ON THE QUALITY ASSESSMENT CRITERIA OF DENSITY INDICES FOR AERIAL NEGATIVE

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ABSTRACT

This paper discusses the internal relation between tonal gradation character and visual character as well as the relation between the tonal gradation character and the microcharacter of aerial negatives. And also, a set of practical quality assessment criteria of density indices for aerial negatives has been proposed in combination with the statistic results of density range.

1 Introduction

As we know, the accuracy of photogrammetric mapping and the reliability of image interpretation depend on the quality of the aerial negatives or its copies used. The tonal gradation character of an aerial negative is usually described by image photographic quality which is assessed with density and contrast indices. Density and contrast indicate the control level of exposure and development, show the reproduction capability of luminance difference of the subject, control the image microcharacter, such as resolution, sharpness, Modulation Transfer Function (MTF) , and influence the accuracy of visual interpretation. So they are the main aspects of aerial photographic specification.

Followed the principle that subjective assessment should accord with objective measurement, this paper discusses the internal relation. between tonal gradation character and visual character as well as the relation between the tonal gradation character and the microcharacter of aerial negative through the visual psychological series wedge experiment, the fuzzy judgement based visual assessment experiment and the measurements of negatives density and microcharacter indices, such as resolution, acutance, RMS granularity, MTF, information capacity. And also, a set of practical quality assessment criteria of density indices has been proposed in combination with the statistic results of density range.

2 Density and Its Visual Feature

As far as a large number of aerial negatives used for plotting, the receiver of image information is visual system of human being, and what stimulates. visual perception is the variation, in brightness with the help of variant optical equipments.

2.1 The sense perception of density

The sense perception of density variation depends on the light flux passed through eyes, so does the brightness variation. The scientists have showed that:

- For human eyes, the amount of brightness perception is directly proportional to the logarithm of the brightness in proper range.

- The capability to distinguish the fine contrast depends upon not only the brightness difference, also the background brightness.

2.2 Visual threshold of contrast

The image visual threshold of contrast is defined as the density difference which is large enough for human to observe. It changes with the density variation, and reaches minimum at a suitable density value, apart from which it will grow larger with the decrease or increase of density.

2.3 An experiment on vision response to density variation

2.3.1 Experiment

By using different sensitivity negatives, thirty wedges have been made under different conditions of exposure and development. And twenty people with good eyesight and experience in photogrammetry took part in the experiment.

Firstly, each density level has been measured with densimeter for each wedge. Then the limit levels of high and low densities, which all tested people could just distinguish. were put down in writing. Finally, six hundred groups of data have been obtained. From the statistic results, we draw some conclusions of vision response to density variation.

2.3.2 Conclusions

- The minimal and maximal densities, which people can just recognize are 0.11 and 2.47 respectively. They fall into the toe and shoulder of characteristic curves. This result shows that the density range which people can adapt to overpasses the linear part of the curve.

- The maximal distinguishable density at the low limit of density is 0.19, and the minimal one at the high limit of density is 2.12. That means that, in order to recognize the details of object, the minimal density should be about 0.20 at lower limit, and the maximal one should be about 2.10 at upper limit.

- The maximal distinguishable contrast threshold at the lower limit of density is 0.07, and at the upper limit of density is 0.15. That indicates that the lowest contrast needed when to recognize the higher density image is twice that of the lower density image. Even though the toe and shoulder of the curve should have the image compressed, the object in the toe is better distinguished than the object in the shoulder. Moreover, the difference between the minimal density and the fog density for negatives should be two times or three times as large as 0.07 in order to recognize the details in shadow.

- In the middle range of density, the visual contrast threshold is less than 0.02. Therefore, much information can be obtained in the middle range of density.

3 Density and Microcharacter

The image microcharacter is used to describe the reproducibility of the fine image. It dominates the measurement and interpretation accuracy of aerial negatives or their copies. When seen with eyes, the microcharacter behaves as sharpness and grainness. The microcharacter indices, such as granularity, acutance, MTF and information capacity, are no doubt related to density. In fact, they are the function of density. Therefore, the microcharacter of image becomes a critical aspect of density index evaluation.

With the help of PDS data collection system, we have calculated the resolution. acutance. RMS granularity, MTF, information capacity of aerial negatives, which are acquired by the same camera chain and developed under the same conditions (see Tab. 1) . The results show as follows :

- Although RMS value changes with the type of film used, it mainly depends on the film emulsion structure. The RMS of black-white negatives is directly proportional to density in linearity . The higher the density is, the larger the RMS. Additionally, the conditions of development have a key influence upon RMS value. There are little differences in their RMS-D curves for the negatives, which are the same type of film, the same development condition, but with different exposure.

- Acutance is directly proportional to the density difference corresponding to the A and B of edge curves, and is inversely proportional to the square of the spread width of the edge curve. For a given object, when the contrast is enhanced. the edge will be sharper.

- The relation between resolution and density is as follows:

(1) Resolution R will be degraded when density is too low or too high. The high density makes the resolution degrade faster than the low one. Therefore, the R value depends mainly on whether the exposure or the development is controlled properly.

(2) The optimal density valve D_r corresponding to the upper limit of resolution R_{max} differs from the type of film. It generally locates on the left part of middle of curve's linear section.

(3)The optimal density range is of corresponding to $0.8R_{max}$. The image which density range exceeds the optimal one is hard to distinguish.

Tab.1 The quality indices of some aerial negatives

No.	type of film	D_a	ΔD	MTFS	R	A	RMS	C	visual	exposure	develop	subject
29	1022 p	0.47	0.87	18	46	223	16	2.68	Q	norm	under	plain
30		0.29	0.52	27	46	252	16	1.69	UNQ	norm	under	hilly
31		1.45	0.90	24	43	209	27	1.48	Q	over	under	plain
32		1.48	0.69	16	43	209	27	1.48	Q	over	under	city
33		1.28	0.96	24	43	209	27	2.34	Q	over	under	hilly
34	3412	0.78	1.32	27	50	457	9	6.00	E	norm	norm	plain
35		0.8	1.00	20	50	457	9	5.17	E	norm	norm	mountain
36		0.33	0.58	23	43	486	7	3.44	UNQ	under	norm	plain
37		0.31	0.42	22	43	486	7	2.96	UNQ	under	norm	mountain
38		1.77	0.77	24	41	223	12	2.70	UNQ	over	norm	plain
39		1.55	1.09	23	41	223	12	3.49	UNQ	over	norm	mountain
25	3414	0.91	0.75	30	57	224	10	5.20	GOOD	norm	norm	plain
26		1.00	1.36	29	56	265	10	6.49	GOOD	norm	norm	mountain
27	3412	0.55	0.87	32	55	148	10	4.84	Q	norm	under	plain
note	camera: LMK; photographic scale: 1:10 000; Q: qualified; UNQ: unqualified											

Appendices to Tab.1: The average density D_a and the image contrast ΔD are calculated by the histogram method; MTFS is the area surrounded by the MTF curve and coordinate axes; R is the image resolution calculated in MTF measurements; A is the acutance (10^{-6}); RMS is the RMS granularity corresponding to the average density D_a; C is the information capacity which is calculated with the following formula:

$$C=N\log_2 M \qquad N=800R^2/cm^2$$

$$M=\mathrm{int}(10^4\Delta D/2\sqrt{2k} * R * RMS+1) \qquad k=1.5$$

- The Information capacity of aerial negatives is directly proportional to contrast and resolution, and is inversely proportional to RMS. If the average contrast is too high, the RMS value will be larger the resolution will be poor, and the information capacity will be smaller. If the average density is too low, the RMS value will be smaller, the resolution and information capacity will be reduced.

4. Statistics of Density Range

4.1 Visual assessment

There have been selected thirty nine aerial negatives, which have different tonal gradations and different subjectives (eight of them supplemented with steropairs). And there have been consulted twenty people consisting of scientists, processors, interpreters, plotter and control extension operators, who make the evaluation of density and contrast for each sample picture. Finally, we obtained the statistic results of comprehensive evaluation for each sample picture according to fuzzy mono-factor judgement rules.

4. 2 Measurements of density index

All sample pictures were firstly digitized by P-1700 scanner (the sampling aperture is 100 micron), then density histogram of each image is obtained. And the density indices of each picture are calculated using the following formula :

fog density $D_0=\sum_{i=f_1}^{f_2} n_i D_i / \sum_{i=f_1}^{f_2} n_i$

average density $D_a=\sum_{i=D_1}^{D_2} n_i D_i / \sum_{i=D_1}^{D_2} n_i$

minimal density D_{min}

$$\sum_{i=D_1}^{D_{min}} n_i \leqslant [(1-T)\sum_{i=D_1}^{D_2} n_i] / 2$$

maximal density D_{max}

$$\sum_{i=D_{max}}^{D_2} n_i \leqslant [(1-T)\sum_{i=D_1}^{D_2} n_i] / 2$$

image contrast $\triangle D=D_{max} - D_{min}$

Where T is the reliable level, and its value is 99 percent.

4. 3 Statistics of density range

According to both the visual assessment results and the measurements of density indices, we have calculated the density range of three classes : the excellent, the qualified, and the unqualified. Thus the results in Tab. 2 were derived.

5. The Establishment of Quality Assessment Criteria

A set of quality assessment criteria for density index of aerial negatives has been proposed in the light of the above experiment results.

5.1 Average density D_a

Basically, the average density D_a should be near D_r, which is the density corresponding to the highest visual resolution R_{max}. Because the sensitized material can reproduce the fine variation in tonal gradation and human can distinguish at the highest sensibility near by D_r. In good conditions of exposure and development, D_r is different in type of film. It is relatively stable, and approaches the left part of middle of characteristic's linear section for a given kind of film. Tab. 2 shows that the optimal value of D_a is generally about 0.9. The image contrast is too small to reproduce the image of low luminance subjective when D_a is less than 0.6. And the image contrast will be degraded and the image of high luminance subjective is compressed when D_a is larger than 1.5. From Tab. 1, it can be seen that the larger the average density is the larger the RMS, the lower the information capacity, and the smaller the acutance as well as the resolution. So the D_a must not exceed 1.3 in order to obtain proper microcharacter.

5. 2 Minimal density D_{min}

D_{min} should be in the linear part of curve, and close to the lower limit of density corresponding to 0. $8R_{max}$. Besides, the difference between D_{min}

and fog density D_0 must be larger than some threshold, so that the image of low luminance subjective can be observed. From the above conclusions, the value 0. 07 is the contrast threshold ΔD in the bottom of low density, when

Tab. 2 The density range of each class

excellent						qualified						unqualified					
No.	D_s	D_a	D_{min}	D_{max}	ΔD	No.	D_s	D_a	D_{min}	D_{max}	ΔD	No.	D_s	D_a	D_{min}	D_{max}	ΔD
6	0.59	1.31	0.68	1.96	1.28	1	0.93	1.50	1.03	1.97	0.94	2	0.72	1.11	0.85	1.38	0.53
9	0.33	0.81	0.41	1.35	0.94	3	0.91	1.59	0.98	2.03	1.05	4	0.69	1.04	0.76	1.31	0.56
10	0.43	0.97	0.52	1.58	1.06	5	0.82	1.65	0.91	2.21	1.30	7	0.08	0.59	0.14	1.38	1.24
11	0.32	0.87	0.47	1.67	1.20	15	0.41	0.86	0.50	1.37	0.87	8	0.04	0.38	0.11	1.23	1.12
12	0.42	1.12	0.74	1.68	0.94	17	0.13	0.71	0.31	1.24	0.93	16	0.05	0.44	0.15	0.89	0.74
13	0.28	0.83	0.46	1.64	1.18	18	0.14	0.74	0.32	1.31	0.99	20	0.16	0.74	0.26	1.19	0.93
14	0.29	0.99	0.40	1.68	1.28	21	0.52	1.07	0.65	1.57	0.92	30	0.06	0.29	0.19	0.71	0.52
19	0.20	0.88	0.32	1.64	1.32	23	0.75	1.19	0.93	1.44	0.51	36	0.07	0.33	0.22	0.80	0.58
22	0.42	1.12	0.74	1.68	0.94	27	0.19	0.55	0.27	1.14	0.87	37	0.05	0.31	0.20	0.62	0.42
24	0.69	1.01	0.80	1.55	0.75	19	0.11	0.47	0.24	1.11	0.87	38	1.29	1.77	1.44	2.21	0.77
25	0.44	0.91	0.50	1.25	0.75	31	0.95	1.45	1.08	1.98	0.90	39	0.94	1.55	1.09	2.18	1.09
26	0.22	1.00	0.29	1.65	1.36	32	1.03	1.48	1.16	1.85	0.69						
28	0.18	0.81	0.29	1.42	1.13	33	0.79	1.28	0.92	1.88	0.96						
34	0.32	0.78	0.47	1.79	1.32												
35	0.37	0.86	0.52	1.52	1.00												
min	0.18	0.78	0.29	1.25	0.75	min	0.11	0.47	0.24	1.11	0.51	min	0.04			0.62	0.42
max	0.69	1.31	0.80	1.96	1.36	max	1.03	1.65	1.16	2.21	1.30	max	1.28			2.21	
ord	$D_{min}-D_0$: 0.20 – 0.45 D_a : 0.80 – 1.10 D_{min}: 0.35 – 0.75 D_{max}: 1.40 – 1.70 ΔD: 0.90 – 1.30					ord	$D_{min}-D_0$: 0.15 – 0.90 D_a : 0.60 – 1.30 D_{min}: 0.30 – 1.00 D_{max}: 1.30 – 2.00 ΔD: 0.70 – 1.30					ord	$D_{min}-D_0$: $<0.15\text{or}>0.90$ D_a : $<0.60\text{or}>1.50$ D_{min}: $<0.30\text{or}>1.00$ D_{max}: $<0.30\text{or}>2.00$ ΔD: $<0.70\text{or}>1.30$				

* D_s=D_{min}-D_0; ord: ordinary case

0. 07 times two is about 0. 15, so the lower limit of D_{min} is about D_0 + 0. 15. Tab. 2 shows that the D_{min} of the excellent picture ranges from D_0+0. 20 to D_0+ 0. 45, and the D_{min} of the qualified one ranges from D_0 + 0. 1 5 to D_0 + 0. 90. The subjective in shadow and the details can not be reproduced when D_{min} is too small. And although the subjective of low luminance can be reproduced very well, but the image of high luminance subjective would be compressed when the D_{min} is too large. The upper limit of D_{min} is controlled by both the contrast ΔD and the maximal density D_{max}.

5. 3 Maximal density D_{max}

D_{max} should be in the top of the curve's linear section, but not in the shoulder. And it must not exceed the upper limit of density corresponding to $0.8R_{max}$. From the above conclusions, the high image contrast is required when people recognize high density image, and the image contrast in shoulder is obviously less than others. So D_{max} should not be too large. In Tab. 2 we can see that the D_{max} ranges from 1.4 to 1.7 for the excellent pictures, that the D_{max} is not less than 1.8 for the most of the qualified one, and that the D_{max} may be 2.0 for pictures with special subjectives . The lower limit of D_{max} is controlled by ΔD and D_{min}, and it need not be defined definitely.

5. 4 Image contrast ΔD

Tab. 1 shows that, it is benefit to raise D_r among proper density range. It can improve the resolution, enhance the reproductivity of details, and obtain high accurace, MTF and information capacity. Tab. 2 and visual assessment results show that the high contrast negatives possess abundant and fine density gradation. and have good visual effects although their D_{max} and D_{min} are not good enough. The visual perception and steroscopic effects would be very poor when ΔD is less than 0.7. And the image tonality would be too hard to keep the details when ΔD is larger than 1.3. Thus ΔD should commonly range from 0.7 to 1.3, and the optimal Contrast is about 1. 1.

5. 5 Fog density D_0

In the preconditions of the complete development, fog density D_0 should be as small as possible. When the fog density increases , the transparency of negatives would be poor, the detail contrast would be reduced, the image resolution would decrease, and the grainness noise would increase. So the fog density D_0 should not overpass 0.2.

5. 6 Processing gamma value

Although the processing gamma value obtained from characteristic curve of wedge is used to appraise the control level of development, it need not to set limit to gamma value. Generally speaking, gamma value should not surpass the maximal value determined by the dynamic sensitometry, and it should be near the gamma value corresponding to the effective sensitivity presented ahead of flying in order to match the development conditions with the exposure conditions. Additionally, processing gamma value plays an important role in adjusting contrast ΔD to the standard level according to the luminance difference of the subjective.

From the above conclusions, we have proposed a set of assessment criteria of density indices for aerial negatives which are listed in Tab. 3.

Tab. 3 The quality assessment criteria

	excellent	qualified
fog density D_0	<0.2*	<0.2*
average density D_a	0.8 ~1.1	0.6 ~1.3
minimal density D_{min}	>D_0+0.2	>D_0+0.15
maximal density D_{max}	<1.7	<1.8 or 2.0 for special
image contrast ΔD	0.9 ~1.2	0.7 ~1.3

* contain the density of film support

Reference

[1] Walls H J. Attridge G G. Basic Photo Science, How Photography Works. Focal Press, 1977

[2] Cai Junliang. The Density Quality Criteria of Aerial Negatives. Serveying and Mapping Standardization, No. 1, 1989