a R, G, or B can print two of C, M or Y colors, one on top of the other, or can print the two colors at different pixel locations. The latter has twice frequency comparing to the former. For light gray, a K dot can be printed, one C, M and Y are printed at different pixel locations, or CMY are printed at same position (i.e., composite black). Printing three dots at three different locations results three times dot frequency than printing a single dot or three dots on same pixel location.

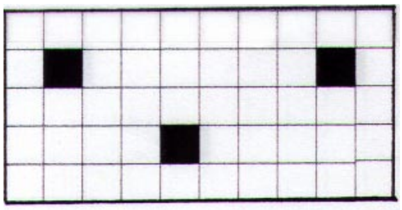


(a) R, G, B dots

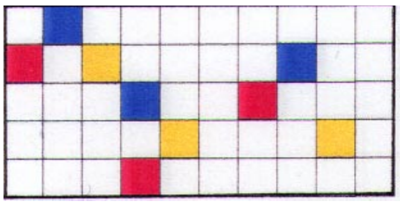


(b) Replaced by C, M, Y dots

Figure 1. Replace RGB by C,M,Y increases dot frequency by 2



(a) K dots



(b) Replaced by C, M, Y dots

Figure 2. Replace K by C,M,Y increases dot frequency by 3

Color Halftone Smoothing Factors

Three design goals for smoothing color halftones consist of: (1) increasing halftone frequency, (2) ordering print color priority, and (3) optimized the basic stochastic screen.

Higher halftone dot frequency produces visually smoother halftones. However, for midle or dark tone area, we may not have enough empty pixel spaces to place single CMY color dot without overlap dots each other. Nevertheless, to replace RGBK by CMY dots as many as possible increases halftone smooth fidelity, and is one of our technical design goals.

The other visual effect is that dots from different colors have different visibility. The visibility of the 8 printable colors are normally in the descendant order: K, B, G, R, M, C, Y, W. Therefore, this order is the priority to be taken care for the eight colors for improving smoothness in mixed color areas. This is another design goal of our technique.

To design the basic stochastic screen (i.e., a dither matrix with N by M size, e.g., N = M = 512) for one color, we used the technique [8] which applies Voronoi tessellation and areas of Voronoi regions to determine the locations of largest voids or tightest clusters, then applies a void-and-cluster algorithm to redistribute the dots in the screen to achieve homogeneous dot distribution for all tonal levels (0 to 255 for a 8bit/pixel system). Dithering process using the generated dither matrix makes optimized uniformity of dot distribution from light to dark tones (i.e., level = 0, 1, 2, Ö, 255). The ranking of the dither matrix elements suggests the dot count growth for optimized homogeneous dot distribution for any given tone level.

We then adjust the matrix according to the input continuous-tone color, (C,M,Y,K) to accomplish increased frequency and color ranking objectives. Thus it results high-quality smooth halftones.

Eight Color Dot Count Calculation

Given a continuous-tone input color (C,M,Y,K), where CMYK are ranged from 0% to 100%, we can derive dot counts of eight possible colors for a CMKY printer: K, K_C (composite black, C+M+Y), B (C+M), G (C+Y), R (M+Y), C, M, and Y, denoted by N_K, N_{C+M+Y}, N_{C+M}, N_{C+Y}, N_{M+Y}, N_C, N_M, and N_Y, as follows:

N_{C+M} = C + M -100%
N_C = C - N_{C+M}
NM = M - N_{C+M}
Total_Print_Dots = N_{C+M} + N_C + N_M

Y first fill white space. If there are not enough white space, then put extra Y on top of N_C then N_M then N_{C+M}.

White_Dots = 100% - Total_Print_Dot
Dot_On_Dot = Y - White_Dots
= Y - (100% - N_{C+M} - N_C - N_M)

if (Dot_On_Dot < 0)
    N_Y = Y
else if (Dot_On_Dot - N_C < 0) {
    N_{C+Y} = DOD
    N_C = N_C - Dot_On_Dot
}
else {
    Dot_On_Dot = Dot_On_Dot - N_C
    N_{C+Y} = N_C
    N_C = 0
}

if (Dot_On_Dot - N_M < 0) {
    N_{M+Y} = Dot_On_Dot
    N_M = N_M - Dot_On_Dot
}
else {
    Dot_On_Dot = Dot_On_Dot - N_M
    N_{M+Y} = N_M
    N_M = 0
    N_{C+M+Y} = Dot_On_Dot
}

By the calculation, color dots are optimized for highest print dot frequency at all possible color inputs. That is, CMYK color dots overlap are minimized.

Adaptive Dithering Process

After calculating eight color dot count, we adjust the basic dither matrix to produce these color dots with uniform color dot distribution. The process is described as follows:

DM = the basic dither matrix
if (N_K >= DM) K = On
DM = DM - N_K
if(N_{C+M+Y} >= DM) C=M=Y=On
DM = DM - N_{C+M+Y}
if (N_{C+M} >= DM) C=M=On
DM = DM - N_{C+M}

if (N_{C+Y} >= DM) C=Y=On
DM = DM - N_{C+Y}
if (N_{M+Y} >= DM) M=Y=On
DM = DM - N_{M+Y}
if (N_C >= DM) C=On
DM = DM - N_C
if (N_M >= DM) M=On
DM = DM - N_M
if (N_Y >= DM) Y=On

The most visible color (K) dots are turned on first, second visible dot (C+M+Y) dots are tuned on secondly, until the least visible color (Y) dots are turned on last. All color dots are turned on according the basic dither matrix element ranks.

Performance Improvement

In order to speed up performance, the color dot count calculation and dithering process can be limited to fewer colors. Some colors, e.g., Y, are not so visible. Therefore, we do not need to care too much the dot placement uniformity for these non-visible colors. This reduces process load and increases performance. One way to do it is to calculate only N_C+M, N_C, and N_M, and dither Y using the reverse of basic dither matrix.

N_{C+M} = C + M -100%
N_C = C - N_{C+M}
N_M = M - N_{C+M}
IDM = 100% - DM
if (N_K >= DM) K = On
DM = DM - N_K
if(N_{C+M} >= DM) C=M=On
DM = DM - N_{C+M}
if(N_C >= DM) C=On
DM = DM - N_C
if(N_M >= DM) M=On
if(Y >= IDM) Y=On

The N_{C+M}, N_{M+Y}, and N_{C+M+Y} are not calculated, and let dithered Y to either on white space or on top of other color dots.

Experimental Results

Figure 3 shows a stochastic screen result using same dither matrix for CMYK colors. The dither matrix was generated by [8]. Figure 4 shows the stochastic screen result with smoothness enhancement using same basic dither matrix as used in Fig. 3 but with adjustment for different colors as described in this paper. Fig. 5 shows a halftoned gray patch using stochastic screen without smoothness enhancement, same as in Fig. 3. Fig. 6 shows a halftoned gray patch using stochastic screen with smoothness enhancement same as in Fig. 4. All sample images were printed on an Epson Stylus 600 color ink jet printer at 720 by 720 dpi print resolution.

As shown, the presented technique produces much improved halftone quality.

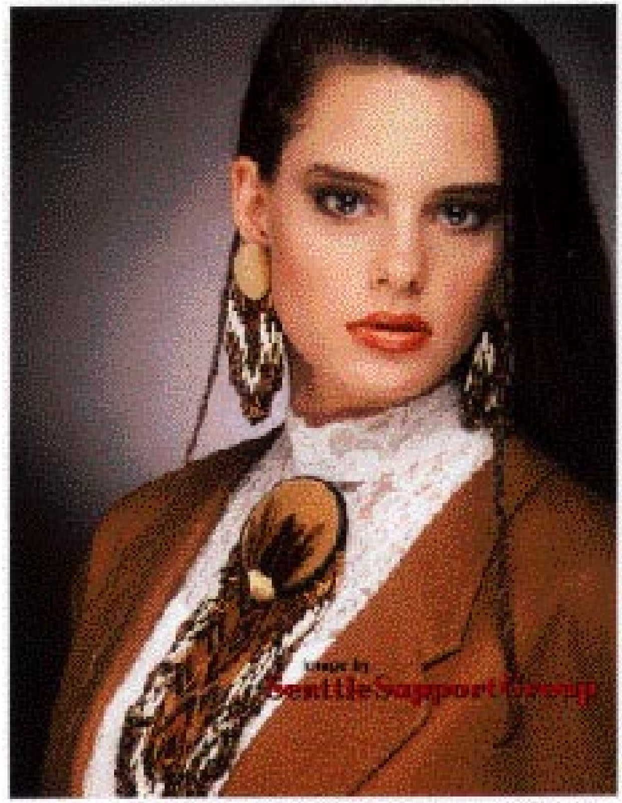


Figure 3. Stochastic screen without smoothness enhancement

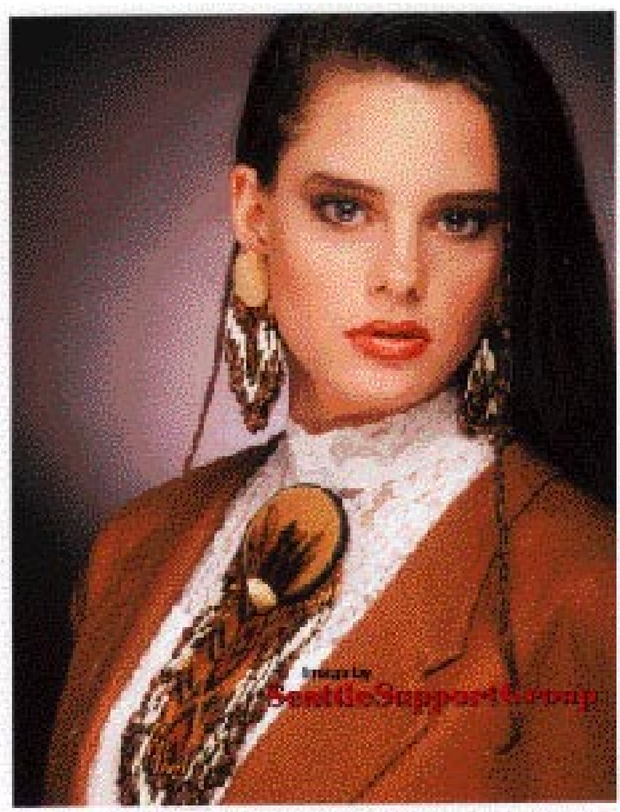


Figure 4. Stochastic screen with smoothness enhancement font.

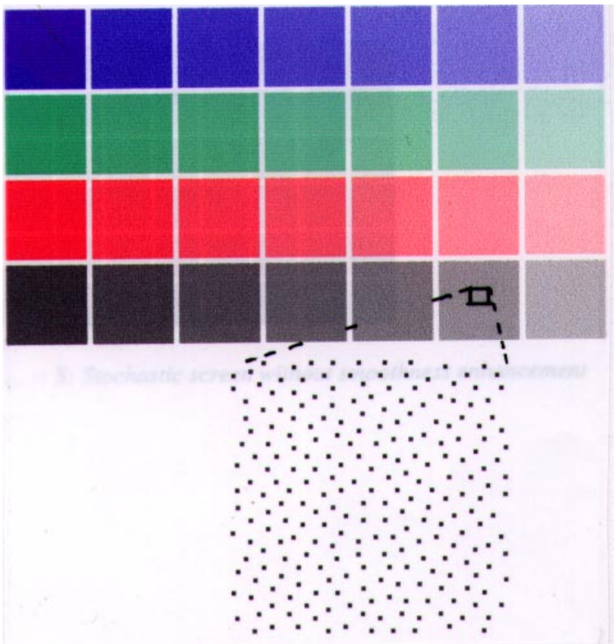


Figure 5. Stochastic screen without smoothness enhancement

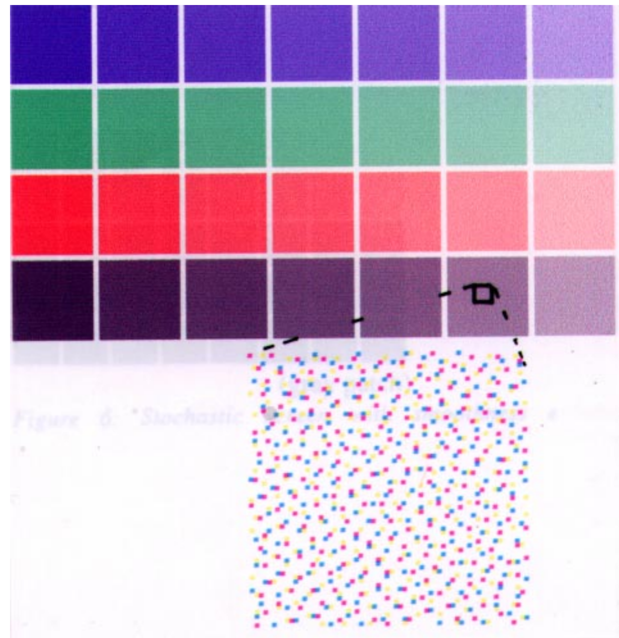


Figure 6. Stochastic screen with smoothness enhancement

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The author(s) have provided replacement color figures for this paper, to enhance the papers' content via CD viewing.