 

# Halftoning Method by CMY Printing Based on BNM

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## Abstract

The overlapping of black dot decreases brightness and black dot is very sensitive to the human visual system in the bright region. In this paper, for gray-level expression, only the bright gray region in the color image was considered for blue noise mask (BNM) approach. To solve this problem, BNM with CMY dot was used for the bright region instead of black dot. We dispersed CMY dots spatially. At first, the threshold was decided to avoid pixel overlap. Below the threshold, BNM was processed and black dots were assigned. Above the threshold, we assigned the corresponding gray level into cyan, double of gray level into magenta, and three times of gray level into yellow. CMY binary dot was made by using BNM. If all cyan, magenta, and yellow dots overlapped, cyan dots were printed only. If magenta and yellow dots overlapped, magenta dots were printed. Finally, we obtained an output image which was composed of black, cyan, magenta, and yellow pixels. Dot-on-dot model with single mask caused problems making black dots overlap, leading to color distortion. Therefore, an approach with three rotated-masks for C, M and Y each was proposed to decrease pixel overlap and color distortion.

## 1. Introduction

Digital image halftoning is a technique to make an equivalent binary image from a scanned photo or graphic images. Low pass filtering characteristic of the human visual system can be applied to get the effect of spatial averaging of local area consisting of black and white pixels in the case of gray image.

The techniques for digital halftoning include ordered dither, error diffusion, and BNM. Ordered dither method uses predetermined threshold to get binary pixel value, and it is faster than other approaches. For simple thresholding, regular patterns can be shown, and its performance will be degraded on the printer with low resolution. Error diffusion method diffuses the quantization error for center pixel into neighborhood pixels. The merits for this approach are clear boundary and good quality. But it has demerits as worm-like pattern in bright, dark region and with slow computation speed.[1-3] BNM approach consists of mask generation and thresholding. The mask has a high frequency band in the frequency domain and threshold for each mask pixels. It is faster than above error diffusion and there is no worm-like pattern because of threshold operation. For the mask pattern, there can be unnatural patterns on the processed image.[4-8] To improve the BNM approach, MTF (Modulation Transfer Function) based on human visual characteristics or circular dot-overlap model is introduced for the design of mask.[9] Recently, this kind of gray level representation is extended to the field of color halftoning. If the mask for gray level expression is applied to three frames as C, M and Y respectively, colorimetric error would increase because there is no factor considering the relationship between color channels. To decrease the colorimetric error, vector error diffusion is introduced.[10] In this approach, error is propagated into neighborhood pixels in the form of vector like CIELab.[11] The reason for using CIELab space is to get uniform error metric in color space. But the complexity of computation is high because transform of RGB into CIELab is non-linear operation and artifacts like smear can be shown.

In this paper, gray and color modules are proposed as gray-level expression with BNM and design of three mask patterns for CMY.

For BNM approach with single mask, there is some dot overlap and this pattern causes color distortion. In this paper, approach with three mask for C, M and Y each is proposed to decrease dot overlap and color distortion. At first, mask for cyan frame is selected as BIPPSMA (binary pattern power spectrum manipulating algorithm) of Mitsa and Parker. The size of mask is 256x256 and mask for magenta can be obtained from rotating cyan mask by 90 degrees. In the same manner, mask for yellow can be obtained by selecting rotation angle as 180 degrees from cyan mask. This way can avoid pixel overlapping of color planes mutually. Therefore this reduces sensitivity to the misregistration of the color planes and a disturbing band effect which is represented in a previous dot-on-dot method.[12]

Secondly, only bright gray region in the color image is considered for BNM approach. By using only black dot, the middle gray range can be well presented, but dark and bright region can not be represented well. For dark region, the overlapping of black dot decreases brightness and black dot in the bright region is very sensitive to the human visual system. To solve this problem, BNM with CMY dot is used for the bright region rather than black dot.

## 2. Construction of BNM

BNM is two-dimensional mask making binary pattern to have blue noise characteristic. Blue noise has no low frequency and has a flat region in the high frequency region. In the BNM, the pixel of each mask is consist of the threshold value. Though, pixel-by-pixel comparison, halftoned image were obtained.

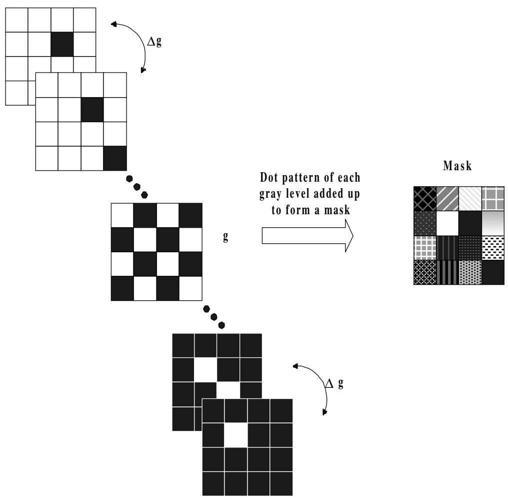



*Figure 1. Construction of BNM using dot patterns.*

At first, the dot pattern having a specific gray level (g) was constructed and a Low Pass Filter was used to make binary pattern removing a periodic low frequency band. In the procedure of constructing the mask, the pixel corresponding to the Δg's gray level was added or removed to make g+Δg's dot pattern from gray level (g). In this way, the dot pattern corresponding to all gray level was constructed, 256 dot patterns made in 8-bit gray level. In the each dot pattern, the pixel value was normalized (0 or 1), summed. Thus, the mask has the all gray level's threshold value. This was faster than error diffusion and there was no worm-like pattern because of threshold operation. For the mask pattern, there could be unnatural patterns on the processed image.

In the proposed algorithm, BNM was constructed by the method using Mitsa and Parker's algorithm (256×256 size ).[4]

## 3. Dispersed CMY Dithering

For gray-level expression, only bright and dark gray region in the color image was considered for BNM approach. By using only black dot, the middle gray range was well presented, but dark and bright region could not be represented well. For dark region, the overlapping of black ink decreased brightness and black dot in the bright region was very sensitive to the human visual system. To solve this problem, BNM with CMY dot was used for the bright region rather than black dot.

In the BNM approach, assume we have two continuous gray level to represent A and A'. To express A', the cross-relationship between A and A' is used while the value of A is preserved. By this relationship, if the input value to be printed is above 2/3 of whole dynamic range, the number of dots is multiplied by 3 compared to the number of dots for A'. The reason for take the threshold as 2/3 is as follows. To print one gray level in BNM, 256 dots are needed for 256×256 size of mask. If the gray value under this threshold is printed by CMY combination, human do not notice artifacts. By coupling the above scheme with threshold of 2/3 and BNM, CMY dots can be printed uniformly for corresponding printed image.

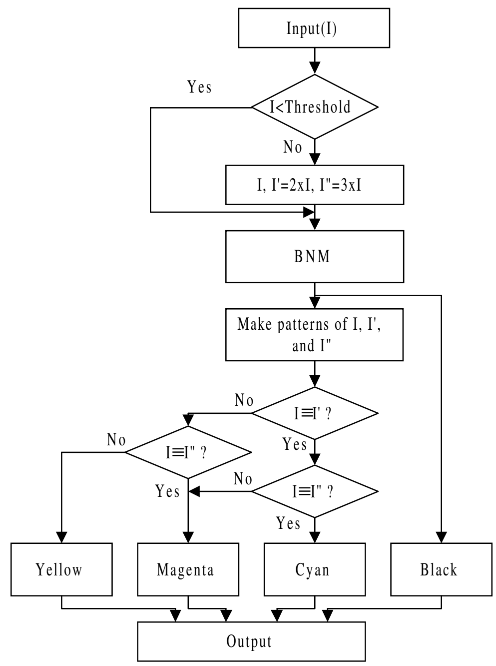



*Figure 2. Block diagram of proposed algorithm.*

The proposed algorithm is below. At first, the threshold was decided to avoid pixel overlap. Below the threshold, BNM was processed and black dots were assigned. Above the threshold, we assigned corresponding gray level into cyan, double of gray level into magenta, and three times of gray level into yellow. CMY binary dots were made by using BNM. If all cyan, magenta, and yellow dots overlapped, print cyan dot only. If magenta and yellow dots overlapped, magenta dots were printed only. Finally, we obtained output image which is composed of black, cyan, magenta, and yellow pixels.

However, using a CMY combination instead of black dots had problems because the printing of one black dot was darker than three dots of CMY, which were dispersed.

Thus, tone rescaling was needed which will be discussed in the following section (3.2).

## 4. Connection of Tone Curve

In this approach, threshold value was set to 2/3 of full dynamic range, for example, 255 was very important for the performance. The size for BNM was 256x256 and to increase one gray level, 256 dots were needed. If the gray level was lower than 2/3 of 255, corresponding CMY dots began to overlap. This CMY dot scheme was applied to the upper 84 gray levels from 172 to 255. Black dot scheme was applied to other range from 0 to 171. This scheme had discontinuity between level 171 and 172 because of distortion in gray level. To avoid the discontinuity, 20 patches were printed in CMY for the range of 2/3 to 1 and measured in the Lab coordinate value by spectrophotometer (MinoltaCM3600d). And sixty-four patches ranging from 0 to 255 were printed in black dot. The gray difference between the patches was four, and they were also measured. These patches also measured. From the analysis of these measurements, for the levels 2/3 and 1 were printed by CMY combination and other levels are printed by black dot.

In Fig. 3, Lab value corresponding to dynamic range from 0 to 255 was evaluated using black dot and CMY dots were used from 172 to 255. In Fig.4, because a high dark area was not noticeable, tone reproduction was needed. Therefore, gray levels from 0 to 171 in response to gray levels from 20 to 192 using black dots was used, in remaining dynamic range, gray levels from 172 to 255 using CMY dots was used.

When black dots and CMY dots were combined, wider dynamic range could be available. A more linear tone curve could be obtained. If a highlight gray level was expressed with some black dots and white paper, granularity was increased. However CMY dots were used like described in the proposed method in the highlight region, granularity was decreased, smoother and a better quality image was obtained.

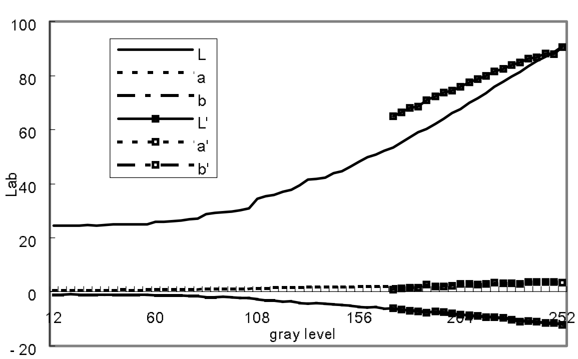



*Figure 3. CIELab value using black and CMY dots.*

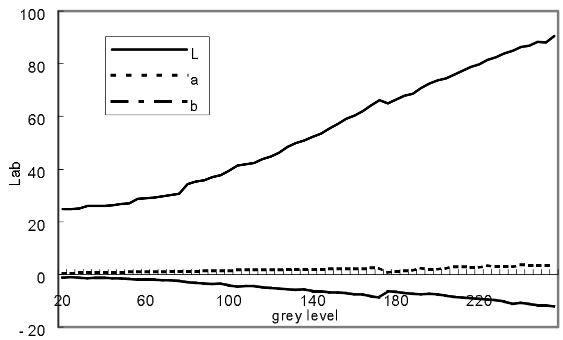



*Figure 4. Connection of tone curve using black and CMY dots.*

## 5. Modified BNM with Rotation Angle

If only single mask was used in BNM, the probability which the black dot would print increased in the same position. In the previous cluster dithering method, for example, rotated scheme used 30°, 45°, 75° rotations between each color plane mask. If this method was used, misregistration and moire pattern of color planes would be reduced and black dot would be less printable than if using a conventional method.

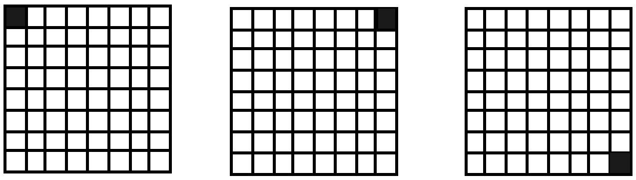
In this paper, three masks scheme that one BNM by BIPPSMA algorithm was constructed and this BNM was rotated 90° repeatedly rotated and then the third mask was obtained. With using this three BNM, each CMY channel was used as threshold mask. Fig. 5(a) shows BNM, Fig. 5(b) is the mask which is rotated by 90° with BNM, and Fig. 5(c) presents the mask which is rotated by 180° with BNM. Because of BNM property, each rotating mask had less pixel value of overlapping. Among these masks, the number of overlapping pixel was two hundreds pixels and the number was smaller than number of total pixels.

$$M_{cyan}(i,j) = \sum_{i=0}^{M}\sum_{j=0}^{N} BNM(i,j), \quad (1)$$

$$M_{magenta}(i,j) = \sum_{i=0}^{M}\sum_{j=0}^{N} M_{cyan}(j,i), \quad (2)$$

$$M_{yellow}(i,j) = \sum_{i=0}^{M}\sum_{j=0}^{N} M_{magenta}(j,i), \quad (3)$$

Here is i=1,…,M, and j=1,…,N.M is the height of mask, N is the width of mask. BNM(i,j) is BNM by BIPPSMA, $M_{cyan}$(i,j) is the mask assigning BNM(i,j), $M_{magenta}$(i,j) is the mask making BNM(i,j) rotate by 90°, and $M_{yellow}$(i,j)is the mask making $M_{magenta}$(i,j) rotate by 90°.



(a) (b) (c)

*Figure 5. (a) BNM by BIPPSMA, (b) BNM by 90° rotation, (c) BNM by 180° rotation.*

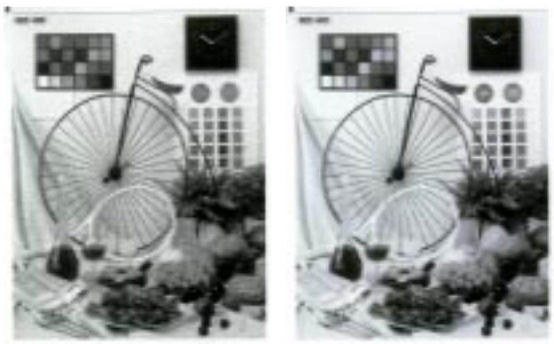


*Figure 6. Result for B/W Bicycle image (a) BNM, (b) Dispersed CMY dithering.*

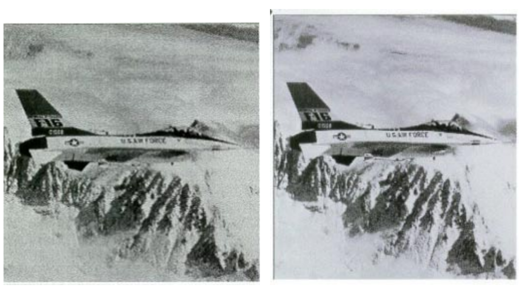


*Figure 7. Result for B/W Airplane image (a) BNM, (b) Dispersed CMY dithering.*

## 6. Experiments

In this paper, gray and color image are used. Fig. 6 shows the result of CMY combination method, and Fig. 7 shows the result of rotated scheme.

Fig. 6 (a) is a bike gray image using BNM and Fig. 6 (b) is a result image when the proposed CMY combination method is used. While BNM had high granularity and narrow dynamic range, the CMY combination method had low granularity, wide dynamic range, and high contrast properties. Because the proposed method used three times more dots than a conventional BNM, it expressed more spatial information while it had a similar gray level with BNM. Fig. 7(a) is an Airplane image, and the proposed method showed better results than the BNM method like in Fig. 6 and Fig. 8(a) is a bike color image using BNM and Fig. 8(b) is a result image used by the proposed rotated method. The dot overlap was reduced remarkably, it presented the region of details. Fig. 9 shows the same result like these found in Fig. 8.

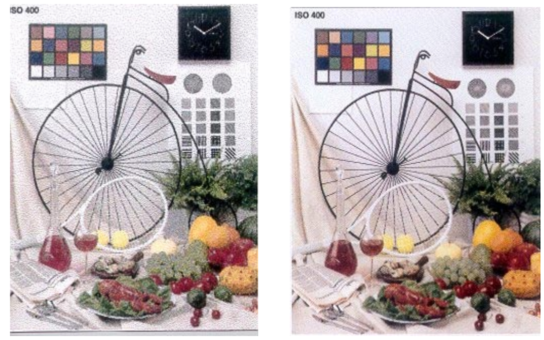


*Figure 8. Result for Bicycle image (a) BNM, (b) rotation of three masks.*

*Figure 9. Result for Color Airplane image (a) BNM, (b) rotation of three masks.*

## 7. Conclusion

In the proposed CMY combination method, achromatic region for color image was printed well with less granular pattern and good quality and contrast compared to the regular BNM approach. Approach with three mask for C, M and Y each was proposed to decrease dot overlap and color distortion. For the experiment, gray region of the processed image was uniform and bright sufficiently compared to conventional results with black dots. In color image, the processed image was more bright and uniform compared to conventional dot-on-dot scheme for each C, M and Y channel. The two proposed methods had low granularity, wide dynamic range and high contrast properties.

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