An Evaluation of Image Quality by Spatial Frequency Analysis in Digital Halftoning

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Abstract

In this paper, we propose a new objective evaluation-value for the quality of digital halftoning images. The proposed evaluation-value are calculated based on the spatial frequencies of original and halftoning images. The viewing conditions are also considered in the evaluation-value as a visual contrast sensitivity function. We had an experiment to examine the relationship between the proposed evaluation-value and subjective evaluation. The four ordered dither methods and an error diffusion method were evaluated in the experiment. We found the proposed objective evaluation-value has high correlation with the subjective evaluation value obtained from the result of the experiment.

Introduction

In the low-cost printer, digital halftoning techniques are often adopted to print out the original images, because the techniques can be implemented by cheap and simple devices. As is well known, quality of usual images is dependent on sharpness, tone scale reproduction, graininess and color reproduction of the observed image.[1] Many quality criteria have been proposed and used to evaluate the usual images. The quality criteria, however, are not always applied to the digital halftoning images, because the digital halftoning images are observed with higher visual property. Only a few criteria have been proposed for the digital halftoning images.[2,5]

The evaluation of the image quality will give a suggestion for the improvement of digital halftoning techniques for high image quality. The blue noise characteristic[2] in the halftoning images is one of the suggestive criteria. The blue noise mask[3] was designed based on the blue noise characteristic. Many more criteria should be used in the halftoning images to improve the quality of digital halftoning images.

In this paper, we propose a new criterion for the quality of digital halftoning images. The criterion was introduced based on the assumption that the quality of images is degraded by the fluctuation of spectrum between the original and halftoning images.

Transfer Function of Digital Halftoning

The MTF (modulation transfer function) is defined as the modulus of spectrum of point spread function in the camera, scanning system and so on. In the digital halftoning, this usual MTF can't be defined because the point spread in the digital halftoning has shift variant characteristic. In the shift invariant system, the MTF can also be measured using the contrast transferred ratio of sinusoidal charts. In this paper, we defined transfer function of specific frequency in digital halftoning using the frequency transfer ratio of sinusoidal charts.

The original sinusoidal charts with 128*128 pixels were made for halftoning in the computer. The four ordered dither methods and an error diffusion method were applied to these original charts. Then, the modulus of spectra of original and halftoning images are compared at the spatial frequency of the sinusoidal wave in the original chart. The specific frequency transfer function (SFTF) is defined as follows:

$$SFTF(u) = \frac{\sqrt{(re'(u))^2 + (im'(u))^2}}{\sqrt{(re(u))^2 + (im(u))^2}}, \tag{1}$$

where u is the spatial frequency of the sinusoidal in the original image, re and im indicate the real and imaginary parts of spectrum in the original images, re' and im' indicate the real and imaginary parts of the spectrum in the halftoning images.

The calculated specific frequency transfer functions are shown in Figure 1. We found that the specific frequency transfer functions are fluctuating. We assumed that the fluctuations cause the noise in digital halftoning images.

Table 1. Experimental Conditions

Images	building, lady, tree, chart (Fig. 3)
Size of images	256 × 256 pixels, 3.5 × 3.5 cm on the display
Viewing distance	2m
Illumination	quasi-darkness
Display	72 dpi, maximum radiance is 63.0 W/(se.m2)
Observers	20 students
Evaluation method	Serial category method with 5 categories

A New Objective Evaluation-Value

In the previous section, we assumed that the fluctuations of specific frequency transfer function cause noises in

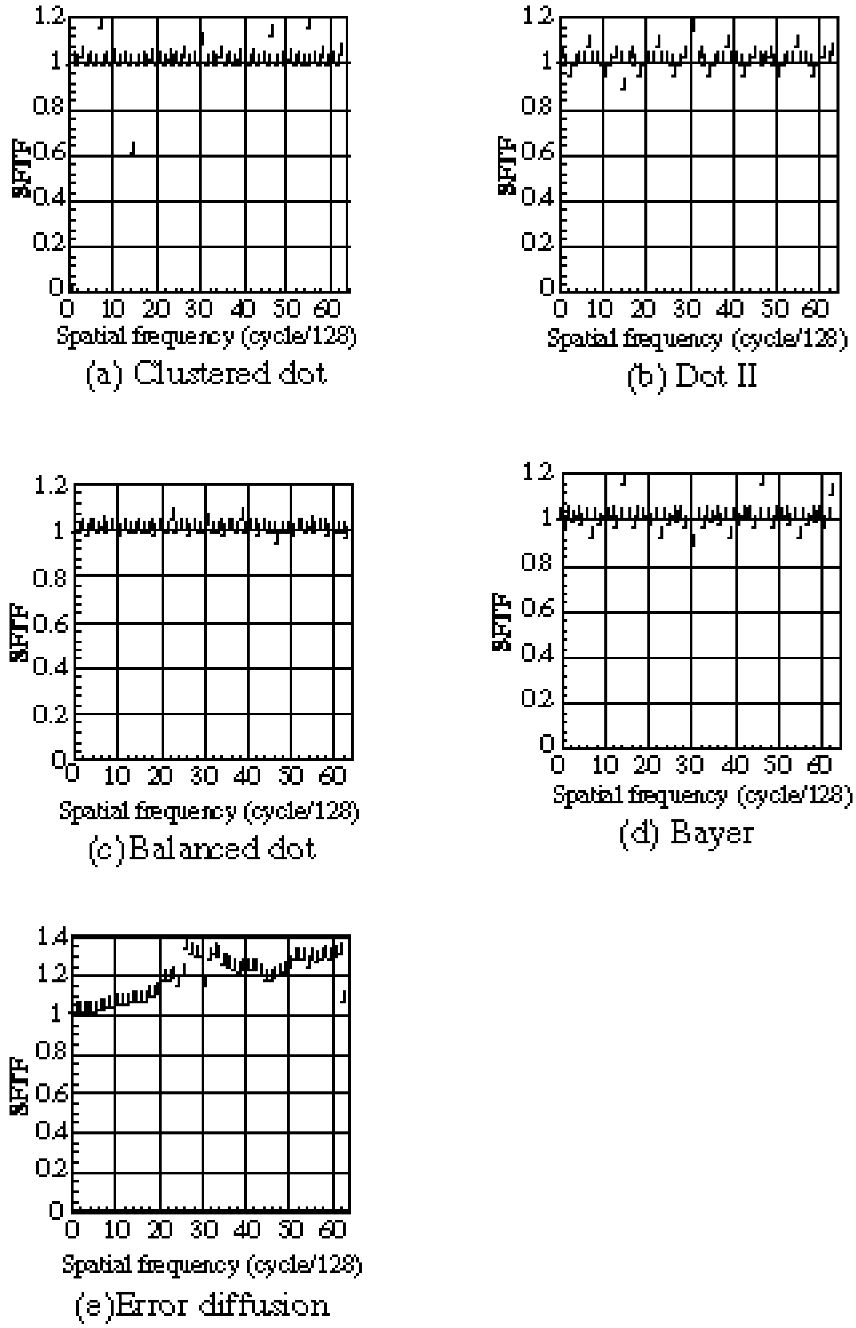

Figure 1. Specific frequency transfer function in digital halftoning

digital halftoning images. In this section, on the basis of this assumption, we propose a new objective evaluation-value for quality of digital halftoning images.

The proposed evaluation-value are calculated based on the spatial frequencies of original and halftoning images. The quality of digital halftoning image fairly depends on the viewing conditions; viewing distance, resolution of output device. The viewing conditions are considered in the evaluation-value as a visual contrast sensitivity function[4] (CSF). The visual contrast sensitivity function is shown in Figure 2. The proposed evaluation-value is calculated as follows:

$$V = \frac{\sum_u \sum_v \left|F_o(u,v)\right| \cdot CSF(U)}{\sum \sum \left|F_h(u,v) - F_o(u,v)\right| \cdot CSF(U)}, \qquad (2)$$

$F_o(I've)$, $F_h(u,v)$: spectrum of original and halftoning images,

$$CSF(U) = aU\ \exp(-bU)\sqrt{1 + c\ \exp(bU)},$$

$$U = \frac{\pi R d \sqrt{u^2 + v^2}}{25.4 \times 180 \times S},$$

$$a = 440(1 + 0.7/L)^{-0.2},$$

$$b = 0.3(1 + 100/L)^{0.15},$$

$$c = 0.06,$$

CSF(U): visual contrast sensitivity function,
U: is an angular spatial frequency,
R: resolution of display (dpi),
d: viewing distance (m),
S: size of image width (pixel),
L: maximum radiance of display (W/(sr m^2)).

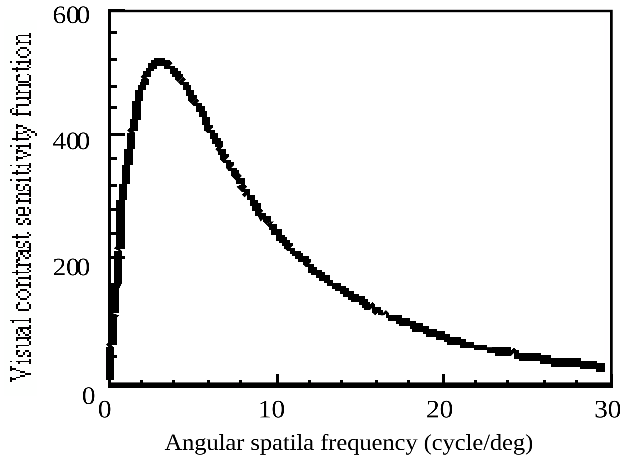

Figure 2. Visual contrast sensitivity function.

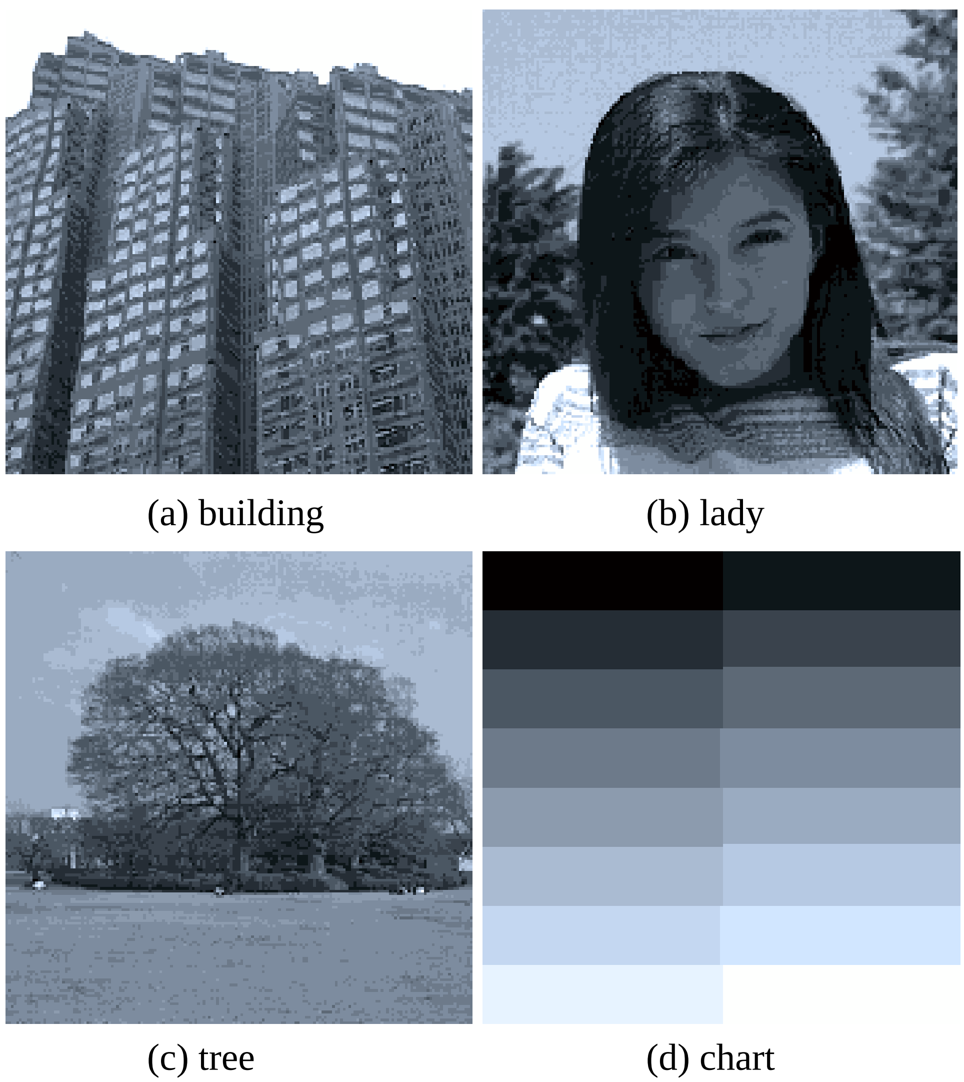

Figure 3. Original images used in the experiment

Experiment and Its Result

An experiment for subjective evaluation was performed for the 20 halftoning images (4 original images by 5 halftoning methods), using the serial category method with 5 categories. The used 4 original images are shown in Fig.3. The images were rated on total image quality. The experimental conditions are shown in Table 1.

Figure 4 shows the relationship between the proposed objective evaluation-value V and ORV (observer rating value) obtained from the result of the experiment. The coefficients of correlation are shown in Table 2.

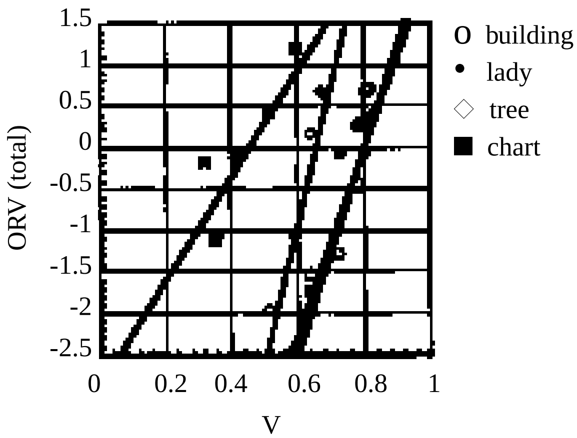

Figure 4. Relationship between the proposed objective-evaluation-value and ORV

Table 2. Coefficients of correlation

	building	lady	tree	chart
Total quality	0.84	0.85	0.98	0.74

From the result of experiment, we found that the proposed evaluation-value have high correlation with the ORV. The relatively low correlation in the chart image cause from the high subjective evaluation value of error diffusion method.

Summary and Discussion

We proposed a new objective evaluation-value for quality of digital halftoning images. The evaluation-value was based on the assumption that the quality of halftoning images is degraded by the fluctuations of spectrum between the original and halftoning images. By the experiment of subjective evaluation, we confirmed the effectiveness of the proposed evaluation-value.

At the halftoning images by the error diffusion method, the proposed evaluation-value didn't correlate well with the subjective evaluation because of the peculiar pattern. We should consider this phenomenon, and make a new evaluation-value to correlate with the halftoning images by the error diffusion method.

In this paper, we defined the specific frequency transfer function as the transfer function of digital halftoning. By this transfer function, we could find the specific frequency transfer functions are fluctuating. However, we can't find the transition of spatial frequency by this specific frequency transfer function. The transition will influence the quality of digital halftoning. We should consider the transition in the objective evaluation-value.

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