The Number of Effective Pixels for Digital Still Cameras and its Picture Quality

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Abstract

To realize good total image quality for digital still cameras, it is important to achieve coexistence of higher resolution and lower noise level. In this research we develop the noise simulation model based on the noise properties of actual digital still cameras. Psychophysical experiments are conducted by using a series of simulated images which have different resolutions and noise levels. Contribution of resolution and noise level to total image quality are discussed by analyzing the experimental results.

Introduction

Although the image area size of CCD devices employed in consumer digital still cameras is getting smaller, the number of effective pixels is increasing dramatically for recent years. This is achieved by the advanced technology of fine electronic-device processing. However, at the same time, it is usually accompanied with some loss of light efficiency captured by the device and consequently increase of noise in the resultant images. Therefore, it is getting more important to investigate the relationships among the number of pixels, device noise level, and perceived image quality.

Many researches have been already carried out to evaluate total image quality. R. Shaw proposed the criteria which satisfy simultaneous resolution and noise.[1] G. M. Johnson has been studying to develop the image quality metrics by using a vision model.[2] However, we think it is necessary to gather psychophysical data which examine the relationship among the attributes to the overall image quality.

In this research, first we develop the noise model to estimate the noise properties propagated through the camera system. This model covers a wide range of variations including device-pixel size, ISO speed settings, etc. Then we make the image quality map so that we can learn the adequate effective pixel number of CCD devices to provide a preferable image under a given picture size and noise level.

Noise Model

Figure 1 shows a simple structure of digital still camera. Optical signal through a lens is sampled and transformed to electric singal by a CCD. After the signal is amplified by a analog processor, it is converted to digital signal by a A/D converter. By a digital processor this digital signal is processed to the digital image and it is recorded to a memory.

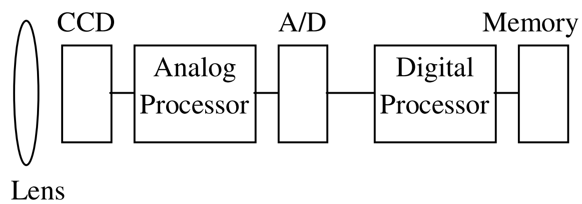


Figure 1. Structure of digital still camera

It is relatively easy to get the properties of noise propagation on digital process. For example, amplifying signal double increases S/N (signal to noise ratio) by 6 dB. And if signal is digital-filtered, S/N varies depending on the frequency response of the digital-filter.

There are many kinds of independent noise which are generated throughout a digital still camera. However, we assume the total noise is composed of dark noise, fixed pattern noise and shot noise. Dark noise is mainly due to thermal noise. Fixed patten noise is due to the variation of aperture size etc., and it is generated during the manufacturing process of CCDs. Shot noise is due to the variation of photons and it is known that its magnitude is proportional to the square root of light intensity level.

The total noise is calculated by taking the sum of those three individual noise and defined by the following equation 1.

$$N_t = \sqrt{N_d^2 + N_f^2 + N_s^2} \quad (1)$$

where N_t, N_d, N_f and N_s denote total noise, dark noise, fixed pattern noise and shot noise respectively. We attempt to measure these three kinds of noise and get total noise.

Dark Noise is measured on the condition that the incident light is intercepted. We measure it by varying analog gain, and get the result as shown in figure 2. It is found that the property of dark noise is proportional to analog gain.

Fixed pattern noise is statistically independent of random noise. Therefore averaging images captured on the same condition, random noise is removed and fixed pattern noise remains. Measuring it by varying incident light intensity level, we get the result as shown in figure 3. It is found that the property of fixed pattern noise is proportional to signal level or incident light intensity level.

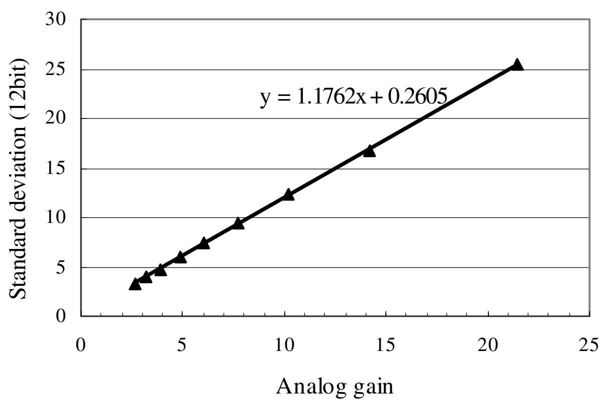


Figure 2. Property of dark noise

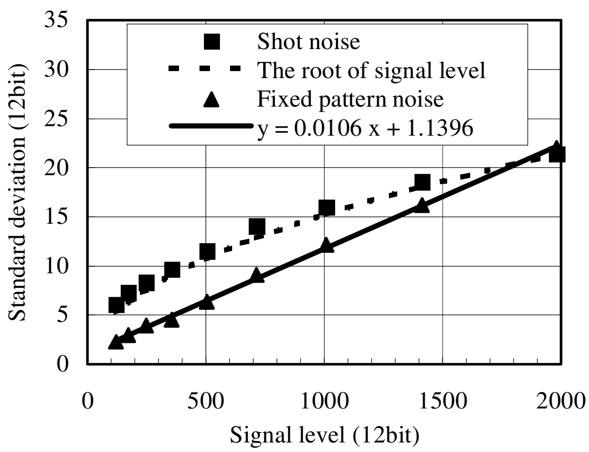


Figure 3. Properties of fixed pattern noise and shot noise

According to our assumption, the random noise removed above is the combination of dark noise and shot noise. Therefore it is possible to get shot noise from measured total noise, dark noise and fixed pattern noise. That is also shown in figure 3. It is clear that the property of shot noise is cetainly proportional to the square root of signal level or incident light intensity level.

As a result of those properties, we make the noise model as follows.

$$N_d(x, g) = m_d \cdot g + n_d \tag{2}$$

$$N_f(x, g) = m_f \cdot x + n_f \cdot g \tag{3}$$

$$N_s(x, g) = m_s \cdot \sqrt{x \cdot g} \tag{4}$$

where m and n are parameters of this noise model, g is analog gain, and x is signal level just after A/D converter and is already amplified by analog gain. Substituting the noise levels for equation 1, we can get a total noise level.

Figure 4 shows that noise levels obtained by the noise model approximately correspond to measured noise levels at the point after digital processor. And it is noticable that this correspondance maintains for different ISO speed settings.

Next we think that the relationship between the noise model and pixel size of CCDs. We investigate the parameters of the noise model by measuring some CCDs that have different pixel sizes, and estimate the relationship between the pixel pitch and the parameters. The result is shown in figure 5. It is found that m_f and m_s increase as the pixel pitch decreases.

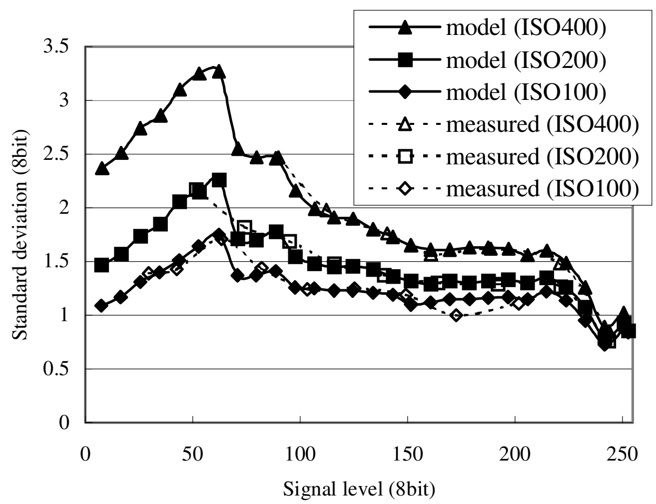


Figure 4.Correspondence between model's noise and measured noise

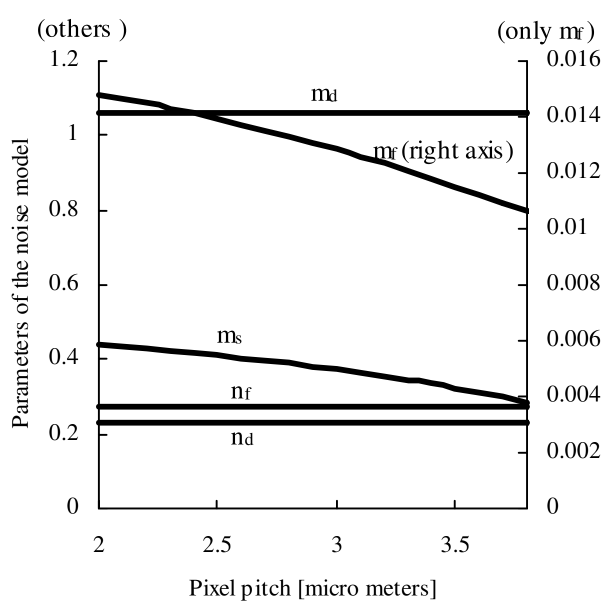


Figure 5. Parameters of the noise model with different pixel pitches

Experimental Setup

Simulated images for the psychophysical experiment are made varying the number of pixels and noise level.

Original images are scanned from 4x5 reversal films with 2400dpi. The images are subsampled to mosaic images. At the subsampling pattern we adopt checker array which is equivalent to the data obtained from Super CCDs[3] as shown in figure 6. Variation of the number of pixels is realized by varying the subsampling pitch. Simulated white noise of which levels are given by the noise model is added to those subsampled images. Here assuming that images are captured by 1/1.7 type CCD, subsampling pitches can be translated into physical pixel pitches. So we can vary parameters of the noise model according to the subsampling pitch. After that the images are signal-processed by the simulator for Super CCD, and resultant images that have three colors of R, G, B at each pixel are given. Table 1 shows those conditions to make images.

Table 1. The Conditions For Experimental Setup

Subsampling pitches	2, 3, 4, 5, 6
Subsampling pattern	Checker array
The number of effective pixels [M pixles]	11.3, 5.0, 2.8, 1.8, 1.3
Pixel pitches [micro meters]	1.9, 2.9, 3.8, 4.8, 5.7
Parameters of the noise model	According to figure 5
ISO speed settings	100, 200, 400, 800, 1600

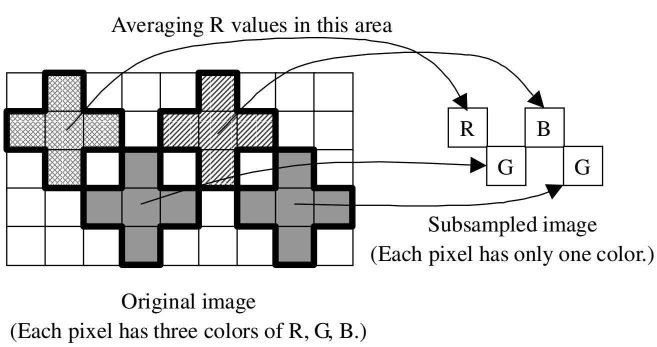
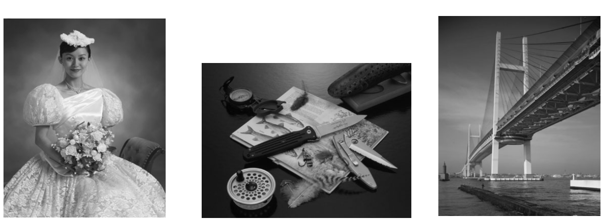


Figure 6. Subsampling pattern (In case that subsampling pitch is 2)



Bride *Knife* *Bridge*

Figure 7. Evaluated scenes

Three scenes as shown in figure 7 are selected for the psychophysical experiment.

As a result, 25 images varied in 5 numbers of pixels and 5 noise levels are given for each scene.

Psychophysical Experiments

To examine the preference of the 25 images described above, we conducted psychophysical experiments. Experimental conditions are shown in table 2.

Table 2. The Conditions of the Experiments

Observers	15 persons having experiences of evaluating images
Illuminance	About 1000 lux
Distance from observer to print	30cm
Print Sizes	A4, L-size (8.9cm x 11.8cm)
Questions to observers	1. "Rank these images according to your preference.", 2. "Select the print with which the image quality is satisfied." 3. "Select the print with which the image quality is not satified."
Statistical method	Thurston Case V

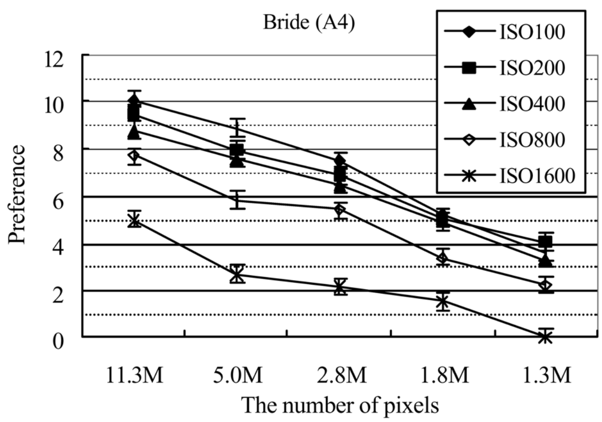
Table 3. The Results of Question 2,3. (Only about Bride scene. The first number in each cell shows the percentage of observers who satisfy the print, and second one shows the percentage of observers who don't satisfy the print. Gray cells show that the first number is and over 80%, and Black cells show that the second number is and over 80%.

pixels \ ISO	100	200	400	800	1600
11.3M	93/0	87/0	87/0	47/0	7/73
5.0M	93/0	73/0	53/7	13/53	0/93
2.8M	27/0	13/13	13/20	7/53	0/100
1.8M	0/47	0/53	0/60	0/87	0/100
1.3M	0/80	0/73	0/80	0/93	0/100

(a) Bride (A4)

pixels \ ISO	100	200	400	800	1600
11.3M	93/0	87/0	87/0	67/7	40/20
5.0M	80/0	80/0	67/0	47/13	7/67
2.8M	47/7	53/7	47/20	27/33	7/93
1.8M	33/20	47/7	33/7	0/47	0/93
1.3M	20/40	20/20	13/20	0/80	0/93

(b) Bride (L)



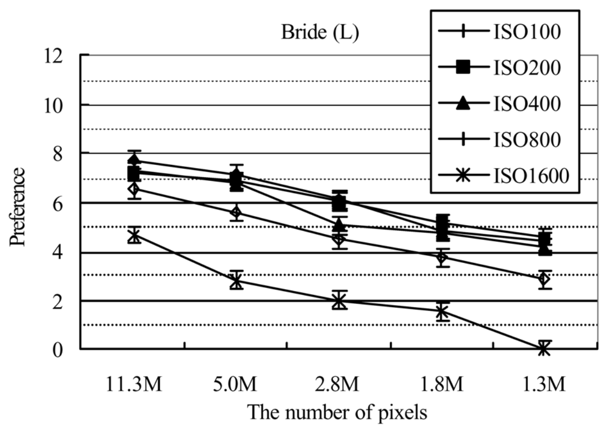


Figure 8. The Results of Question 1 (Only about Bride scene)

The psychophysical results are shown in figure 8 (Question 1) and Table 3 (Question 2, 3). And we find out the following results.

- As the number of pixels increases, the preference of the image becomes higher. There is also difference between 11.3M and 5.0M.
- In case of L-size, the difference among the number of pixels is smaller compared to A4-size.
- The difference between ISO 100 and 200 is small.
- Especially in high ISO speed, in ISO 1600, the difference between 11.3M and 5.0M is obvious. This is because that the noise pattern is getting small.
- About most 5.0 M images and higher, 80 % of observers accept that the quality is satisfied.

Conclusions

From the results so far examined in this experiments, it is found that the preference of image quality increases as the number of pixels increases.

On the other hand, it is interesting to learn that most observors satisfy with the image quality of 5.0M pixels or higher. Therefore this suggests that a digital still camera with 5.0M pixels is enough to provide good image quality for consumer use.

For consumer digital cameras, the number of pixels of CCD is a significant factor not only for its image quality but also for determination to buy. These results will give a hint to design CCDs according to target users.

References

1. Rodney Shaw, "Satisfying simultaneous resolution and noise criteria in digital images", IS&T's 2000 PICS Conference, pp. 71-74, (2000).
2. Garrett M. Johnson and Mark D. Fairchild, "Sharpness Rules", IS&T's 2000 Color Imaging Conference, pp.24-30, (2000).
3. T. Yamada, et al., "A Progessive Scan CCD for DSC Application", ISSCC2000 Digest of Technical Papers, pp. 110-111, (2000).

Biography

Masaya Tamaru received MS degree at Kobe University and he joined Product Planning & Development Div., Electronic Imaging Products Div., Fuji Photo Film in 1996. Currently he is engaged in developing image processing for digital still cameras.