

# Multitoning Method Based on Threshold Modulation Using MJBNM for Banding Artifact Reduction

Tae-Yong Park, Myong-Young Lee, Chang-Hwan Son, and Yeong-Ho Ha, School of Electrical Engineering and Computer Science, Kyungpook National University, Taegu, Korea

## Abstract

This paper proposes a multitoning method based on threshold modulation using a Modified Jointly Blue Noise Mask (MJBNM) to reduce banding artifacts. Since banding artifacts appear as uniform dot distributions around the intermediate output levels, such halftone patterns result in discontinuity and a visually displeasing output in smooth transition regions. Therefore, to reduce these banding artifacts, the principal cause of banding artifacts is first analyzed. Based on the analytical results, the proposed method then arranges the dot distribution by introducing pixels to the neighborhood of the output levels through threshold modulation using an MJBNM, which takes into account the chrominance error and correlation between channels. Depending on the input value, the original threshold range of the MJBNM is first scaled linearly so that the minimum and maximum of the scaled range include some more pixels than the adjacent two output levels containing the input value. If an input pixel is inside the vicinity of any intermediate output level producing banding artifacts, the output is set to one of those output levels based on comparing the result to scaled threshold values and a threshold modulation parameter that determines the dot density. Otherwise, a conventional multitoning method is applied. As a result, the proposed method effectively decreases the appearance of banding artifacts around the intermediate output levels.

## Introduction

Multitoning[1],[2] is essentially an extension of bi-level halftoning[3],[4], i.e. black and white, that introduces more intermediate levels between the ON and OFF states to produce the appearance of continuous tone images. Various multitoning techniques are already widely used for better image reproduction, and advancements in printing technologies have led to research efforts on improved multitoning algorithms. Nonetheless, although multitoning is the predominant color reproduction methods, it still suffers from banding artifacts around the intermediate output levels. These banding artifacts appear as uniform dot distributions and result in discontinuity and a visually displeasing halftone output in smooth transition regions at the printer output level. Thus, F. Faheem et al.[5] suggested a novel method based on the idea of a gray level separation to eliminate such unwanted banding artifacts, where a generalized gray level transform is used to decompose the image into constituent gray images according to the dot growth pattern defined by the transform. Each channel is then halftoned in a correlated fashion. Although this method is simple to implement and reduces banding artifacts, a high frequency granularity is visible in the mid-tones. Also, different dot growth patterns are used for the low and high frequency regions due to the image-dependent characteristic. And Q. Yu et al.[6] proposed an over modulation method to

achieve a smoother transition for the intermediate output levels based on stochastic screening. With this simple technique, the dot patterns around the intermediate output levels are manipulated to introduce the desired halftone patterns. However, since this algorithm is mean preserving with respect to the input, a preprocessing step has to be added to modify the input pixel values according to an over modulation function. Also special correlation or spectral characteristics have to be considered during the screen design, as a regular screen is not optimal for this method.

## Cause of Banding Artifacts in Multitoning Based on Stochastic Screening

The technique of stochastic screening can easily be generalized to multitoning due to its implementation simplicity. Before an input value is compared pixel by pixel to a threshold value in the stochastic screen, the threshold range, which originally has 256 levels from 0 to 255, is scaled to a certain intermediate range. Figure 1 shows the transformation of the threshold range according to the input value. However, the multitoning result reveals that banding artifacts appear inside any neighborhood with an intermediate output level. For example, if the input value is inside [82, 85], the threshold range is scaled using the following equation:

$$\begin{aligned} Th_s &= 85 - (255 - Th_o) \times \frac{(85 - 0)}{(255 - 0)} \\ &= Th_o \times \frac{85}{255} \end{aligned} \quad (1)$$

As only the original threshold range [246, 255] is scaled to range [82, 85], there is little probability that the scaled threshold value will be larger than the input value. Therefore, the output values inside neighborhood [82, 85] of output level 85 have 85 as the output value. Also, the scaling transformation function for input value [85, 88] is given as follows:

$$\begin{aligned} Th_s &= 170 - (255 - Th_o) \times \frac{(170 - 85)}{(255 - 0)} \\ &= 85 + Th_o \times \frac{85}{255} \end{aligned} \quad (2)$$

The threshold range is first scaled to range [85, 170]. At this time, as only the original threshold range [0, 9] is scaled to range [85, 88], most of the input values are larger than the scaled threshold value. Therefore, the input values inside neighborhood [85, 88] of output level 85 have 85 as the output value. As a result, banding artifacts appear as uniform dot distributions around the intermediate 85 output levels.

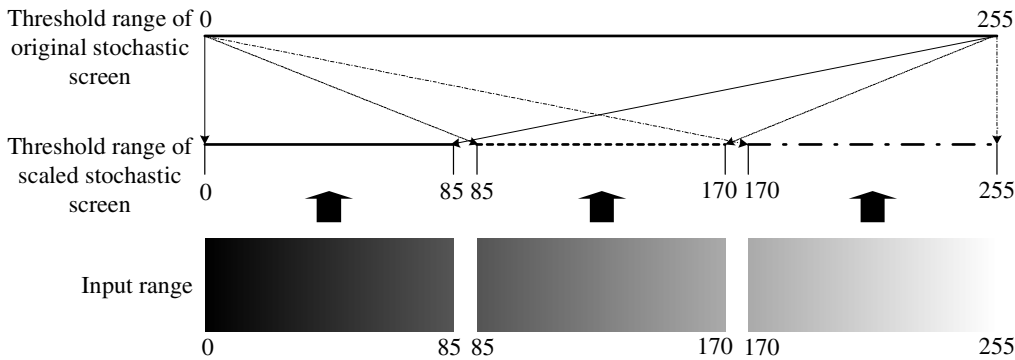


Figure 1. Transformation of threshold range according to input value

### Proposed Multitoning Method for Banding Artifact Reduction

To achieve a smoother transition around intermediate output levels, the dot distribution needs to be adjusted by introducing pixels in the neighboring output levels. Accordingly, this paper proposes a modified threshold modulation using a Modified Jointly Blue Noise Mask (MJBNM)[7]. Figure 2 shows a flow chart of the proposed method for banding reduction, which consists of two steps. The first step scales the original threshold range of the MJBNM using a modified linear function, then the second step is the quantization process. Adjacent output pixels are introduced according to the scaled threshold value, and the dot pattern determined depending on the extent of the threshold modulation.

#### Scaling of Original Threshold Range Using Modified Linear Function

The first step involves scaling the original threshold range using a modified linear scaling function for multitoning that maps the threshold value linearly so that the minimum and maximum of the scaled range include some more pixels than the adjacent two output levels containing the input value. As such, the ratio of the original threshold values relative to these extremes is maintained. For example, if an input value is between two adjacent output levels  $X_1$  and  $X_2$  ( $X_1 < X_2$ ), the original threshold range  $[0, 255]$  is transformed linearly into range  $[X_1 - R, X_2 + R]$ . However, there are two exceptions at both ends: if  $X_1 = 0$ ,  $X_1 - R = 0$  and if  $X_2 = 255$ ,  $X_2 + R = 255$ . This transformation process can be expressed as follows:

$$Th_s = Th_{s(max)} - (Th_{o(max)} - Th_o) \times \frac{(Th_{s(max)} - Th_{s(min)})}{(Th_{o(max)} - Th_{o(min)})} \quad (3)$$

$$= (X_2 + Th_o + R - 255) \times \frac{(X_2 - X_1 + 2R)}{255}$$

where  $Th$  is an abbreviation for the threshold, subscript  $o$  and  $s$  denote the original and scaled threshold, respectively, and  $max$  and  $min$  are the maximum and minimum value in a given threshold range, respectively. Here  $Th_{o(min)}$  and  $Th_{o(max)}$  are 0 and 255, respectively, because the printer used in this study has a tone scale reproducibility of 8 bits for each primary color. Plus,  $R$  is the control factor that affects the density of the

adjacent output pixel around the intermediate output level. As the value of  $R$  increases, the ranges  $[X_1 - R, X_1]$  and/or  $[X_2, X_2 + R]$  are further expanded. Therefore, there is every probability that numerous adjacent pixels are printed inside the neighborhood of an intermediate output level. If the value  $R$  is small, hardly any adjacent pixels are printed. Figure 3 shows multitoning images for a gray ramp image relative to the value of  $R$  around intermediate output level 85, and the results confirm that the quantity of adjacent output pixels grows according to the control factor  $R$ .

#### Quantization Processing Using Threshold Modulation

Thus novel quantization method achieves a smooth tone representation around an intermediate output level by introducing adjacent output pixels. As such, this second step first checks whether an input value is inside any of the predetermined ranges for the intermediate output levels. If not, the input pixel is quantized by a pointwise comparison with a scaled threshold value. As a result, the output is set to one of two output levels containing the input value based on the comparison result.

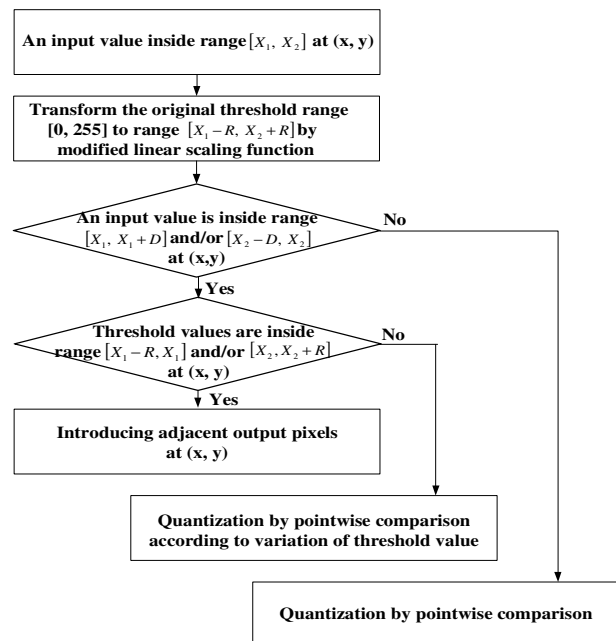


Figure 2. Flow chart of proposed method for banding reduction

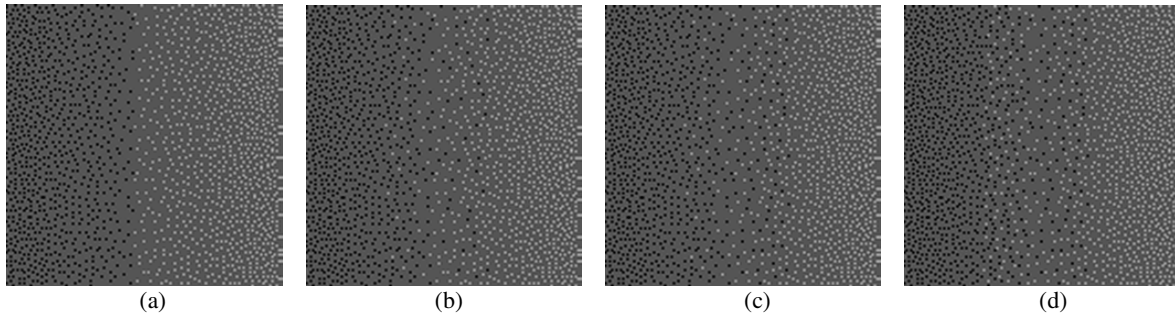


Figure 3. Gray ramp multitoning images relative to value of  $R$  around intermediate output level 85; (a) 0, (b) 1, (c) 2, and (d) 3

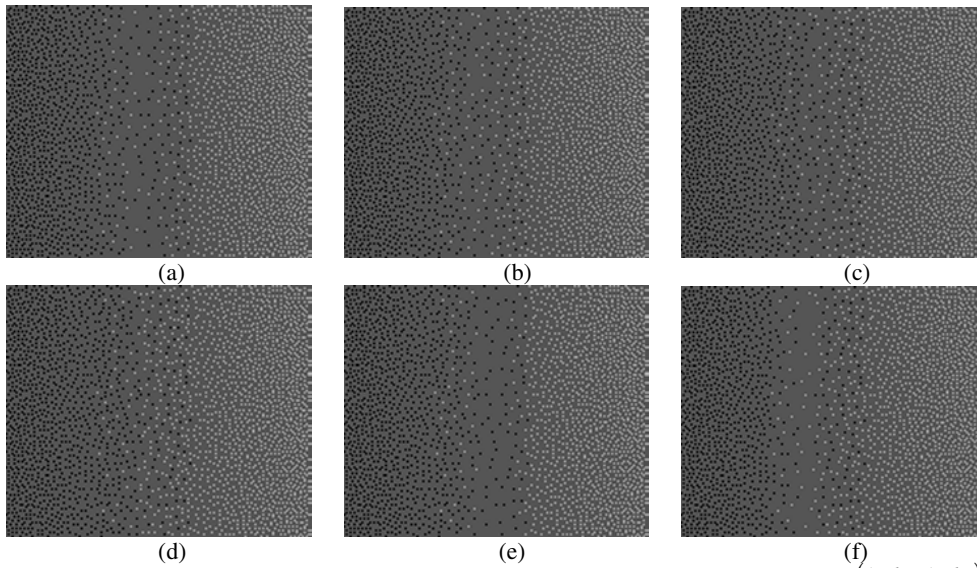


Figure 4. Multitoning patterns around intermediate output level 85 relative to specific modulation factors  $(\Delta Th_1, \Delta Th_2)$ ; (a) (0,0), (b) (1,-1), (c) (2,-2), (d) (3,-3), (e) (2,2), and (f) (-2,-2)

Otherwise, the output value is determined according to the scaled threshold value located at the same position as the input value. Assume the device has 4 output levels, 0, 85, 170, and 255. This quantization can then be represented as follows:

$$\text{If } X_1 - 5 \leq a \leq X_1$$

$$\text{then } O(x, y) = \begin{cases} X_1 + 85, & \text{if } X_1 \leq Th_s \leq X_1 + 2 \\ X_1 + 85, & \text{if } X_1 - 87 \leq Th_s \leq X_1 - 85 \\ X_1 - 85, & \text{if } a < Th_s \\ X_1, & \text{if } a \geq Th_s + \Delta Th_1 \end{cases}$$

$$\text{If } X_1 < a \leq X_1 + 5$$

$$\text{then } O(x, y) = \begin{cases} X_1 - 85, & \text{if } X_1 - 2 \leq Th_s \leq X_1 \\ X_1 - 85, & \text{if } X_1 + 85 \leq Th_s \leq X_1 + 87 \\ X_1, & \text{if } a < Th_s \\ X_1 + 85, & \text{if } a \geq Th_s + \Delta Th_2 \end{cases}$$

(4)

where  $a$  is the input value at position  $(x, y)$ . Also,  $\Delta Th_1$  and  $\Delta Th_2$  are the threshold modulation factors used to manipulate the multitone patterns to achieve a smoother visual transition. Figure 4 shows the multitoning patterns around the intermediate output level 85 relative to specific modulation factors. When

both factors have the same sign, a smooth dot pattern is untenable. Also, in the case of a low absolute value and high absolute value, the dot density from the dot distribution is sparse and dense, respectively. Plus, in equation (4),  $X_1 - 87$  is larger than 0 and  $X_1 + 87$  does not exceed 255. Among the 4 conditions, the upper 2 conditions have priority over the lower 2 conditions in each quantization process.

## Experiment

The proposed multitoning method based on a threshold modulation of an MJBNM was applied to  $1024 \times 128$  gray and  $512 \times 640$  color ramp images, and the multitoning results compared with those for a multitoning method using a stochastic screen and over modulation technique for banding artifact reduction. The quality of the multitone images were objectively evaluated using the human visual system-weighted root mean squared error (HVS-WRMSE) [6] for the gray ramp images and the S-CIELAB color difference  $(\Delta E_{ab}^*)$  [8] between the original image and its multitone version for the color ramp images.

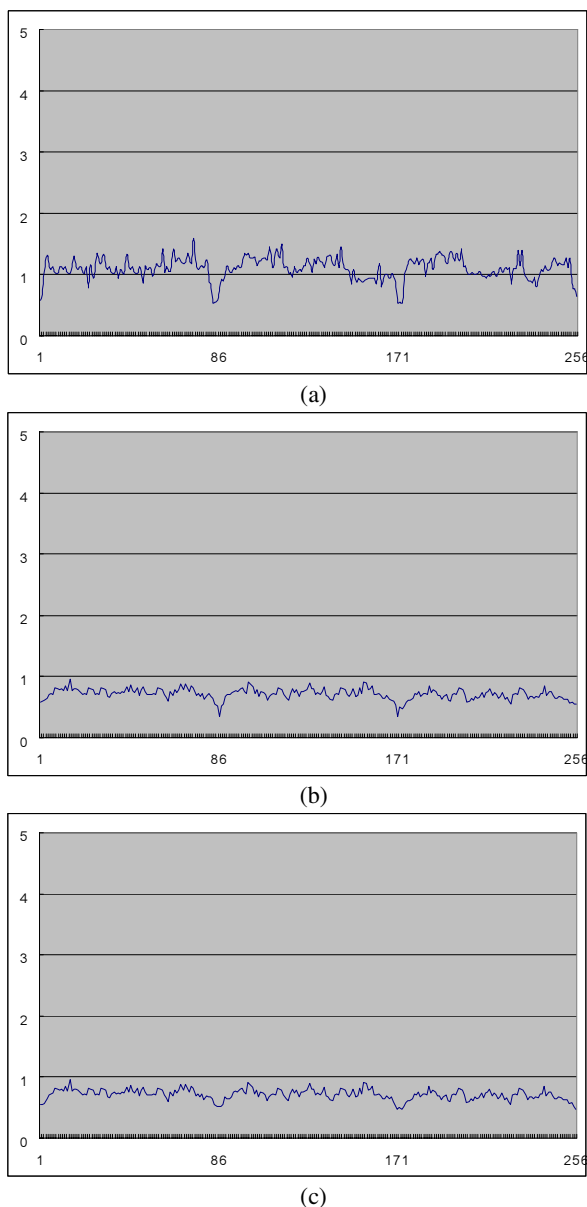
### Objective Evaluation Using HVS-WRMSE

The root-mean-squared error (RMSE) is the square-root of the average of the individual squared differences between the original version and its reproduced version. Plus, the human visual system is weighted to characterize the low-pass nature of the visual system. Figures 5(a), 5(b), and 5(c) show the HVS-

WRMSE versus the gray level calculated directly from data in the digital file for the three multitone methods i.e., multitone using an MJBNM, over-modulation using an MJBNM, and the proposed method based on threshold modulation using an MJBNM, respectively. All the multitone methods have the same four-level output, 0, 85, 170, and 255. When compared to Figure 5(c), Figures 5(a) and 5(b) reveal a steep increase and decrease in the HVS-WRMSE at the output levels, respectively, confirming that the proposed method achieved a uniform tone reproduction around the intermediate output levels.

### Objective Evaluation Using S-CIELAB Color Difference

Since the proposed method applies a scalar multitone method using a stochastic screen, visual pattern noise and color error can be caused by the interaction of uncorrelated channels, even though each color separation has a visually pleasing pattern and



**Figure 5.** HVS-WRMSE graphs versus gray level for gray ramp image: (a) multitone using MJBNM, (b) over-modulation using MJBNM, and (c) proposed method based on threshold modulation using MJBNM

low luminance error. In a color image, this pattern is less pronounced, yet still objectionable. Therefore, the present focus is only on the color discrimination and appearance caused by the spatial pattern of the multitone target. To measure the color difference in the color images, the S-CIELAB metric that considers the spatial patterns of the image was applied to the three multitone methods. The S-CIELAB color difference with the original image was calculated directly from the digital data and 2.67, 1.83, and 1.51 for the results corresponding to Figures 5(a), 5(b), and 5(c) respectively. Therefore, the experiment confirmed that the color difference was decreased because of the reduction of banding artifacts. When compared to the over modulation technique, the proposed method provided a comparable improvement, which only resulted from the dot pattern around the intermediate output levels.

### Conclusion

This paper proposed a multitone method that uses threshold modulation with an MJBNM to reduce banding artifacts. The proposed method analyzes the principal cause of banding artifacts in multitone by stochastic screening using a mathematical description. Based on the analytical results, the proposed method arranges the dot distribution by introducing pixels in the neighborhood of the output levels using threshold modulation with an MJBNM. First, the original threshold range of the MJBNM is scaled using a modified linear function, then the quantization is processed according to the scaled threshold value and the dot pattern determined depending on the extent of the threshold modulation. In experiments, the reproduction image resulting from the proposed method achieved a smooth tone representation around the intermediate output levels.

### References

- [1] R. Miller and C. Smith, "Mean-preserving multilevel halftoning algorithm," Human Vision, Visual Processing, and Digital Display IV, San Jose, CA, Proc. SPIE vol. 1913, pp. 367-377, 1993.
- [2] J. L. Mitchell, G. R. Thompson, C. W. Wu, T. J. Trenary, and Y. Qiao, "Multilevel color halftoning," Ninth Color Imaging Conference, Scottsdale, Arizona, USA, pp. 189-193, 2001.
- [3] R. Ulichency, Digital halftoning, The MIT Press, 1993.
- [4] H. R. Kang, Digital color halftoning, The SPIE Optical Engineering Press, 1999.
- [5] F. Faheem, G. R. Arce, and D. L. Lau, "Digital multitone using gray level separation," Journal of Imaging Science and Technology, vol. 46, no. 5, pp. 385-397, September/October 2002.
- [6] Q. Yu, K. J. Parker, K. Spaulding, and R. Miller, "Digital multitone with overmodulation for smooth texture transition," Journal of Electronic Imaging, vol. 8, no. 3, pp. 311-321, July 1999.
- [7] Y. S. Kwon, Y. T. Kim, H. K. Lee, and Y. H. Ha, "Modified jointly blue noise masks approach using S-CIELAB color difference," Ninth Color Imaging Conference, Scottsdale, Arizona, USA, pp. 194-198, November 2001.
- [8] X. M. Zhang and B. A. Wandell, "A spatial extension to CIELAB for digital color image reproduction," Proc. of the SID Symposium, vol. 27, pp. 731-734, 1996.

### Author Biography

Tae Yong Park received the B. S. and M. S. degrees in School of Electrical Engineering and Computer Science from Kyungpook National University, Taegu, Korea, in 2001 and 2004, respectively. Now he is pursuing Ph. D. degree in School of Electrical Engineering and Computer Science from Kyungpook National University, Taegu, Korea. His current research interests are in the areas of digital color halftoning, color management, and color image processing.