Color Halftoning with Blue Noise Masks

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Abstract

Color halftoning using a conventional screen requires rotating the screen by different angles for different color planes to avoid Moiré patterns. An obvious advantage of halftoning using a Blue Noise Mask (BNM) is that there are no screen angles or Moiré patterns. However, a simple strategy of employing the same BNM on all color planes is unacceptable in cases where a small registration error can cause objectionable color shifts. In a previous paper, we proposed shifting or inverting the BNM for different color planes. The shifting technique can, at certain shift values, introduce low frequency contents into the halftone image, whereas the inverting technique can be used only on two color planes. In this paper, we propose a technique that uses four distinct BNMs that are correlated in a way such that the low frequency noise resulting from the interaction between the BNMs is significantly reduced.

Introduction

Halftoning a color image is a much more complicated issue than halftoning a greyscale image. All the qualities required of black and white halftone images apply to color halftone images that are composed of multiple color planes, but, in addition, the interactions between color planes must be controlled. Color halftoning is the process of generating halftone images for the different color planes, for example, cyan, magenta, yellow and/or black for a printing device. A straightforward way of halftoning a color image would be to use the same halftone technique that is applied to a greyscale image, to the color planes separately. For example, the same clustered-dot kernel can be used to halftone the C, M, Y, K planes separately to obtain four halftone images. These four halftone planes are then used to control the placing of color on paper. This technique is simple and easy to implement, but it has its problems. In conventional clustered-dot halftoning, one immediate problem of such simple technique is the appearance of Moiré patterns where misregistration problems occur. Moiré patterns are caused by the low frequency components of the interference of the color planes. To avoid Moiré patterns, the screens are typically oriented at different angles, usually about 30°apart. At 30° separation, the Moiré is at about half the screen frequency, thereby producing a high-frequency "rosette"-shaped beat pattern.[1] Typically, cyan and magenta are oriented at ±15°, yellow at 0°, and black at 45° in order to minimize visible rosette beat patterns. This angle selection for clustered-dot halftoning can be a limitation in the case of hi-fi color printing. Recently, one direction of research on color printing is the introduction of more colors in the printing process to expand the color gamut imposed on the CMYK colors. These extra colors must be assigned a rotation angle to eliminate Moiré patterns. However, there is a limit to the number of angle selections, otherwise Moiré patterns will arise when two color planes are not sufficiently rotated. Stochastic halftoning such as the Blue Noise Mask (BNM)[2] and error diffusion[3] eliminates this problem completely. The dots created by stochastic screening are randomly placed, thus screen rotation is unnecessary in halftoning color images. But stochastic screening has its own problems in halftoning color images. For error diffusion, the resulting correlated patterns can be objectionable; for the BNM, periodic tiling patterns can be more noticeable as more color planes are overlayed.

To improve the visual quality of color halftoning using error diffusion, Miller and Sullivan[4] treat the color image as a vector space. Instead of halftoning the color components separately, they halftone each pixel as a color vector (also called vector error diffusion). The color image is first converted to a nonseparable color space (for a separable color space, vector error diffusion gives the same results as scalar error diffusion), and the pixel is assigned to the halftone color that is closest to it in the color space. The vector error is distributed to neighboring pixels in the same manner as scalar error diffusion. Klassen et al[5] also proposed a vector error diffusion technique that minimized the visibility of color noise. It is based on the property of the human visual system that the contrast sensitivity decreases rapidly with increasing spatial frequency.[6] Thus the minimum contrast for which noise is visible rises rapidly with increasing spatial frequency. One approach to achieve increased spatial frequency is to avoid printing pixels that have a relatively high contrast with the pixels in their neighborhood. Thus, light grey is printed using non-overlapping cyan, magenta, and yellow pixels, along with white ones.

Color halftoning using a BNM has been studied by Yao and Parker.[7] In the next section, we will explain these techniques and point out their problems. Then we will propose a new technique to improve the quality of color halftone images.

Blue Noise Mask Techniques in Color Halftoning

Previous Techniques

We mentioned that using the same halftone screen on the different color planes is the simplest way to produce color halftoned images. This technique can be used directly with the BNM color halftoning. We call it the dot-on-dot technique. Unlike a clustered-dot screen or the

Bayer's dither array which generate structured dot patterns, the dots produced by the BNM are unstructured, thus reducing Moiré patterns to the minimum. A potential problem of this technique is when a misregistration of the color planes occurs, which will have a disturbing banding effect. Thus, the dot-on-dot technique can be inappropriate for some printers.

To decrease the correlation of the color planes, we can use shifted BNMs. This will also increase the spatial frequency of the printed dots. For example, we can use a BNM on the cyan plane, then shift the BNM in the horizontal and vertical directions in a wrap-around manner and use the shifted BNM on yellow. Similarly, the BNM can be shifted by different amounts to be applied to magenta and black. This technique will tolerate misregistration problems that would produce a banding effect with the dot-on-dot technique. However it is difficult to control the behavior of the patterns when a pattern is overlapped with its shifted version and low frequency structures may appear at certain specific shift values.

Another technique uses an "inverted" BNM for a color plane. Inverting a BNM means taking the complement of a BNM:

$$m_i(i,j) = 255 - m(i,j)$$

where $m_i(i,j)$ is the inverted mask. Using a BNM and the inverted BNM results in the highest spatial frequency and yields better patterns than the shift technique. However, this strategy is appropriate for only two BNMs, a BNM and its inverted version, whereas a color image has three or more color planes.

A New Technique

The new technique we propose here is an extension of the invert technique. The new approach is based on the same idea, i.e., increasing the spatial frequency of the pattern of dots, but this new technique will not limit the number of BNMs that can be used as the invert technique does, so it is more appropriate for halftoning color images with multiple color planes.

The first step is to generate a BNM that produces visually pleasing unstructured binary patterns. Then four separate seed patterns are made from this BNM to be used as starting patterns to generate four different BNMs for the color planes. Assuming that the BNM values are between 0 and 255, for all the locations that have a value between 0 and 63 (including 0 and 63), we make a binary pattern by setting the pixels corresponding to those locations to black dots, while the remaining pixels are white dots; for all the locations that have a value between 64 and 127 (including 64 and 127), we make a second binary pattern by placing black dots on those locations and placing white dots on the remaining elements of the BNM. Similarly, we make a third binary pattern from values between 128 and 191 and a fourth binary pattern from values between 192 and 255. All the four binary patterns correspond to level 192, and there are no common black dots between any two of these binary patterns. The way these binary patterns are made ensures that they are blue noise patterns. The binary patterns made out of values between 64 and 127 and values between 128 and 191 may have some barely visible patterns. We can use our filtering technique to move a small number of pixels to eliminate the periodic patterns. Starting with the four seed binary patterns, we make four BNMs. When these BNMs are applied to color images, they will achieve the highest spatial frequency in highlight areas and the quality of the halftone images are significantly improved over the shift technique.

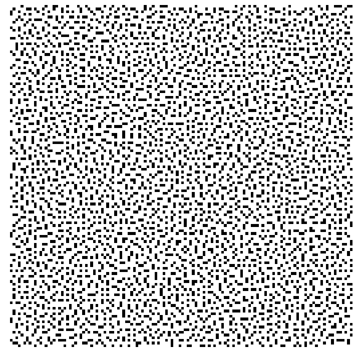

Figure 1. Seed pattern for cyan

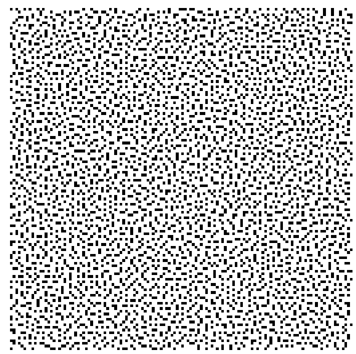

Figure 2. Seed pattern for magenta

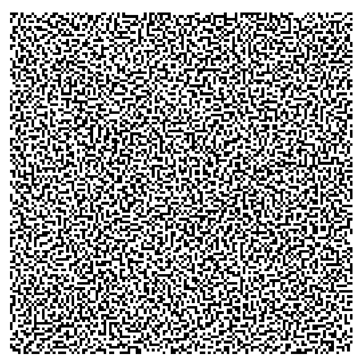

Figure 3. Cyan pattern overlapped with its shifted version

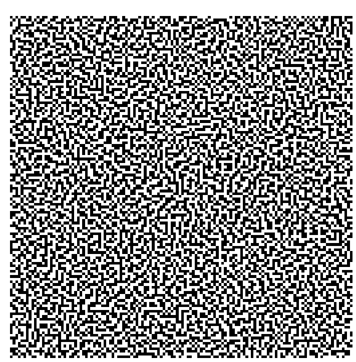

Figure 4. Cyan pattern overlapped with magenta pattern

The new technique is related to the invert technique. Actually, if we make two BNMs with the new technique by making seed patterns with mask values between 0 and 127 and mask values between 128 and 255, we end up with the BNM and the inverted BNM, which is just the invert technique. Thus, the invert technique is a special case of the new technique. The new technique is not limited by the number of color planes. We can make more than four BNMs using this technique, which will be useful in hi-fi color printing. Figure 1 is the seed pattern for cyan. Figure 2 shows the seed pattern for magenta. Figure 3 is the pattern obtained by combining the cyan pattern and the cyan pattern shifted by (5,9) (the shift technique). Figure 4 is the combination of the cyan pattern and the magenta pattern using the new technique. Color halftoning is assumed to be a multiplicative process in obtaining Figures 3 and 4, i.e., the dot is on if either cyan or magenta is on. The pattern in Figure 4 is obviously superior to the pattern in Figure 3.

Conclusion

We have introduced a new technique to halftone color images using BNMs. It is based on the idea of increasing the spatial frequency of printed dot patterns to make use of the reduced sensitivity of the human visual system at high spatial frequency. It makes a different mask for each different color plane and the number of masks that can be made is adjustable for hi-fidelity color applications.

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