하드웨어 특성에 기반한 모델기반 변형된 블루 노이즈 마스킹

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Modified Blue-Noise Masking Based on Hardware Characteristics

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요 약

본 논문에서는 기존의 중간조 처리 방법들의 단점을 개선하고 원영상의 색을 충실히 재현하기 위해 도트 패턴 데이터베이스를 사용한 모델 기반의 중간조 처리 방법을 제안한다. 제안한 방법은 우수한 화질의 출력 영상을 얻기 위해 BNM을 기반으로 도트 패턴을 생성한 후 원형 도트 중첩 모델과 하드웨어의 점이득을 적용하여 도트 패턴 데이터베이스를 생성한다. 도트 패턴 데이터베이스는 하나의 밝기값에 도트 패턴각각 하나씩 구성되므로 출력 영상에서 원영상 화소의 색을 충실히 재현할 수 있다. 이 과정에서 인간 시각 특성을 적용하여 현재 화소의 색에 대해 국부적으로 인간 시각에 적합한 도트 패턴을 선택한다.

I. INTRODUCTION

Digital dithering is the process of generating a pattern of dots, within a limited number of levels, for the reproduction of a continuous tone image. Digital dithering is necessary for displaying continuous tone images in media when the direct rendition of tones is impossible. Accordingly, many dithering techniques are included in printing algorithms.[1]

Conventional order dithering[1,2] uses linear quantization through which input gray levels are equally divided by the printer resolution. This algorithm requires only simple processing and uses less computational time, however, it does not consider the hardware characteristics of the printer, therefore, differences in intensity are produced between a monitor and a printed image.

To solve these problems, model-based dithering of dot-pattern selection is proposed. The proposed algorithm uses a dot-pattern database that models overlapping phenomena among neighbor printing dots. A dot-pattern is defined as a part divided from a dot-profile which is the binary pattern resulting from the dithering of a constant gray level. In this paper, a dot-profile is generated using conventional blue noise masking. Therefore, the visual appearance of a dot pattern is similar to that of a dot-profile produced using blue noise masking. There are two steps involved in the proposed algorithm: the generation of a dot-pattern database and the selection of a dot-pattern from the dot-pattern database to represent the gray level. To solve the gray level difference problem, the gray levels of the dot-pattern sets are calculated using the circular dot-overlap model. Thereafter, the dot-pattern sets are reordered according to the results. In this paper, in order to improve the visual quality of the color dithering, the contrast sensitivity function (CSF) of the human visual system is used wherein the contrast sensitivity decreases rapidly with an increasing spatial frequency. Using this CSF, the visual difference between the original image and the dithered image can be computed as a numerical value. As a result, the optimal dot-pattern can be selected from the database.

Ⅱ. PROPOSED MODEL-BASED DITHERING USING DOT PATTERN SELECTION

2.1 Construction of dot-pattern database

The proposed algorithm modifies the weaknesses of the existing color dithering methods and constructs a dot-pattern database to represent the exact color component of the original image using a circular dot-overlap model.[4] A dot-pattern database is constructed independently for each CMY ink. The BNM used in the proposed method was developed by Parker[2,3] and its size is 256×256. By thresholding the BNM with each gray level, dot-profiles are constructed for every gray level. Using these dot-profiles, dot-patterns of $N_H \times N_W$ size for adjusting the resolution of the printer can then be recursively constructed by shifting 1 pixel. At this point, all previously constructed dot-patterns are excluded. The set of all the clipped dot-patterns is defined as the dot-pattern set.

As it is clipped from a BNM, the dot-pattern set already has blue-noise characteristics. When one pixel of the original image is dithered with the CMY dot-pattern databases independently, the color of the dot-pattern in the pixel of the reproduced image can be estimated as the average color of the dot-pattern in each CMY plane. The average color of one dot-pattern in a reproduced pixel, $P_{i,j} = \{P^C_{i,j}, P^M_{i,j}, P^Y_{i,j}\}$ is

$$P^C_{i,j} = \frac{1}{N_H N_W}\sum_x \sum_y p^C_{x,y}, \quad 0 \le x \le N_H,\ 0 \le y \le N_W,$$
$$P^M_{i,j} = \frac{1}{N_H N_W}\sum_x \sum_y p^M_{x,y}, \quad 0 \le x \le N_H,\ 0 \le y \le N_W,$$
$$P^Y_{i,j} = \frac{1}{N_H N_W}\sum_x \sum_y p^Y_{x,y}, \quad 0 \le x \le N_H,\ 0 \le y \le N_W, \qquad (1)$$

where (i, j) is the location of a pixel in an original image and (x, y) is the location of a dot in the dot-pattern. The values of $p^C_{x,y}, p^M_{x,y}, p^Y_{x,y}$ are the gray levels of one dot in a $N_H \times N_W$ dot-pattern. In an ideal case, the gray level of each color dot is 255 and the value of a blank dot is 0. However, an actual printed image has smaller color values because the size of a dot is larger than that of an ideal case die to ink absorption. The proposed method modifies this error and represents the exact color values by applying a dot-overlap model to the dot-pattern. For color dithering, the dot-pattern set is sorted and divided into a subset according to color values between 0 and 255. This sorted dot pattern is defined as the dot-pattern database.

The dot-overlap model used in the construction of a dot-pattern database assumes that the dot is circular and its ideal size covers the total area of an ideal rectangular dot and its ink has no absorption. Then the radius of an ideal dot is $T/\sqrt{2}$. The dot overlap can be modeled as in Fig. 1.

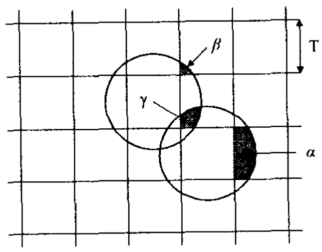

Figure 1. Circular dot-overlap model of ink.

The size of a dot-pattern is $N_H \times N_W$. Therefore, a dot-pattern database has a limited ability to express all color values. Furthermore, a dot-pattern may not exist for some color values. These color values are, therefore, substituted with the dot-patterns of the closest color value that contains a few dot-patterns in both the up and down direction. The error due to this compensation can be reduced by a CSF dot-pattern selection algorithm that chooses an appropriate dot-pattern for the color value of a pixel in the original image.

Using the constructed dot-pattern database of CMY color inks, the original image can be dithered by randomly selecting the dot-pattern. The resulting dithered image represents the color values of the original image, however, it has a poor image quality as it has lost its blue-noise characteristic. Accordingly, a dot-pattern selection algorithm is needed to maintain the blue-noise characteristics.

2.2 Dot-pattern selection algorithm

In this paper, a dot-pattern selection algorithm is proposed that uses the characteristics of the CSF of the human visual system and considers the dot-patterns selected for neighboring pixels.

The CSF used in this paper is a model that approximates the response of the human visual system. This model is basically a low-pass filter and can be represented as follows:

$$V_{u,v} = \begin{cases} a(b + c\tilde{f}_{u,v})\exp(-(c\tilde{f}_{u,v})^d), & if\ \tilde{f}_{u,v} > f_{\max} \\ 1.0, & otherwise \end{cases} \quad (2)$$

where a = 2.2, b = 0.0192, c = 0.114, and d = 1.1; $\tilde{f}_{u,v}$ is the radial spatial frequency in cycles/degree and f_{max} is the frequency at which the function peaks. To make use of the human visual model, a conversion from cycles/degree to cycles/inch is required. Let P be the printer resolution, d the viewing distance from the eye to the object, $N \times N$ the size of the image, (u, v) a location in the FT (Fourier transform) domain and $\tilde{f}_u$, $\tilde{f}_v$ the spatial frequency in cycles/degree in the two dimensions. It can be shown that

$$\tilde{f}_u = \frac{2udP}{N}\tan(0.5°), \quad \tilde{f}_v = \frac{2vdP}{N}\tan(0.5°), \quad (3)$$

where a viewing distance of 20 inches is assumed. The radial frequency can be given by

$$\tilde{f}_{u,v} = \sqrt{\tilde{f}_u^2 + \tilde{f}_v^2}. \quad (4)$$

To incorporate the decrease in sensitivity at angles other than horizontal and vertical, the radial frequency is scaled such as shown

$$\tilde{f}'_{u,v} \rightarrow \tilde{f}_{u,v} / s(\theta) \quad (5)$$

$$s(\theta) = (\frac{1-w}{2})\cos(4\theta) + (\frac{1+w}{2}) \quad (6)$$

where w is 0.7 as a symmetry parameter. $\tilde{f}'_{u,v}$ can then be substituted into Equation (20).

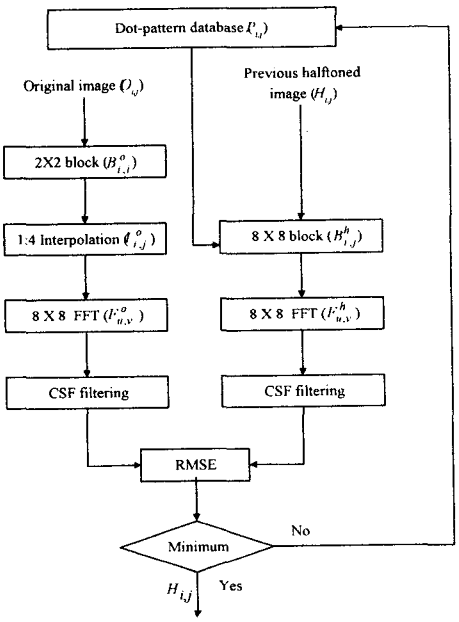

Figure 2. Global structure of dot-pattern selection algorithm.

Using this CSF, the difference between the visual responses to the original image and the dithered image can be computed as a numerical value. Therefore, an dot-pattern for a color value can be selected from the database.

In order to select the most appropriate dot-pattern for a current pixel from the cyan database, a local block method is used. A local 2 ×2 block of the original image and its corresponding halftone block of dot-patterns are compared using a CSF, FFT, and RMSE. Fig. 2 shows the global structure of the selection algorithm for a cyan dot-pattern.

Ⅲ. EXPERIMENTAL RESULTS

Fig. 3 shows images printed by various halftoning techniques. Here, (a) is the result of ordered dither, (b) is the result of error diffusion, (c) is the result of blue noise masking, (d) is the result of proposed dot-pattern selection method. In (a), (b), and (c), the colors were degraded due to the overlapping of printing dots. And (a) shows blocking effect in the smooth region. As the result of applying the proposed method, (d) had visual characteristic of blue noise mask and reproduced accurate gray levels. Thus, the proposed method can substantially reproduce the color values of the pixels in original image and obtain better image quality.

To compare the halftoning techniques, color difference ($\varDelta E^*_{ab}$) was calculated. The reproduced colors were measured by spectrophotometer. From the result, $\varDelta E^*_{ab}$ was calculated as follows;

$$\Delta E^*_{ab} = \sqrt{(L^*_O - L^*_R)^2 + (a^*_O - a^*_R)^2 + (b^*_O - b^*_R)^2} \quad (7)$$

where $L^*_O a^*_O b^*_O$ is CIEL*a*b* values measured on the monitor, $L^*_R a^*_R b^*_R$ is CIEL*a*b* values measured on the printer. Table 1 shows the comparison of the $\varDelta E^*_{ab}$ in the Macbeth color chart by using two conventional methods and the proposed method. The two conventional methods are error diffusion and blue noise masking. In the table, the proposed algorithm takes less error than the conventional methods.

Table 1. The comparison of $\varDelta E^*_{ab}$ between colors displayed on the monitor and colors reproduced on the printer.

	Ordered dither	Error diffusion	Blue noise masking	The proposed method
$\varDelta E^*_{ab}$	22.13	21.88	19.96	14.20

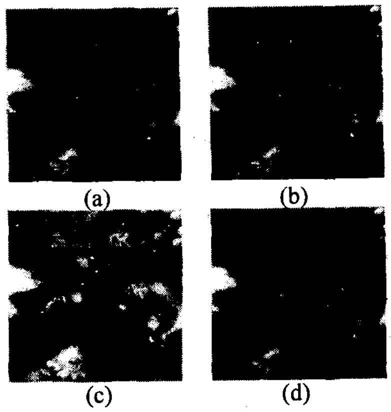

Figure 3. Fresh image printed by various halftoning techniques. (a) Ordered dither. (b) Error diffusion. (c) BNM. (d) The proposed method.

Ⅳ. CONCLUSION

In order to improve the visual quality of color halftoning, model-based dithering of dot-pattern selection was proposed. The proposed method could represent linear color change, because it considered the problem of dot-overlap. To solve the problem of dot-overlap, the gray levels of dot-pattern sets were calculated using a circular dot-overlap model and then measured by a spectrometer. Thereafter, the dot-pattern sets were reordered according to the results. In this process, in order to improve the visual quality of the color dithering, the contrast sensitivity function of the human visual system was used. As a result, the proposed techniques enable limited-color output devices to display and print high quality color images.

Reference

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[3] T. Mitsa and K. J. Parker, "Digital Halftoning Technique Using a Blue-Noise Mask," *Journal of Optical Society in America A*, vol. 9, no. 11, pp. 1920-1929, November 1992.

[4] T. N. Pappas, D. L. Neuhoff, "Printer Model and Error Diffusion," *IEEE Trans. On Image Processing*, vol. 4, no. 1, pp. 66-80, 1995.