Adaptive color halftoning for minimum perceived error using the Blue Noise Mask

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ABSTRACT

Color halftoning using a conventional screen requires careful selection of screen angles to avoid Moiré patterns. An obvious advantage of halftoning using a Blue Noise Mask (BNM) [1] is that there are no conventional screen angle or Moiré patterns produced. However, a simple strategy of employing the same BNM on all color planes is unacceptable in case where a small registration error can cause objectionable color shifts. In a previous paper by Yao and Parker [2], strategies were presented for shifting or inverting the BNM as well as using mutually exclusive BNMs for different color planes. In this paper, the above schemes will be studied in CIE-LAB color space in terms of root mean square error and variance for luminance channel and chrominance channel respectively. We will demonstrate that the dot-on-dot scheme results in minimum chrominance error, but maximum luminance error and the 4-mask scheme results in minimum luminance error but maximum chrominance error, while the shift scheme falls in-between.

Based on this study, we proposed a new adaptive color halftoning algorithm that takes colorimetric color reproduction into account by applying 2-mutually exclusive BNMs on two different color planes and applying an adaptive scheme on other planes to reduce color error.

We will show that by having one adaptive color channel, we obtain increased flexibility to manipulate the output so as to reduce colorimetric error while permitting customization to specific printing hardware.

Keywords: Blue Noise Mask, color halftoning, Moiré, CIE-LAB, luminance, chrominance, colorimetric color reproduction.

1. INTRODUCTION

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. Color image halftoning is significantly more complicated than halftoning a grayscale 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. In conventional clustered-dot halftoning, the same screen can be used to halftone the C, M, Y, K planes separately to obtain four halftone images. To avoid Moiré patterns when misregistration problems occur, the screen is typically oriented to different angles before being applied to color planes. Recently, one direction of research on color printing is the introduction of more colors to expand the color gamut. These extra colors must be assigned rotation angles to eliminate Moiré patterns. However, there is a limit to the number of angle selections. Therefore, it can be difficult to apply the conventional color halftoning technique to hi-fi color printing.

Stochastic halftoning using a Blue Noise Mask (BNM) eliminates this problem. The dots created by a BNM are placed in an unstructured pattern, thus screen rotation is unnecessary in halftoning color images.

2. HUMAN VISUAL SYSTEM

It is a well known property of the human visual system that the contrast sensitivity decreases rapidly with increasing spatial frequency.[3,4] Thus the minimum threshold above which patterns are visible rises rapidly with increasing spatial frequency. One approach to achieve increased spatial frequency so as to minimize the visibility of color halftone noise is to select wherever possible low contrast color combinations and to generate the finest possible "mosaic" pattern without large clumps. Therefore, light grey is printed using non-overlapping cyan, magenta, yellow pixels, along with white ones, as opposed to printing occasional K clusters on a large white background. These issues will be further explored in section 3 where we will give a brief review of different strategies that have been proposed to color halftoning using BNMs. A color patch will be halftoned with these schemes, and the output will be passed through a human visual model and studied in CIELAB space in terms of perceived color error. Based on this study, an adaptive scheme will be proposed to minimize the perceived error in color halftoning using BNMs.

3. BLUE NOISE MASK TECHNIQUES IN COLOR HALFTONING

We have developed the following schemes to apply the BNM to color planes.

3.1 The dot-on-dot scheme

The simplest application of the BNM utilizes the same BNM for each color plane and this is known as the dot-on-dot technique. Although this approach is the easiest for implementation, it is rarely used since it will give the highest level of luminance modulation and the output will be most sensitive to misregistration.

3.2 The shifted mask scheme

To decreased correlation of the color planes, we can employ a shifted BNM for halftoning each color plane. 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 magenta plane. Similarly, the BNM can be shifted by different amounts to be applied to yellow and black. This technique will tolerate misregistration problems. However, if the set of shifts is carelessly chosen, then low frequency structures may appear when a color pattern is overlapped with its shifted version.

3.3 The inverted mask scheme

In this strategy, we apply one mask to one color plane and its inverted version to another. Inverting a BNM means taking the 255 complement of a BNM. In light regions, this scheme results in the non-overlapping arrangement of color dots with high spatial frequency. However, it is only applicable for two color planes (typically Cyan and Magenta), therefore, some other scheme has to be used to determine at least one of the color planes.

3.4 The four-mask scheme

This scheme is actually an extension of the invert technique. Four anti-correlated BNMs are generated from four mutually exclusive seed pattern such that color dye is maximally dispersed to achieve high spatial frequency.

In a previous paper [5], an evaluation of these schemes is given in CIELAB space using a human visual model. Our analysis shows that different perceived errors are produced by different BNM techniques. In general, the dot-on-dot scheme results in minimum chrominance error but maximum luminance error and the four-mask scheme results in minimum luminance error but maximum chrominance error, while the shift scheme result falls in between. Since the dot-on-dot scheme has implementation disadvantages, a natural solution to reduce perceived colorimetric error is applying 2-mutually exclusive BNMs on two color planes and applying an adaptive scheme on other planes. Another advantage of this adaptive scheme is that we will be able to take color reproduction into account.

4. NEW ADAPTIVE COLOR HALFTONING SCHEME USING BNMs

Figure 1 and 2 show the flow chart of this new scheme.

In this proposed methods, it is necessary to know the LAB values of the eight primary colors of the destination printer. Thus, we first printed these solid color patches, measured the colors of each patch and generated a lookup table(LUT) of the LAB values for each color.

Then, one BNM is applied to the cyan plane and its inverted version on magenta plane. In this way, we can achieve the highest spatial frequency. At each image pixel, there is only two possible values for yellow plane, either 255 or 0. Therefore, we have to choose one from two possible primary color (c1 and c2) for that image pixel. To do that, first we find the correspond LAB values for c1 and c2 as well as the LAB values for original pixel (c0), then the distances in LAB space between c1 and c0 and c2 and c0 are calculated, and we will pick the primary color which gives the smaller distance for that specific pixel. Finally, we calculate the luminance and chrominance error between the chosen primary color and original color, and pass the error to neighbor pixels to update those original pixel values in error diffusion [6,7] sense.

5. EXPERIMENTAL RESULTS

To compare the performance of the new adaptive scheme with other schemes mentioned earlier, we applied them to a sample image (a "sunflower" image) and evaluated the perceived luminance and chrominance error of the resulting halftone images. The printer used in this experiment is a Tektronix Phaser340 color printer.

In the proposed adaptive scheme, we need to generate a lookup table for the LAB values of eight primary colors. Thus, we first printed these solid color patches and measured the RGB values of each patch with a high quality scanner. We then converted the RGB values into LAB values using the following equation [8]:

$$
\begin{aligned}
X &= 0.49 * R + 0.31 * G + 0.2 * B \\
Y &= 0.17697 * R + 0.81240 * G + 0.01063 * B \\
Z &= 0.01 * G + 0.99 * B
\end{aligned}
$$

$$
\begin{aligned}
L &= 116\,(Y/Y_n)^{1/3} - 16 \\
a^* &= 500\,[\,(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\,] \\
b^* &= 200\,[\,(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\,]
\end{aligned}
$$

The "sunflower" image is halftoned with the proposed adaptive scheme as well the dot-on-dot scheme and the four-mask scheme. Assuming the viewing distance is 10 inches and printer resolution is 300 dpi, the perceived mean-square-error (normalized) between the original image and each halftone image for the luminance channel and chrominance channel is given by the following chart:

	Dot-on-Dot	4-mask	Adaptive
luminance error	0.031	0.022	0.016
chrominance error	0.155	0.201	0.203

Under same condition, the experiment and analysis is repeated for the color patch we used in section 3, the error chart is given below:

	Dot-on-Dot	4-mask	Adaptive
luminance error	0.041	0.034	0.018
chrominance error	0.277	0.296	0.276

6. DISCUSSION

As we can see, lowest luminance error is achieved using the new adaptive scheme compared with other schemes. The tradeoff is computation complexity. It can be seen that the approach is easily extended to K and other "high fidelity" color inks. With vector error diffusion, some artifacts should be considered, such as color smearing at the transition area. For that discussion, a good reference would be Ref. 7.

7. CONCLUSION

In this paper, we propose a new adaptive scheme to achieve high spatial frequency and low perceived error simultaneously for color halftoning with Blue Noise Masks. We have shown that, by having one color channel adaptive, we obtain increased flexibility to manipulate the output so as to reduce colorimetric error while permitting customization to specific printing hardware.

8. REFERENCE

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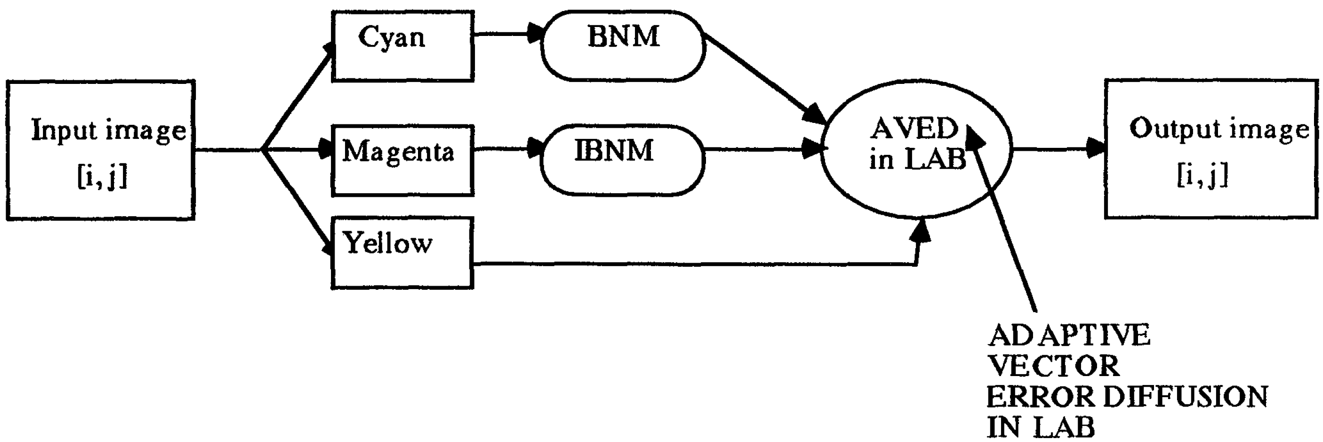

FIGURE 1. OVERVIEW OF ADAPTIVE COLOR HALFTONE

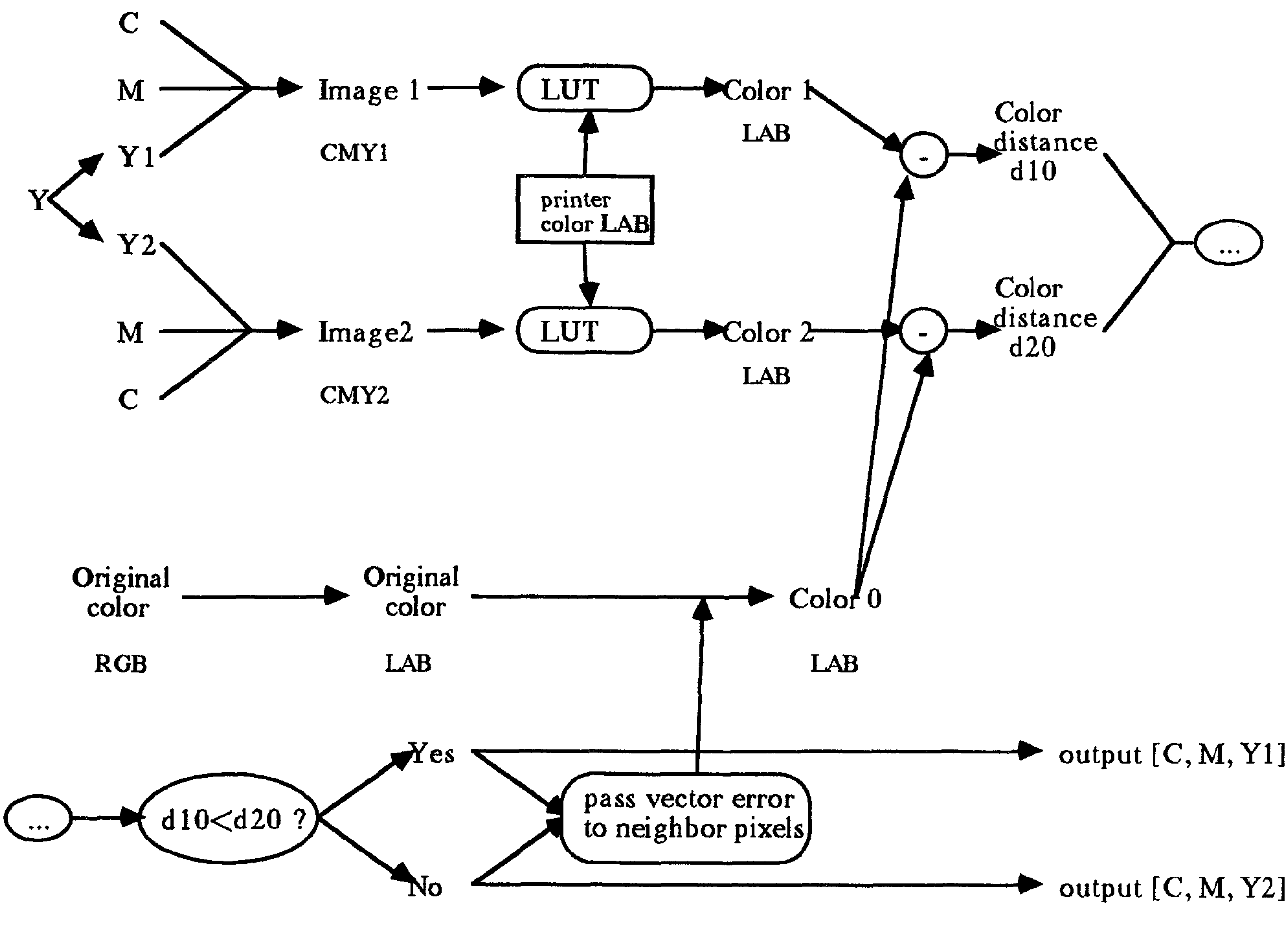

FIGURE 2. DETAILS OF ADAPTIVE DECISION STEP