Color Quantization and Dithering Method Based on HVS Characteristics

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Abstract

New methods for both color palette design and dithering based on HVS (human visual system) characteristics are proposed. Color quantization for palette design uses the sensitivity and spatial masking effect of HVS. Dithering operation for printing uses nonlinear quantization which considers overlapping phenomena of neighboring printing dots and modified dot diffusion algorithm is followed to compensate the degradation produced in the quantization process. The proposed techniques can produce high quality image in the low bit color devices.

Introduction

Recently, the use of color image data is growing fast in the area of image processing.[1,2] To express natural color in the conventional low cost color devices, it should be quantized to a few color palette for monitoring and dithering for printing.

In this paper, color palette design and dithering based on HVS characteristics is proposed. In the quantization for color palette design process, activity function and distortion measure are calculated by considering the spatial masking effect of HVS.[3,4] The activity histogram with respect to grey value is also obtained to determine threshold values which maximize the inter-cluster variance and divide the input colors into 8 clusters. Then each distortion error calculated from the distortion measure in each cluster is used to search a cluster of maximum distortion. The searched set is again divided into 8 clusters and this process can be applied repeatedly to make the desired number of color in the palette design.

Conventional dithering uses linear quantization which maps 8-bit input values to 4-bit quantized values.[5,6] In this process, the color can be degraded due to the overlapping of printing dots. Thus, quantization step is adjusted to consider this overlapping phenomena, which is occured in the vicinity of neighboring printing dot. In the dithering process, modified dot diffusion is also proposed. It diffuses hue according to the input image characteristic in the HSI color coordinate of representing HVS color sensing properties. Filtering of the quantization error by low pass filter before dot diffusion is followed so that the quantization error has to be diffused only in the intra-region.

Color Palette Design

Color palette design is selecting the prescribed number of colors to display an image without noticeable perceived difference. In this design process, proper color quantization is necessary and distortion error between input color and quantized color is used to judge quantized image quality. In the conventional quantization algorithms, mean squared error is commonly used as distortion measure. In this paper, an activity-weighted distortion measure based on the spatial masking effect of HVS is proposed. The spatial masking effect means that human vision is more sensitive to quantization errors in smooth region than those in edge region. To use this effect, color activity value in the local region of input color image is first calculated by weighting the squared difference between input grey value and mean value in each red, green, and blue channel.

$$A(\vec{c}) = \frac{1}{M}\sum_{i=0}^{M-1}\{\alpha(c_{i,R}-c_{\overline{m},R})^2+\beta(c_{i,G}-c_{\overline{m},G})^2+\gamma(c_{i,B}-c_{\overline{m},B})^2\}^{\frac{1}{2}} \tag{1}$$

where M is the number of pixels of local region, $c_{i,R}$, $c_{i,G}$, and $c_{i,B}$ are grey values of input color, and $c_{\overline{m},R}$, $c_{\overline{m},G}$, and $c_{\overline{m},B}$ are mean values of the local region in each channel. The larger color activity value is, the error is less sensitive to human vision. The smaller color activity value is, the error is more sensitive to human vision.

And the distortion measure is proposed and defined by weighting the activity function to the quantization errors.

$$D = \sum_{\substack{k=1 \\ \vec{c}_i \in \Omega_k}}^{N} \frac{1}{A(\vec{c}_i)^2}\|\vec{c}_i - \vec{\mu}_k\|^2 = \sum_{\substack{k=1 \\ \vec{c}_i \in \Omega_k}}^{N} \frac{1}{A(\vec{c}_i)^2}E_q \tag{2}$$

where N is the size of color palette (i.e. 256), $\vec{c}_i$ is input color, Ω_k and $\vec{\mu}_k$ are k-th color cluster and its centroid color, and E_q is the quantization error of input color. This measure makes the sensitive color quantize finely. If not, quantize coarsely.

Based on the activity value and the distortion measure, the proposed color quantization algorithm can be performed in hierarchically two steps. In the first step, the input colors are divided into 8 initial color clusters by thresholding method using inter-cluster variance. To calculate the inter-cluster variance, activity histogram (x_i) with respect to grey level is obtained as shown in Figure 1 (a).

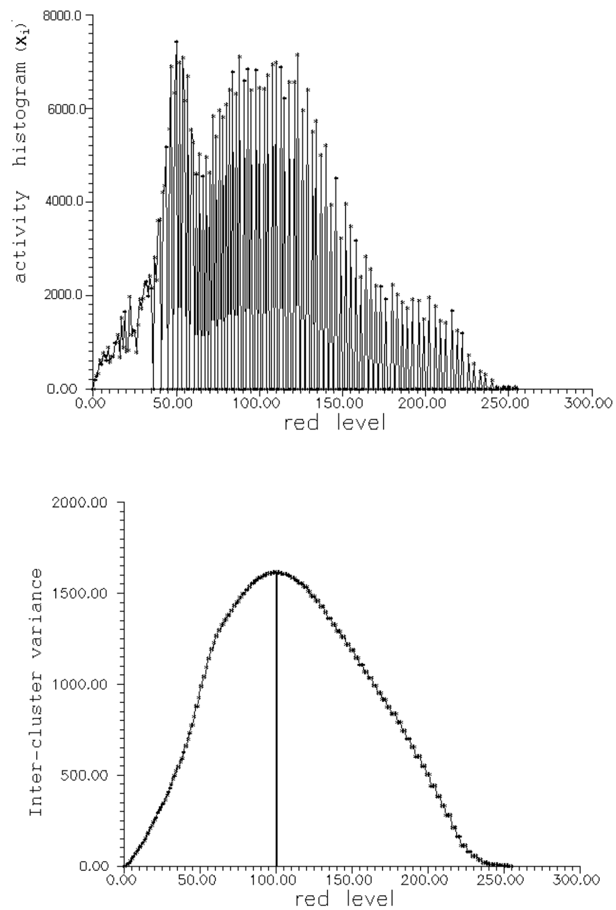


Figure 1. Activity histogram and its inter-cluster variance in red channel. (a) activity histogram (b) inter-cluster variance

According to the activity histogram, the inter-cluster variance for red channel is calculated as follows.

$$\sigma_R^2 = \rho_1 \left(\frac{1}{K=1} \sum_{i=0}^{K} \chi_i - \bar{\chi} \right)^2 + \rho_2 \left(\frac{1}{255-K} \sum_{i=K+1}^{255} \chi_i - \bar{\chi} \right)^2 \quad (3)$$

where $p_{i\,=} (x0 + x1 + \bullet\bullet\bullet + xk)/X$ and $p2 = (xK{+}1 + xK{+}2 + \bullet\bullet\bullet + x255)/X$ with $X = \sum_{i=0}^{255} x_i$ and $\bar{x} = X/256.$. Then the calculated variance in red channel is shown in Figure 1 (b). Similarly, $\sigma_G{}^2$ and $\sigma_B{}^2$ can be obtained for green and blue channels, respectively. Thus the threshold value can be determined as the grey value of maximum variance. By threshold values for red, green, and blue, 8 clusters are obtained.

In the second step, the color cluster of the maximum distortion is again divided into 8 color clusters using the distortion measure and thresholding method. This process is repeatedly applied until 256 or less color clusters are obtained. Color palette is made from the centroids of the obtained color clusters, and finally the input colors are mapped to the color palette.

Nonlinear Quantization and Modified Dot Diffusion for Color Printer

Conventional dithering uses linear quantization which maps 8-bit input values to 4-bit quantized values. The dithering makes the color degrade due to the overlapping of printing dots. To improve this drawback, nonlinear quantization for dithering is proposed. Quantization step is adjusted in proportional to the area which intersection area is subtracted from total area of each neighboring printing dot as shown in Figure 2. This step can be varied according to the printing order of dithering matrix. Actually marked areas and their calculated grey values are shown in Table 1. This nonlinear quantization can reduce the degradation of printed image.

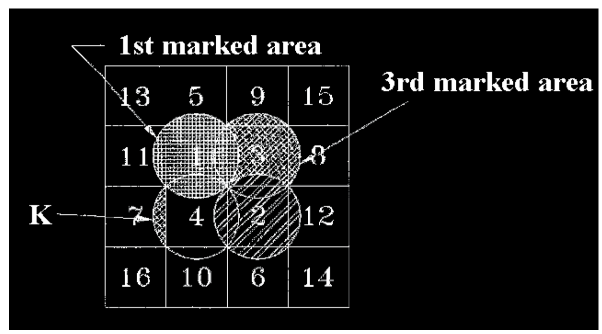


Figure 2. The printing of dots and their overlapping

Table 1. Quantized Values and Calculated Grey Values Based on Marking Area

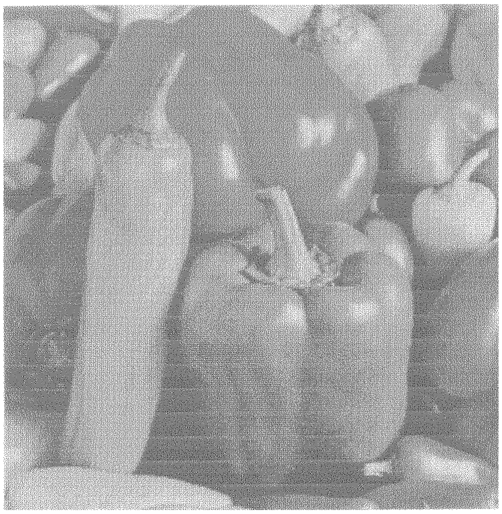
q	marked area	r	Δr	q	marked area	r	Δr
1	1/16+4K	230	25	9	9/16+11K	87	13
2	2/16+8K	205	25	10	10/16+11K	73	14
3	3/16+8K	189	16	11	11/16+9K	59	14
4	4/16+8K	173	16	12	12/16+8K	46	13
5	5/16+9K	154	19	13	13/16+6K	34	12
6	6/16+10K	136	18	14	14/16+4K	23	11
7	7/16+11K	118	18	15	15/16+4K	11	13
8	8/16+12K	100	18	16	1	0	11

* q is the quantized value, r is calculated grey value, and Δr is increment

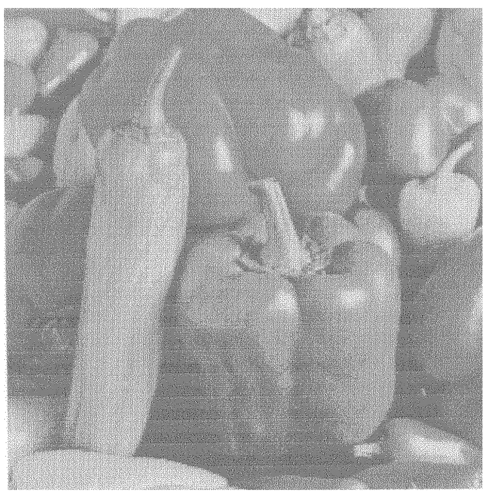
In the dithering process, dot diffusion is modified by adjusting the amount of hue diffusion according to the intensity and saturation of input image in the HSI color coordinate. The amount of hue diffusion is given by

$$\Delta H' = \begin{cases} \Delta H \times S \times \frac{I}{127}, & I \le 127 \\ \Delta H \times S \times \frac{(255-I)}{127}, & otherwise \end{cases} \quad (4)$$

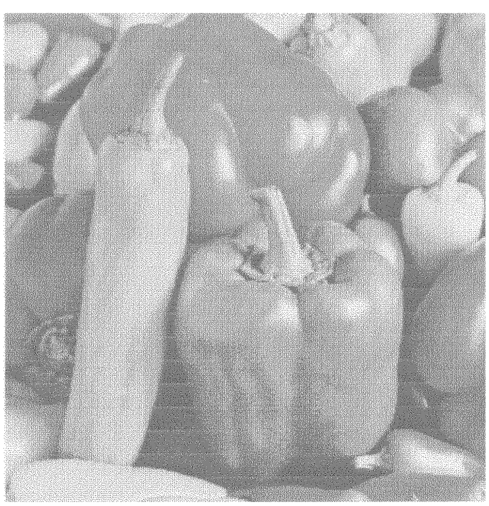
where $\Delta H'$ is hue amount to be diffused, ΔH is hue error occured in the quantization process, S is saturation value, and I is intensity value.



(a) the original image



(b) the quantized image for monitor



(c) the dithered image for printing
Figure 3. Images for comparison

In color printing using the modified dot diffusion, filtering the quantization error by low pass filter is suggested before dot diffusion because the quantization error has to be diffused only in the intra-region. In this paper, the 3×3 average filter is used for simple and fast processing.

Experimental Results

In the experiment, we used PC with VGA board of 256 colors and a HP Deskjet 560K of 300 dpi inkjet printer. Color quantization operations are performed separately on each color component, R, G, and B. Displayed image on the monitor using the proposed color quantization method shows almost no noticeable difference comparing to the original color image. And also the printed result using the proposed color dithering method shows high quality and less color degradation than the conventional printing method. Figure 3 (a) and (b) show the original image and the quanitzed one for monitor using conventional dithering and (c) the printed one using proposed dithering.

Conclusion

New methods for displaying and printing a full resolution color image on a limited color output device have been proposed. The color quantization for palette design consisted of hierarchical method based on HVS characteristics. This technique used activity-weighted distortion measure based on the sensitivity and spatial masking effect of HVS. In the color printing, dithering of nonlinear quantization is proposed to reduce color degradation by considering the overlapping phenomena of printing dots. In the dithering process, modified dot diffusion was also proposed. The proposed techniques enables the limited-color output devices to be used to display and print full resolution color images.

References

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