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A Comparison of PSNR, WSNR and ESNR Evaluation Methods for The Two Value Modulated Images

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Abstract

We have proposed an objective evaluation method using ESNR as the measure of approximation by the visual model, which coincides with MOS, a subjective evaluation method. For two-value images, we have used five kinds of modulation methods: 1) ordered dither, 2) least mean error, 3) pulse density four division, 4) simple two-value, and 5) random dither methods. The purpose of this paper is to investigate the validity of ESNR, by comparing the proposed method together with the existing representative methods such as PSNR and WSNR, with the subjective method MOS. The results of a series of experiments show that the ranking by MOS coincides with ESNR, though does not coincides with PSNR and WSNR.

Keywords : Event Reporting, PSNR, WSNR, ESNR, Digital Item

1. INTRODUCTION

The image quality evaluations are classified into a subjective and an objective evaluation method. The subjective evaluation methods are based upon the judgment by a person's sight. It is frequently used thanks to its convenience. However, there are such faults with this method as the evaluation results change easily according to the environmental conditions and it is time and laborious to do. In contrast, the objective evaluation methods perform quantitative of evaluations using the measurements of physics. However, using the so far proposed methods such as SNR (Signal to Noise Ratio)[1][2], the results do not always agree with those by human evaluations.

We have, therefore, constructed a visual model for human visual information processing that is processed hierarchically through the external world, the retina and finally, in human brain. We proposed an objective evaluation method reflecting the subjective evaluation method made by people using this visual model[5]. As the modulated method that changes a halftone images into a two-value image, there are 1) ordered dither method, 2) least mean error, 3) pulse density four division, 4) simple two values and 5) random dither. When a person looks at the whole of those two-value images, this visual model uncovered theoretically the process how a human recog-

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nizes those as a pseudo halftone image.

The purpose of this paper is to investigate the validity of ESNR (Eta SNR), by comparing with the subjective method MOS (Mean Opinion Score), the representative existing methods that are PSNR (Peak SNR) or WSNR (Weighted SNR), and then, ESNR. We show that the ranking by MOS coincides with ESNR, although not with PSNR and WSNR.

In this paper, section 2 describes an original image and various modulated images. Section 3 describes the conditions of a subjective evaluation experiment. Section 4 describes the evaluation method of PSNR and WSNR. Section 5 explains the evaluation method of ESNR using the visual model. In section 6, we compare PSNR, WSNR and ESNR with MOS and present the validity of ESNR. Section 7 concludes this paper.

2. ORIGINAL IMAGE AND TWO VALUE MODULATED IMAGE

The original images that are used in our experiment are those that have been used as standard images in general. They are SIDBA-GIRL, SIDBA-Moon Surface and SIDBA-Milk Drop as shown in Fig.1. The original images are 256×256=65536 pixels and 256 gray levels. Figure 2 shows the ordered dither images (D) of three original images. Figure 3 shows the least mean error images. Figure 4 shows the pulse density four-division images (P). The number of pulses modulates each image so as to be closest to the original image. Figure 5 and Figure 6 show the simple two value images (S) and the random dither image (R), two value modulated images respectively.

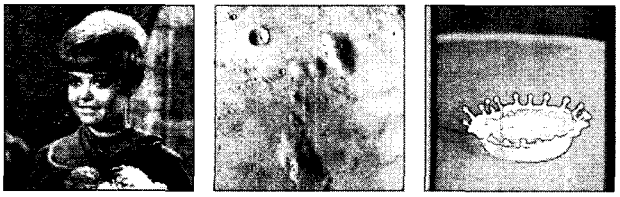

Fig. 1. Original image(Girl, Moon Surface, Milk Drop)

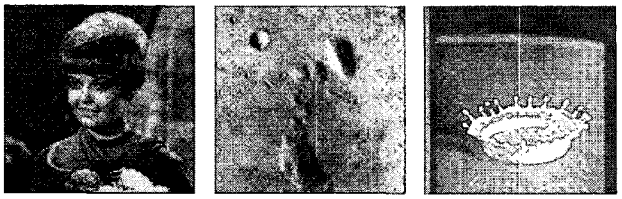

Fig. 2. Ordered dither image (D) (Girl, Moon Surface, Milk Drop)

Fig. 3. Least mean error image (H) (Girl, Moon Surface, Milk Drop)

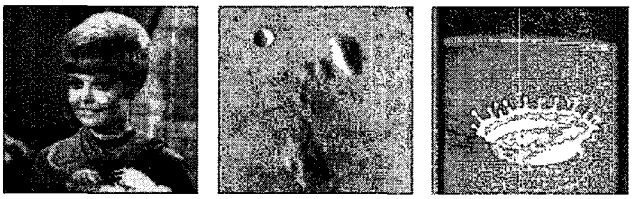

Fig. 4. Pulse density four division image (P) (Girl, Moon Surface, Milk Drop)

Fig. 5. Simple two-value image (S) (Girl, Moon Surface, Milk Drop)

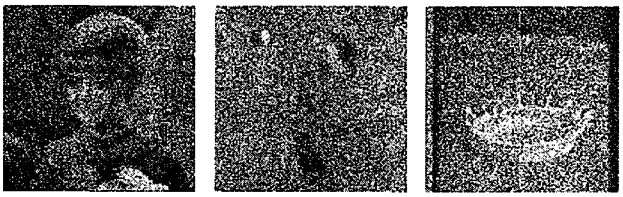

Fig. 6. Random dither image (R)(Girl, Moon Surface, Milk Drop)

3. CONDITIONS OF THE SUBJECTIVE EVALUATION EXPERIMENT

Table 1 indicates the conditions of a subjective evaluation experiment, which are based on ITU-R recommendation. The original images and the various modulated images are shown simultaneously. Numbers are set for each of the latter, as 1,2,3,4, and 5 in the order of similarity to the original images and the smoothness of the halftone. The viewpoint is located at by the distance of 4 times of the height of an image. The light of the room is low. Fifteen persons perform the experiment.

The result is represented by the average of the subjective average ranking MOS (Mean Opinion Score). Ranking 1 of MOS means closest to the original, while ranking 5 means the furthest from the original image.

Table 1. Condition of subjective evaluation experiment

Modulated method Visual distance	Various pulse modulated images 4H(H: height of a image)
Illumination	Low(Semi-darkroom)
The maximum luminosity The number of evaluation persons	75 cd/㎡ 15 persons
Evaluation measure The presentation method	Compared with the nearness between the halftone of the various pulse modulated images and the halftone of original image, and the score of 1,2,3,4, and 5 is attached to the superior order. To a evaluation person, an original image and various pulse modulated image are shown simultaneously, and are evaluated

4. EVALUATION METHOD OF PSNR AND WSNR

The definitions of PSNR and WSNR are shown in the formulae (1), and (2), respectively. PSNR is the result of evaluation that is obtained by comparing a modulated image $\hat{f}(r)$ directly with the original image $f(r)$. WSNR is the compared result of evaluation when both images are translated in the space frequency domain, where $S(\mu,\nu)$ denotes the FFT image of the original image, and $\hat{S}(\mu,\nu)$ denotes the FFT image of the modulated image.

$$PSNR = 10 \log_{10} \frac{(S_{\max})^2}{\frac{1}{N}\sum_{i=1}^{N}\{f_i(r)-\hat{f}_i(r)\}^2} \quad (1)$$

$$WSNR = 10 \log_{10} \frac{(S_{\max})^2}{\sum_{\mu=1}^{255}\sum_{\nu=1}^{255}\{S(\mu,\nu)-\hat{S}(\mu,\nu)\}^2 \cdot W(\mu,\nu)} \quad (2)$$

Here, $\hat{W}(\mu,\upsilon)$ is a weighted function in the specific space frequency domain indicated as in literature [3]. N is the number of pixels, and Smax is the maximum value of pixels.

WSNR that takes the space frequency characteristics of a person's sight into account is thought to coincide with the subjective evaluation, however some counter examples are known as following. WSNR does not coincide with the subjective evaluation for the ITE skin color chart, a mountain village in ITE Switzerland, ITU-BARBARA, SIDBA-GIRL, and SIDBA-AERIAL. Therefore, it is known that WSNR is the evaluation measure that tends to be dependent on the used images [4].

5. EVALUATION METHOD OF ESNR BY THE VISUAL MODEL

Figure 7 is an outline figure of the proposed visual model. In general, it is known to take blur in the visual observation of the image when a focus become out. It is shown by expression (3) of fundamental equation of the

visual pattern.[7] Here, τ is the amount of blur and $f(r,\tau)$ is called a visual pattern. $f(r,\tau)$ is an image that contains blur to original image $f(r)$. The fundamental function system defined in relation to the fundamental equation is an orthogonal function system (Hermite polynomial system) that is independent from blur. This is uniquely defined. The two value modulated image $\hat{f}(r)$ correspond to original image $f(r)$. The $\hat{f}_{MN}(r)$ is the limited series expansion representation by the fundamental function system of $\hat{f}(r)$ and is referred restoration image. M=M_0, N=N_0 of optimum number of terms are chosen. It has already been proven to close restoration image $\hat{f}_{MN}(r)$ to original image $f(r)$[5]. This is a principle that gives the fundamental of the image evaluation method by the visual model. A concrete content of the evaluation method is occupied to the following. Restoration images $\hat{f}_{MN}(r)$ from various modulated image $\hat{f}(r)$ is requested. The expression $\hat{f}(r)$ of blur τ=0 with number m=M, n=N of limited series is occupied to the formula (4), (5), (6). Here, Np is a number of pulses of the entire images. $H_m(x_0\text{-}a_0/\sigma_0)$, $H_n(y_0\text{-}b_0/\sigma_0)$ is Hermite polynomials with respects to m and n respectively. M and N are the number of terms of Hermite polynomials. (a_0, b_0) is visual-point and σ_0 is visual field. G(r,τ) is gussian distribution. r is the position vector, r = e_xi + e_yj.

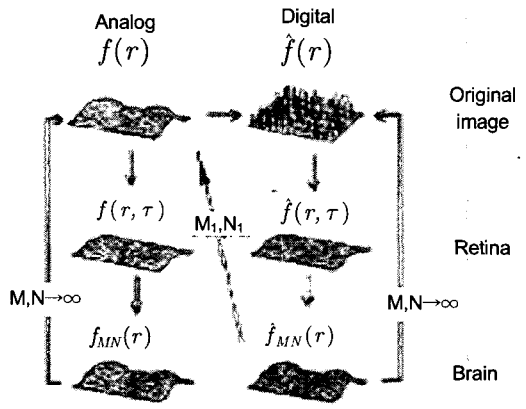

Fig. 7. Outline diagram of visual model

$$\left(\nabla^2-\frac{\partial}{\partial\tau}\right)f(r,\tau)=0 \tag{3}$$

$$\hat{f}_{MN}(r)=\sum_{m=1}^{M}\sum_{n=1}^{N}\left(\frac{1}{m!n!}\right)\tilde{B}_{mn}H_m\left(\frac{x-a_0}{\sigma_0}\right)H_n\left(\frac{y-b_0}{\sigma_0}\right) \tag{4}$$

$$\tilde{B}_{mn}=V\sum_{i=1}^{N_p}G(r_0-P_i,\tau_0)H_m\left(\frac{P_{ix}-a_0}{\sigma_0}\right)H_n\left(\frac{P_{iy}-b_0}{\sigma_0}\right) \tag{5}$$
$$(m=0,1,2,\cdots)(n=0,1,2,\cdots)$$

$$G(r,\tau)=\frac{1}{4\pi\tau}e^{-\frac{r^2}{4\tau}} \tag{6}$$

Then, measure of approximation η^2 is expressed as formula (7). η^2 is calculated by the error of $f(r)$ and $\hat{f}_{MN}(r)$ by NORM the second power of NORM, and normalize it.

$$\eta^2=\frac{\left\|f(r)-\hat{f}_{MN}(r)\right\|^2}{\left\|f(r)\right\|^2} \tag{7}$$

It is important to find a restoration image for the best approximation number of terms M_0 and N_0 such that η^2 becomes minimum.

$$f(r)\cong\hat{f}_{M_0N_0}(r) \tag{8}$$

η^2 for M≡M_0,N≡ N_0 is made into the objective evaluation measure of various modulated method. Instead of

η^2, we use ESNR (Eta SNR) as defined by the formula (9), taking after to SNR representation.

$$ESNR = 10\log_{10}\frac{\|f(r)\|^2}{\|f(r)-\hat{f}_{MN}(r)\|^2} \quad (9)$$

As the value of ESNR increase, the difference of $f(r)$ and $\hat{f}_{MN}(r)$ decrease, when $\hat{f}_{MN}(r)$ becomes closer to $f(r)$, and we regard the accuracy of η^2 higher.

6. COMPARISON OF PSNR, WSNR, ESNR AND MOS

Figures 8~10 show the results of the comparison with MOS, of PSNR, WSNR, and ESNR of Girl, Moon-Surface, and Milk-Drop, respectively[8]. On the horizontal axis, the modulations methods are aligned, while the vertical axis shows either MOS of the subjective evaluation or the [db] values of the objective evaluation. On the vertical axis, the lower direction means the superior. We denote the order of the superiority (or inferiority) is using the mathematical comparison symbols.

For the comparison of the various modulations in the case of Girl as shown in Fig.8, the order of the superiority

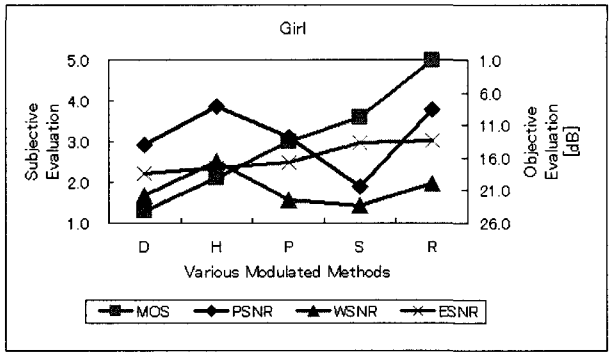

Fig. 8. Comparison of various evaluation methods (Girl)

is D>H>P>S>R for the subjective evaluation MOS, S>D>P>R>H for PSNR, and S>P>D>R>H for WSNR, D>H>P>S>R for ESNR. Only ESNR among other evaluation methods coincides with MOS.

In the case of Moon-Surface of the Fig.9, the order of the superiority is D>H>P>S>R for MOS, S>P>D>R>H for PSNR, S>D>H>P>R for WSNR, and D>H>P>S>R for ESNR. Only ESNR coincides with MOS.

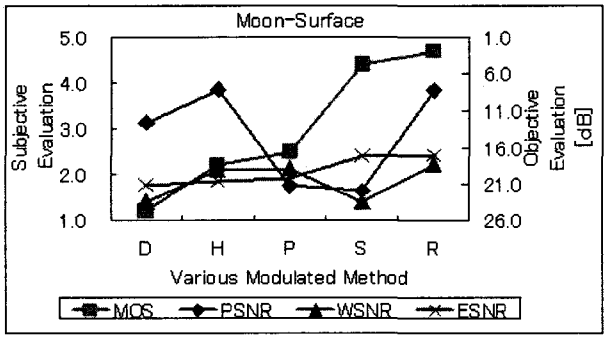

Fig. 9. Comparison of various evaluation methods (MoonSurface)

In the case of Milk-Drop Fig.10, the order of superiority is D>H>P>S>R for MOS, S>P>D>R>H for PSNR, S>D>R>H>P for WSNR, and D>H>P>S>R for ESNR. Only ESNR among these coincides with MOS.

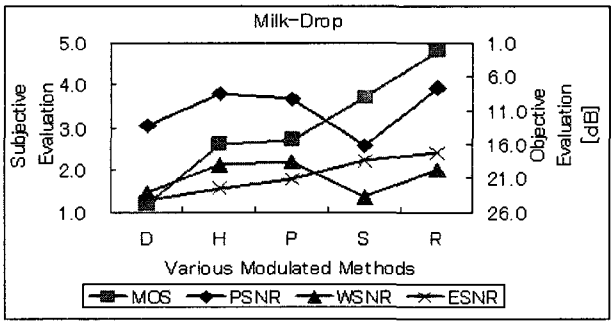

Fig. 10. Comparison of various evaluation methods (MilkDrop)

While the order of superiority or inferiority with the subjective evaluation MOS does not coincide with PSNR and WSNR in the above three kinds of images, it proved

that the measure of the approximation ESNR by the visual model coincides with the superiority or inferiority by MOS in the subjective evaluation.

7. CONCLUSION

In this paper, we have used three kinds of images of SIDBA-Girl, SIDBA-MoonSurface, and SIDBA-MilkDrop as a standard image. We have used the two value images that are modulated by five kinds of methods: 1) ordered dither, 2) least mean error, 3) pulse density four divisions, 4) simple two values and 5) random dither. We have compared PSNR that is a frequently used objective evaluation method, WSNR that incorporates a smoothing operation, ESNR using visual model that is propose in this paper, with the subjective evaluation MOS.

The comparison results show that PSNR and WSNR are different from the subjective evaluation MOS, while ESNR of the measure of approximation coincides with the superiority or inferiority of the subjective evaluation MOS. Therefore, it has been made clear that ESNR with the measure of approximation by the visual model is effective, for the objective evaluations of various two value modulated images.

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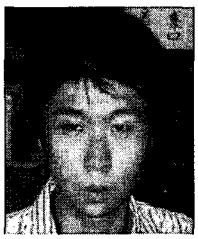

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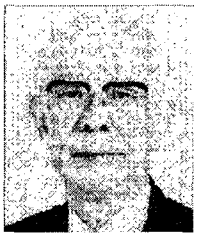

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