Improvement of Sharpness and Graininess for Color Image by Computer Processing and Its Image Quality Measurement

Kimiyoshi Miyata,**, Makiko Baba*, Norimichi Tsumura*, Hideaki Haneishi*, and Yoichi Miyake**
** Graduate School of Science and Technology, Chiba University*
1-33 Yayoi-Cho, Inage-Ku, Chiba 263-8522, Japan
*** Information Technology R&D Center, Mitsubishi Electric Corporation*
5-1-1 Ofuna, Kamakura, Kanagawa 247-8501, Japan

Abstract

Digital imaging systems consist of three devices; acquisition, recording, and display. In this research, the system is formulated as linear model for evaluating and improving the total image quality with respect to sharpness and graininess. On the basis of the model, the subjective quality of degraded image is estimated, then the model is applied to improve the image quality. The experimental results showed that the method proposed in this research is effective for evaluation and improvement of the image quality.

Introduction

Many kinds of digital imaging devices such as digital cameras and color ink-jet printers have been developed and widely used for recording color images instead of conventional photographic system. However, a little has been studied on the evaluation of quality of digital images obtained by the digital imaging system.[1] Bartleson showed that the total image quality is determined by the one which either sharpness or graininess is poor in the photographic images.[2]

In this research, the digital imaging system was formulated as linear model. Two objective criteria were defined to evaluate sharpness and graininess based on the linear model, and those were related to total image quality obtained from a subjective evaluation experiment. The resultant relation between them was named as image quality map. The image quality map was applied to improve the image quality of digital images. Computer simulation was carried out to improve the total image quality in the case where the image is degraded by noise in the image acquiring device. The low-pass filter to reduce the noise in the processing device was determined by using the image quality map. The effect of the filtering was confirmed by a subjective evaluation experiment.

Linear Model for Digital Imaging System

The digital imaging system is formulated as linear model. The original image $f(x,y)$ is degraded by point spread function (PSF) $h_a(x,y)$ and additive noise $n_a(x,y)$, then acquired image $f_a(x,y)$ is represented by Equation (1).

$$f_a(x,y) = h_a(x,y) * f(x,y) + n_a(x,y), \tag{1}$$

The operator * denotes the convolution integral. In the frequency domain, Equation (1) is represented by Equation (2).

$$F_a(u,v) = H_a(u,v)F(u,v) + N_a(u,v), \tag{2}$$

In this research, PSF is assumed as Gaussian form with mean zero and variance σ_h^2. The additive noise is assumed as Gaussian white noise with mean zero and variance σ_n^2. In this paper, subscript a, p, and d is corresponding to acquisition, processing, and display device, respectively. The functions represented in capital letter are also corresponding to their function in the spatial domain. The acquired image, processed image, and displayed image is represented by Equation (3), (4), and (5).

$$F_a = H_aF + N_a, \tag{3}$$

$$F_p = H_aH_pF + H_pN_a + N_p, \tag{4}$$

$$F_d = H_aHpH_dF + HpH_dN_a + H_dNp + N_o, \tag{5}$$

If the overall PSF and noise are denoted by H_o and N_o, following equation is obtained.

$$F_d = H_oF + N_o. \tag{6}$$

Figure 1 shows a schematic diagram of the imaging system considered in this experiment.

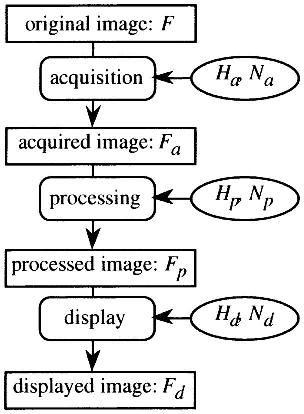


Figure 1. Schematic diagram of digital imaging system consisting of image acquisition, processing, and display device.

Objective Criteria and Monitor Response

Sharpness Criterion

Although several criteria are used to evaluate the sharpness of images,[3–5] modulation transfer function (MTF) is commonly used. In the imaging system, overall MTF is represented as cascaded form of each MTF. In this research, the criterion S for evaluating the sharpness is defined by Equation (7).

$$S = k_s \ln\left(\sum_{v=0}^{V-1} \sum_{u=0}^{U-1} \left|H_a(u,v)\right| \left|H_p(u,v)\right| \left|H_d(u,v)\right| C(u,v) \right) \qquad (7)$$

In Equation (7), k_s is coefficient for normalization, u and v is spatial frequency, U and V is maximum frequency. $H_a(u,v)$, $H_p(u,v)$, and $H_d(u,v)$ are Fourier transform of each PSF. $C(u,v)$ is the contrast sensitivity function of the human visual system[7] defined as

$$C(u,v) = af\exp(-bf)\sqrt{1 + c\exp(bf)} \qquad (8)$$

$$a = 440(1 + 0.7/L)^{-0.2}$$
$$b = 0.3(1 + 100/L)^{0.15}$$
$$c = 0.06$$
$$f = \sqrt{u^2 + v^2}$$

where L is maximum luminance of the CRT monitor.

Graininess Criterion

In the graininess evaluation of the images, root mean square (rms) granularity is commonly used as objective criterion.[5,6] The rms granularity is obtained by measure-ment of uniform density area, or Fourier transform of the fluctuation of the density data.[5] In this experiment, the objective criterion G to evaluate graininess is defined by Equation (9), which corresponding to the overall rms granularity for the imaging system with weight of the human visual system.

$$G = k_g \sqrt{\sum_{v=0}^{V-1} \sum_{u=0}^{U-1} \left\{ g_a(u,v) + g_p(u,v) \right\} C(u,v)^2} \qquad (9)$$

$$g_a(u,v) = \left|N_a(u,v)\right|^2 \left|H_p(u,v)\right|^2 \left|H_d(u,v)\right|^2$$
$$g_p(u,v) = \left|N_p(u,v)\right|^2 \left|H_d(u,v)\right|^2$$

In Equation (9), k_g is coefficient for normalization. $N_a(u,v)$, $N_p(u,v)$, and $N_d(u,v)$ are Fourier transform of the noise in each device. The other functions and variables are the same in Equation (7).

Measurement of Monitor Response

A CRT monitor is used as image display device in this experiment. There are many kinds of technique for measuring the PSF of display devices.[8-10] In this experiment, the PSF $h_d(x,y)$ of the CRT monitor was obtained from the line spread function (LSF) measured by photographic technique. Firstly, a line pattern of one dot width was displayed on the monitor. Then, the pattern was taken by a photographic camera, and the density distribution of the line pattern, which recorded on the reversal film, was measured by a microdensitometer. The measured density distribution was converted to luminance distribution using gray scale charts taken by the camera simultaneously. Finally, the luminance distribution was approximated by Gaussian function with variance of σ_{hd}^2. The PSF was calculated from the LSF under the assumption that the CRT monitor has an isotopic property. Figure 2 shows the obtained luminance distribution of the CRT monitor. The variance σ_{hd}^2 is 1.08×10^{-6}.

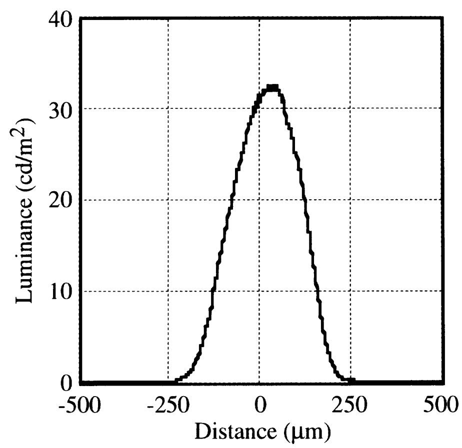


Figure 2. The measured LSF of the CRT monitor used in the experiment.

Image Quality Map

Sample Preparation

Although total image quality is affected by many factors, only sharpness and graininess are considered in this experiment. The total image quality is related to two objective criteria based on the subjective evaluation experiment. This relation is called as image quality map in this research. Thirty-six sample images produced by the combination of six different response function $H_p(u,v)$, and noise level $N_p(u,v)$ were prepared and displayed on the CRT monitor. The response function was changed by variance σ_h^2 of Gaussian form, and the noise level was changed by variance σ_n^2 of the noise. The values of σ_h^2 are 0.00, 8.10×10^{-7}, 1.69×10^{-6}, 2.89×10^{-6}, 6.25×10^{-6}, and 1.08×10^{-6}. The values of σ_n^2 are 0, 16, 32, 48, 64, and 80, respectively.

Figure 3 shows a schematic diagram of the imaging system for preparing the image quality map. Figure 4 shows the original images used in the experiment. The image is digitized in 512 by 512 pixels with 256 levels in each color plane Red, Green, and Blue.

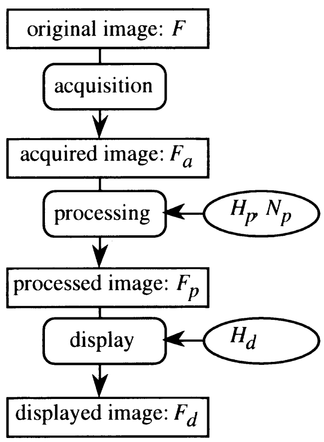


Figure 3. Imaging system for preparing the samples. Response function and noise level in the image processing device are changed in 6 levels each.

(a) Portrait (ISO/JIS SCID N1).

(b) Cafeteria (ISO/JIS SCID N2).

Figure 4. Original images used in the experiment.

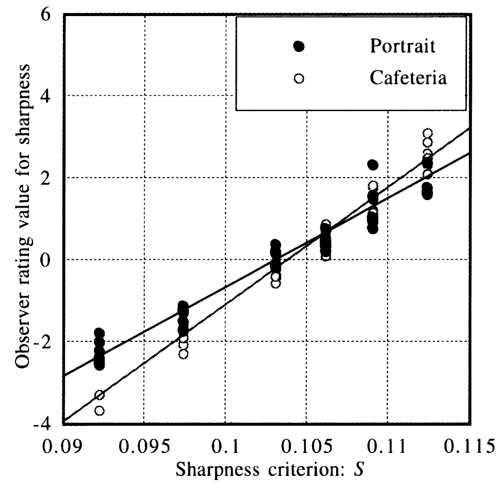


Figure 5. Relationship between observer rating value and sharpness criterion S.

Subjective Evaluation Experiment

Image quality of the degraded image was rated by 21 observers who are students of our laboratory (16 males and 5 females). The observers were asked to evaluate on three kinds of quality; total image quality, sharpness quality, and graininess quality. Each quality of 36 images was rated by five rank successive categories method, and the rating values were calculated statistically. [11]

Figure 5 shows the relation between the observer rating value (ORV) for the sharpness and sharpness criterion *S*. The straight line in the figure shows a result of linear regression between them. The correlation coefficient of the linear regression is 0.953 for portrait scene and 0.988 for cafeteria scene. Figure 6 shows the relation between the ORV for the graininess and graininess criterion *G*. The correlation coefficient is 0.968 and 0.967 for portrait and cafeteria scene respectively. Both criteria *S* and *G* are well correlated with the ORV. From the definitions of the criteria, a higher value of the criterion *S* means better sharpness quality, and a lower value of the criterion *G* means better graininess quality.

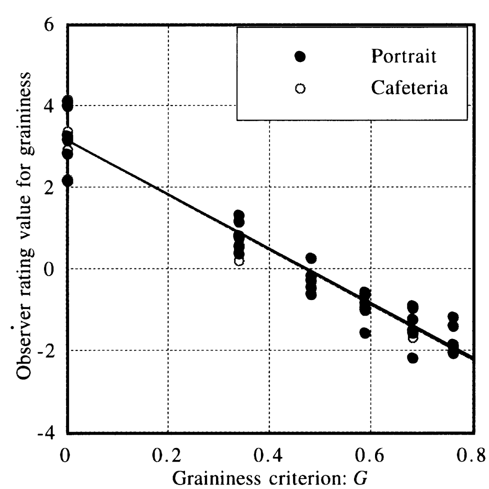
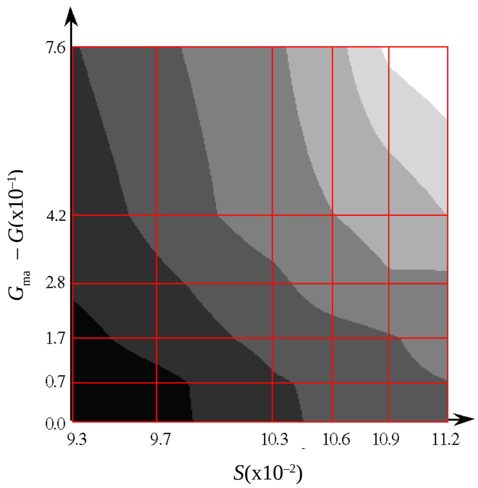
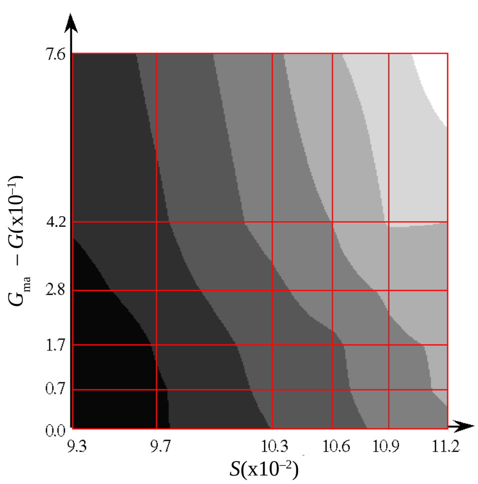


Figure 6. Relationship between observer rating value and graininess criterion G.

By using these criteria, the ORV for the total image quality was related to the sharpness and graininess criteria as the image quality map shown in Figure 7. The horizontal and vertical axes are show the sharpness criterion S and graininess criterion G, respectively. The gray area with same density shows the same ORV for the total image quality. The brighter area represents higher ORV. This figure shows the similar result obtained by Bartleson's experiment. This relationship is used as image quality map in the following simulation.



(a) Portrait



(b) Cafeteria

Figure 7. Relationship between the total image quality, the sharpness criterion S and graininess criterion G.

Computer Simulation for Image Quality Improvement

Overview of Computer Simulation

The image quality map and objective criteria are applied to improve the total image quality in the case where the image is degraded by a noise added in the acquiring device. Figure 8 shows a schematic diagram of imaging system for the simulation. In the simulation, it was assumed that the noise $N_a(u,v)$ with variance σ_n^2 is added in the acquisition device. The noise is reduced by the spatial filter $H_p(u,v)$ resulted by the PSF of the processing device. The filter is determined using the image quality map and objective criteria.

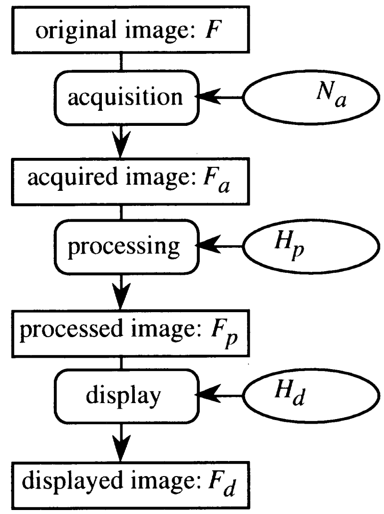


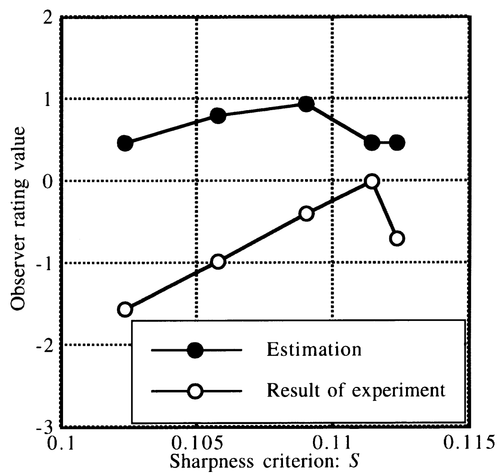
Figure 8. Schematic diagram of imaging system for simulation experiment to improve the total image quality.

Preparation of Samples

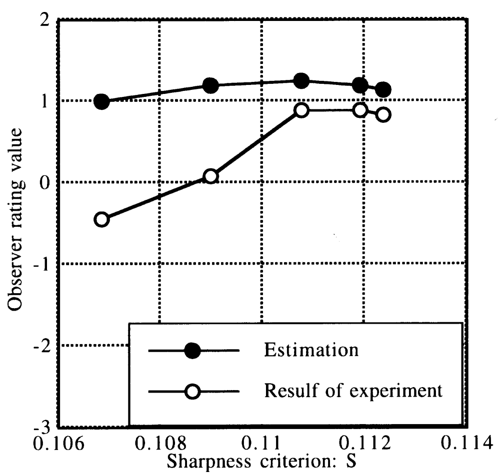
Five samples, which named as sample 1 to 5, were prepared to confirm the improvement of image quality for each scene. Sample 1 is without filtering of $H_p(u,v)$, sample 3 is filtered by $H_{pm}(u,v)$, and the others are comparing samples. The filter $H_{pm}(u,v)$ is expected to obtain the highest image quality, and it is determined by an iterative method. Firstly, an initial $H_p^{i=0}(u,v)$ is considered, and S^i and G^i are calculated under the condition that noise $N_a(u,v)$ is added in the acquisition device. The total image quality for S^i and G^i is obtained using the image quality map. Next, $H_p^{i+1}(u,v)$, which is stronger blur filter than the initial one, is considered, and S^{i+1} and G^{i+1} are calculated again. The total image quality for S^{i+1} and G^{i+1} is obtained from the image quality map. This cycle was repeated until the response function $H_{pm}(u,v)$, which provides the highest total image quality, is obtained.

Result of Simulation Experiment

To confirm the improvement of the total image quality, a subjective evaluation experiment was carried out using 20 observers (18 male and 2 female). The rating and calculation methods of the image quality are the same as that to obtain the image quality map. The result of the subjective evaluation experiment is shown in Figure 9. The vertical axis is the ORV for the total image quality, and horizontal axis is the sharpness criterion S. The lower number on the horizontal axis represents stronger blurring effect. The solid dots show the estimated ORV obtained using the image quality map, and the open dots show the result from the subjective evaluation experiment. On the basis of the estimation, sample number 3 was expected to be the highest image quality. In the cafeteria scene, the peaks of the estimation and result of the experiment are match, however, the peak of the result of the experiment is shifted to weaker filter in the portrait scene.



(a) Portrait.



(b) Cafeteria

Figure 9. Results of the experiment for improving the total image quality.

Discussion

The objective criteria used in this research were correlated well with the subjective evaluation. Therefore, the result of the computer simulation, which expecting to obtain the highest image quality, shows that the peaks were corresponding for cafeteria scene. However, the peaks of the estimation and result of the experiment were not corresponding to portrait scene. The further consideration based on the human evaluation for the total image quality is required for more accurate evaluation of the total image quality from sharpness and graininess.

Conclusion

The quality of the images obtained through the digital imaging system has evaluated based on the sharpness and graininess. Recently, users of the imaging devices can build the digital imaging systems meeting to their aspects. The imaging devices should be designed to satisfy the aspect. To achieve this, the subjective and objective evaluations are both required. This research provides an advantage for evaluation and improvement of quality of image obtained through imaging systems.

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