Eye Movement Analysis and its Application to Evaluation of Image Quality

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Abstract

It is well known that an image has a particular gazing area. From the experimental results of our previous papers, we found that total image quality is highly influenced by quality of the gazing area. In this paper, we evaluated total image quality of degraded images by a physical quality criterion (PQC) calculated from the gazing area. The experimental result showed that the calculated PQC is not dependent on the scene. On the other hand, PQC calculated from the whole area of the image is dependent on the scene content. In this paper, the effectiveness of the evaluation of image quality under the consideration of gazing area is presented and discussed.

1. Introduction

The quality of images is dependent on sharpness, tone reproduction, graininess and color reproduction characteristics of the observed images. Many physical quality criteria (PQCs) such as acutance, RMS granularity and color difference, have been proposed and used for evaluation of image quality[1-5]. The evaluation using these PQCs has given a good suggestion for the improvement of imaging systems. The image quality also depends on the content of scene. However, the content has not been considered in conventional PQCs. It is well known that an image has a particular gazing area[6], and this area is dependent on the content of scene[7]. In the experimental results of our previous papers[7,8], we found that the total image quality is highly influenced by quality of the gazing area.

In this paper, we apply the information of gazing area to the conventional method of image evaluation to take into account the content of scene. First, the eye movements are analyzed for original and degraded images, and the gazing area used for the evaluation is decided from the analysis for each scene. We extract an appropriate PQC for the image quality from the extracted gazing area. The PQC is also extracted from the whole area of the image, then these PQCs are compared with each other by correlation coefficients. The correlation coefficients are calculated from linear regressions between the subjective image quality and each measure.

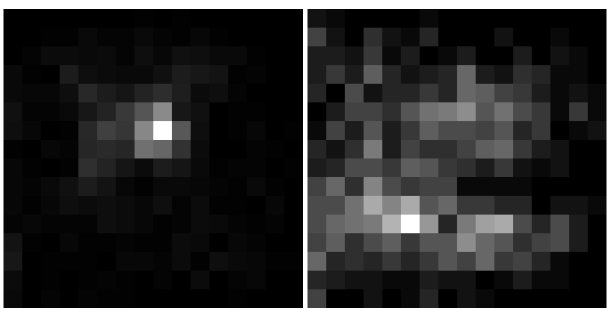
This paper is organized as follows. The measurement of gazing area of degraded images by changing the sharpness, graininess and chroma is discussed in section 2. In section 3, we describe a subjective rating experiment of images where sharpness and graininess are degraded variously. The difference of PQC between the gazing area and whole image is analyzed in section 4. Finally, in section 5, we discuss and summarize our experimental results.

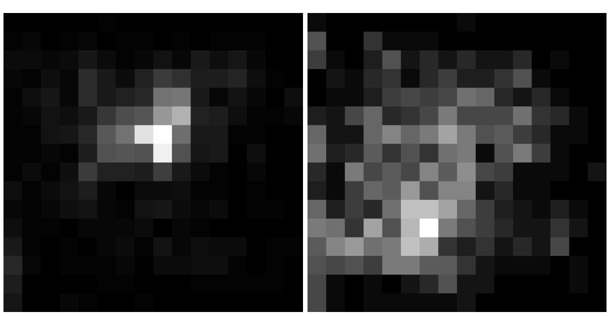
2. Measurement of gazing area in various degraded images

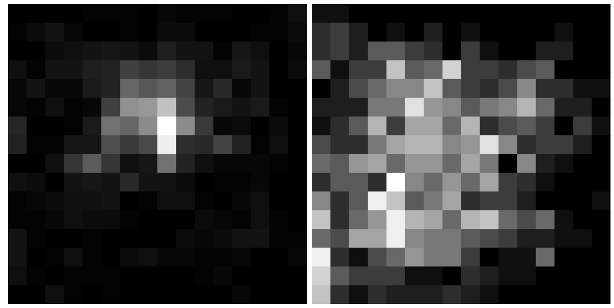
Two kinds of original scene (ISO/JIS-SCID N1 portrait and N2 cafeteria, 512x512 pixels at 8 bits) used in the experiment are shown in Fig. 1. We produced three kinds of degraded images; blurring, noise addition and chroma shift for the original image. Eye movements during the viewing of the images were measured by using eye camera with phototransistor (Eye Movement Monitor, Takei Kiki Kogyo Co. LTD., Japan). Six observers viewed these images displayed on a monitor (GDM-2000TC, SONY Corporation, Japan) in a light room for a minute. In the observation, the observers were asked to evaluate total image quality of the displayed image. Eye movements of six students (five males, one female) were measured and the average data was used for the following experiments.

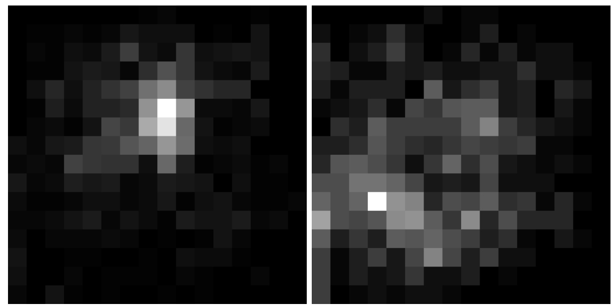
Gazing point was defined by the same method proposed by a previous paper[9]. The images were divided into 16x16 sub-regions and the number of gazing points was counted for each sub-region. The minimum and maximum numbers of gazing point in sub-regions were scaled 0 to 255 gray levels. Then, we can visualize eye movement as 8 bits gray image. Figures 2, 3, 4, and 5 show examples of eye movement distribution of original and degraded images. In the figures, brighter regions indicate the concentrated gazing points. The sub-regions larger than 20 were defined as gazing area of the image. Figure 6 shows the resultant gazing area. This result indicates that the shift of gazing area is small among degraded images in the evaluation of the total image quality. This result suggests that the area may be fixed in each scene even if degradation occurs. Therefore, we considered that the gazing area can be used for the evaluation of degraded image.

(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 1. Original images used in the experiment.


(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 2. Gazing points distribution maps of original images.


(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 3. Gazing points distribution maps of blurred images.


(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 4. Gazing points distribution maps of noise images.


(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 5. Gazing points distribution maps of chroma shift.


(a) scene #1 (portrait) (b) scene #2 (cafeteria)
Figure 6. Gazing area determined from distribution maps.

3. Subjective evaluation of degraded image

Though there are many factors to determine the image quality, we focus here on the sharpness and graininess. The sharpness of the image was changed by Gaussian filtering in the frequency domain with different half-width of the filter. The graininess of the image was changed by adding a random noise with different amplitude.

Thirty-six sample images calculated by combinations of six different degrees of the sharpness and graininess were prepared and displayed on the CRT monitor. Image quality was rated by fifteen observers who are student of our laboratory (thirteen males, two females). The viewing distance and angle were 45 cm and 20 degrees respectively. The observers were asked the total quality of 36 images by five ranks successive ordered method, and the rating values were calculated statistically[10].

4. The relationship between gazing area and subjective evaluation

We calculate the PQC Qm in each sub-region of the degraded images by Eq. (1)[11].

$$Qm = k\int_{v=0.0}^{1.1}\int_{u=0.0}^{1.1}\left|Fo(u,v) - Fd(u,v)\right|CSF(u,v)dudv \quad (1)$$

where u and v are spatial frequencies on the retina, Fo(u,v) and Fd(u,v) are power spectra of the original image and degraded image respectively, and k is a coefficient for normalization. CSF(u,v) is a contrast sensitivity function of the human visual system calculated by Eq. (2)[12].

$$CSF(u,v) = af\exp(-bf)\sqrt{1+\exp(-bf)} \quad (2)$$

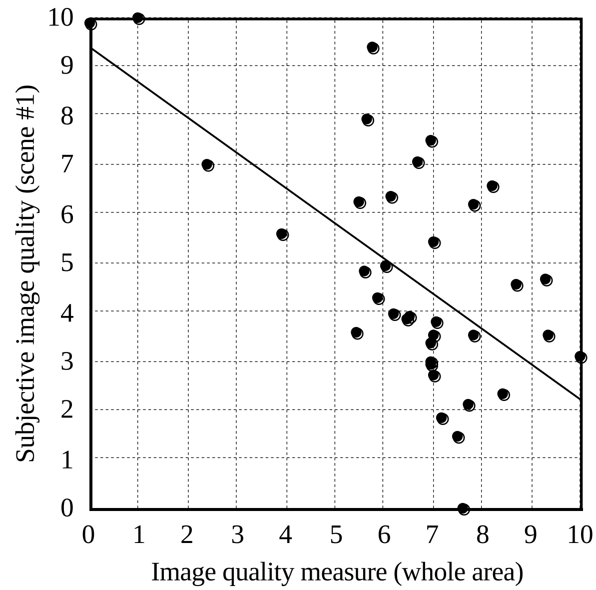
$$a = 440(1+0.7/L)^{-0.2}$$

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

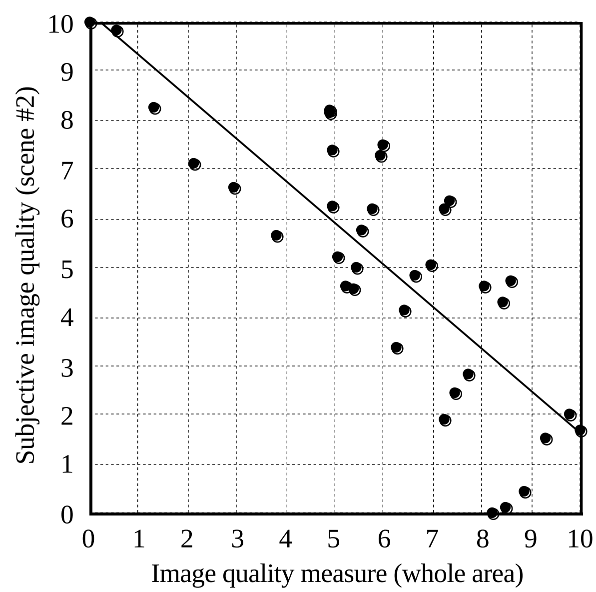
$$c = 0.06$$

$$f = \sqrt{u^2+v^2}$$

As a PQC for total image quality, we used maximum values of Qm among the sub-regions in the gazing area and whole area respectively. Figure 7 (a) and (b) shows the relationship between the observer rating value and PQC calculated by Eq.(1) for whole area in scenes #1 and #2. The correlation coefficients are 0.631 and 0.809. On the other hand, Fig. 8 shows relations between the observer rating values and the PQC based on the gazing area. The correlation coefficients for scene #1 and #2 were 0.789 and 0.809 respectively. Figure 8 shows that the PQC obtained by the gazing area is well correlated to the observer rating value in both scenes #1 and #2.

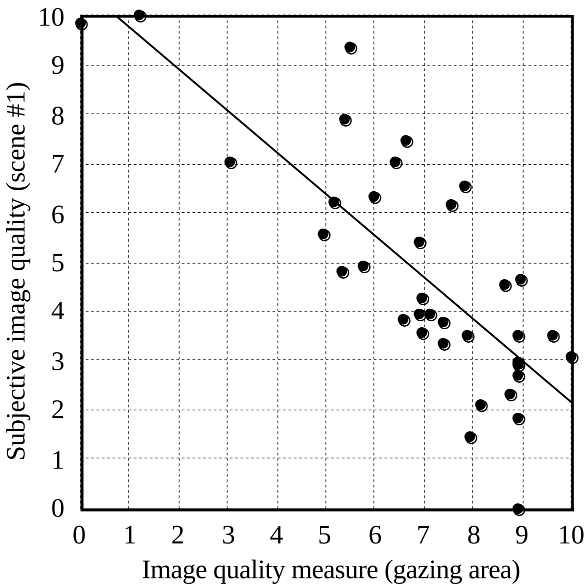


(a) scene #1 (portrait)

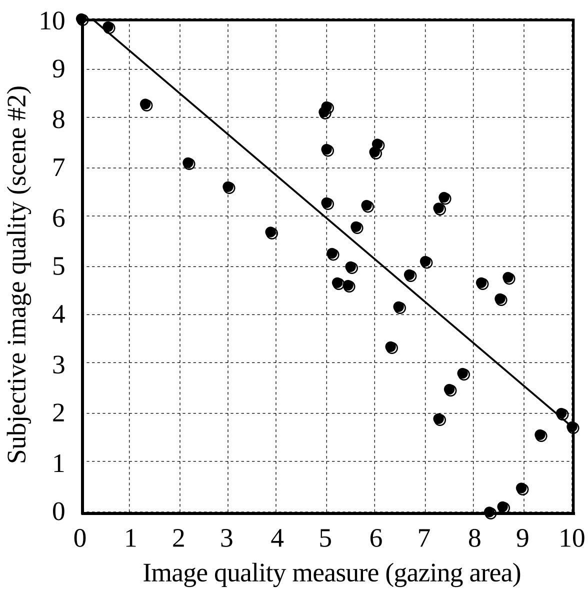


(b) scene #2 (cafeteria)

Figure 7. Relationship between the observer rating value and PQC obtained by the whole area of the image.



(a) scene #1 (portrait)



(b) scene #2 (cafeteria)

Figure 8. Relationship between the observer rating value and PQC obtained by the gazing area.

5. Discussion and conclusion

The gazing area of two typical scenes; cafeteria and portrait, were measured in changing the graininess and sharpness. Physical quality criterion (PQC) was defined by using visual contrast function and power spectrum of the image both in gazing area and whole area. Thirty-six images with different image quality were rated by fifteen observers and the observer rating value was compared with the PQC. The results showed that the PQC calculated in the gazing area is well correlated to the observer rating value and it is not dependent on the scene contents.

In this experiment, we analyzed only two scenes, therefore it will be necessary to analyze more images to confirm the proposed method. We believe, however, that the method is significant to evaluate the image quality.

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