

Comparing Image qualities of Silver Halide Films and Digital Still Cameras

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Abstract

Image qualities of prints from color negative films and of those from digital still cameras are compared in terms of a number of pixels, a number of recording levels and a signal-to-noise ratio derived from granularity or a quantizing interval.

The comparison is done in two steps of a psychological evaluation of prints in terms of sharpness and graniness, an analysis of the evaluated results based on information theory. The conclusion is that prints from color negative films have an advantage in a number of pixels and prints from digital still cameras have an advantage in a signal-to-noise ratio when optimum exposure levels are set.

Introduction

Although the comparison of color negative films(CNF) and digital still cameras(DSC) have been done by several authors[1,2] we decided to update the comparison because both CNF and DSC have improved very much since then.

Though DSC still have some difficulties in exposure lattitudes due to narrow dynamic range and in moire due to aliasing, their image qualities in terms of a number of pixels, a number of recording levels and a signal-to-noise ratio have improved capable enough to compare to that of CNF.

We compare image qualities of DSC which adopts additive color filters and single CCD to that of CNF in terms of a number of pixels, a number of recording levels and a signal-to-noise ratio.

Psychological Evaluation

Image qualities of prints from DSC and CNF are compared by psychological evaluation in terms of sharpness and graniness.

The Super G ACE400 and REALA of Fuji Photo Film with three different formats of 135 and Half and 110 (we refer these as like ACE400(135), REALA(135) for convenience) are adopted as CNF and the F3 of Nikon is used as a camera. Also DCS460 of Eastman Kodak and DS300 of Fuji Photo Film are adopted as DSC.

A close-up of a woman with macbeth color checker is used as original scene to avoid image defects of moire and optimum exposure levels are set per manufacturers recommendation.

Table 1. Devices used in the experiment

Device	Speed	Size
DCS460	80	3060×2036
DS300	150	1280×1000
ACE400(135)	400	36mm×24mm
ACE400(Half)		24mm×17mm
ACE400(110)		17mm×13mm
REALA(135)	100	36mm×24mm
REALA(Half)		24mm×17mm
REALA(110)		17mm×13mm

Three different sizes of prints are made. Prints from CNF are made by using conventional color paper and printer. Prints from DSC are made by adjusting their gamma to that of prints from CNF, resizing their size by using bi-cubic-spline interpolation of photoshop, then printed out to color paper by using Laser printer **Frontier** of Fuji Photo Film.

Table 2. Conditions of printing

Item	DSC	CNF
Printer	Frontier	Enlarger C450
Print Material	LASER PAPER	Super FA9
Print Size	A4(297mm×210mm)	
	2L(178mm×127mm)	
	L(127mm×89mm)	

These prints are observed by sixteen observers and their image qualities are compared by a method of pair comparison for each print size. Though there are several factors which would affect psychological evaluation such as a moire or a difference in tone reproduction, observers are requested only to evaluate sharpness and graininess. Following relations are found.

- psychological relation between prints from DCS460 and those from ACE400(135) differed between observers. About one half of them evaluated prints from DCS460 is superior to those from ACE400(135) while other half evaluated inferior. Above relation is treated as statistically equivalent. Also same relation is found between prints from DS300 and those from ACE400(110) and same treatment has done.

- Almost every observer evaluated prints from DCS460 are inferior to those from REALA(135) and prints from DS300 are inferior to those from REALA(110).

- above relations do not depend on print size.

We denote above relations by following expressions.

$$\text{ACE400(135)} \fallingdotseq \text{DCS460} < \text{REALA(135)} \quad (1)$$
$$\text{ACE400(110)} \fallingdotseq \text{DS300} < \text{REALA(110)} \quad (2)$$

Image Entropy

The realtion between prints from DSC and those from CNF derived from psychological evaluation is analyzed based on information theory.

Entropy(also called information capacity) is originally introduced to analyze one dimensional data such as voice. Although there are several ways to extend the entropy to analyze two dimensional data such as image[3,4] we adopt following definition which we call **image entropy**.

$$H(P,K) = \log_2 PK = \log_2 P + \log_2 K \quad (3)$$

where $H(P,K)$, P and K denotes the image entropy, a number of pixels and that of recording levels of given image respectively.

To calculate a number of pixels of CNF one should define a size of pixels of CNF. If we assume a shape of the pixel is square, the length of one side of the pixel is usually defined by following equation.

$$a = \frac{1}{2f}$$

where f is the frequency when Modular Transfer Function(MTF) corresponds to 0.5.

$$\text{MTF}(f) = 0.5$$

To adjust the difference that CNF are multi-layered media while DSC are mono-layered we multiply three to the number of pixels of CNF.

$$P = 3 \cdot \frac{A}{a^2}$$

where A represents an effective area of CNF.

Since the frequency of ACE400 is 50cycles/mm a number of pixels of three formats are given as follows.

$$P(135) = 3 \cdot \frac{36\text{mm} \times 24\text{mm}}{(0.01\text{mm})^2} = 25.92 \times 10^6$$
$$P(\text{half}) = 3 \cdot \frac{24\text{mm} \times 17\text{mm}}{(0.01\text{mm})^2} = 12.24 \times 10^6$$
$$P(110) = 3 \cdot \frac{17\text{mm} \times 13\text{mm}}{(0.01\text{mm})^2} = 6.63 \times 10^6$$

Where $P(135)$,$P(\text{half})$ and $P(110)$ denotes a number of pixels of formats of 135, half and 110 respectively. Since the frequency of REALA is 60cycles/mm a number of pixels of three formats are given as follows.

$$P(135) = 3 \cdot \frac{36\text{mm} \times 24\text{mm}}{(0.0083\text{mm})^2} = 37.32 \times 10^6$$
$$P(\text{half}) = 3 \cdot \frac{24\text{mm} \times 17\text{mm}}{(0.0083\text{mm})^2} = 17.62 \times 10^6$$
$$P(110) = 3 \cdot \frac{17\text{mm} \times 13\text{mm}}{(0.0083\text{mm})^2} = 9.54 \times 10^6$$

Next we calculate a number of recording levels. A number of recording levels of CNF is usually defined as below.

$$K = \frac{\Delta D}{2\sigma}$$

where ΔD denotes the effective density range of CNF and σ denotes the granularity measured by the pixel mentioned above. The effective density range of common CNF is 2.0.

$$\Delta D = 2.0$$

Since a granularity of ACE400 around the density of 1.0 measured with a circular aperture of diameter 48μm is 0.0054, σ is given by following expression by Selwyn's law.

$$\sigma = 0.0054\sqrt{\frac{\pi(24\mu\text{m})^2}{(10\mu\text{m})^2}} = 0.023$$

Thus a number of recording levels of ACE400 is given by below.

$$K = \frac{2.0}{2 \times 0.023} = 44$$

Since a granularity of REALA around the density of 1.0 measured with a circular aperture of diameter 48μm is 0.004, σ is given by following expression by Selwyn's law.

$$\sigma = 0.004\sqrt{\frac{\pi(24\mu\text{m})^2}{(8.3\mu\text{m})^2}} = 0.020$$

Thus a number of recording levels of REALA is given by below.

$$K = \frac{2.0}{2 \times 0.02} = 50$$

A number of recording levels of DSC is desided by a noise level of CCD and that of amplifier and a quantizing interval. Since we have no data to judge which is dominant, we assume a quantizing interval is dominant. This assumption implies that a number of recording levels of DSC corresponds to that of nomial, say 256.

$$K = 256$$

We have to note that a failure of the assumption immediately gives $K < 256$.

Image entropy of devices are shown in Table 4.

Table 3. Image Entropy of devices

Device	P	K	$\log_2 PK$
DCS460	6.23×10^6	256	30.6
DS300	1.28×10^6	256	28.3
ACE400(135)	25.92×10^6	44	30.1
ACE400(Half)	12.24×10^6	44	29.0
ACE400(110)	6.63×10^6	44	28.1
REALA(135)	37.32×10^6	50	30.8
REALA(half)	17.62×10^6	50	29.7
REALA(110)	9.54×10^6	50	28.8

The conclusion derived from preliminary analysis based on image entropy is consistent with the result of the psychological evaluation.

A number of recording levels

A number of recording levels used in image entropy is that of effective levels in the sense of a signal-to-noise ratio. But as well known, human eye can recognize image content when a signal-to-noise ratio is less than one because of pattern recognition. To consider this phenomenon, we re-define a number of recording levels without granularity and think K as an index proportional to a signal-to-noise ratio.

A density measurement of gradation exposured CNF gives a smooth density vs $\log E$ curve(characteristic curve). This means that films have more density resolution than a densitometer does. Since common densitometers have a density resolution of 0.01, the number of recording levels of CNF will satisfy following inequality.

$$K_0 \geq \frac{2.0}{0.01} = 200$$

where K_0 denotes a number of recording levels of CNF. But when we made a print from CNF in a large magnification, tone jumps are observed. This fact means that a number of recording levels of CNF is less than the number of Just Noticeable Difference(JND) of human eye. According to Munsell[5], the number of JND of human eye on reflection prints are about 351, following inequality holds.

$$K_0 \leq 351$$

Finally we get following inequality.

$$200 \leq K_0 \leq 351$$

Since the number of recording levels of DSC satisfies following inequality,

$$200 \leq 256 \leq 351$$

it is sufficient to think that the number of recording levels of DSC and CNF are equivalent.

$$K_0 = 256$$

Table 5 can be obtained.

Table 4. Image Structures of CNF and DSC

Device	P	K_0	K
DCS460	6.23×10^6	256	256
DS300	1.28×10^6	256	256
ACE400(135)	25.92×10^6	256	44
ACE400(Half)	12.24×10^6	256	44
ACE400(110)	6.63×10^6	256	44
REALA(135)	37.32×10^6	256	50
REALA(half)	17.62×10^6	256	50
REALA(110)	9.54×10^6	256	50

Conclusion

Image qualities of prints from DSC and CNF are compared in terms of a numebr of recording levels, a number of pixels and a noise level.

CNF have an advantage in a number of pixels and DSC have an advantage in a signal-to-noise ratio. A number of recording levels seems equivalent.

Table 5.
Comparison of image qualities of CNF and DSC where ○, △ and × represents superior, equivalent and inferior to another respectively.

Item	DSC	CNF
Number of Recording Levels(K_0)	△	△
Number of Pixels(P)	×	○
Signal-to-noise ratio(K)	○	×

We have to note that above conclusions are of capability of CNF and DSC focused on sharpness and graininess but not of performance which are influenced by factors such as exposure level fluctuation and artifacts.

References

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