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PRINT QUALITY AND INFORMATION THEORY

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Print quality and information theory

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Systems producing printed reproductions of originals are communication systems. Information theory will find application in this special field as it does in other fields of telecommunication.

The definition of information by Shannon [1]

$$H = - k \sum p(i) \log p(i) \qquad (1)$$

is derived from statistical considerations. Shannon himself recognized that the information H has the form of entropy as defined by Boltzmann. That's why he preferred to use the term entropy (of a message) instead of the term information.

Brillouin [2] introduced the negentropy principle of information which gives evidence that information H connected with a physical system is related to entropy S by

$$H = S_0 - S_1 \qquad (2)$$

This means that any transfer of information in a physical system is inevitably connected with a definite transfer of energy. Information theory and thermodynamics are equivalent means to describe the behaviour of communication systems. Results obtained in terms of information theory may be translated into results in terms of thermodynamics and vice versa.

Communication systems considered as thermodynamic systems have a thermal (exergetic) efficiency

$$\eta < 1 \qquad (3)$$

Wolf [3] recognized that the thermal efficiency η is an equivalent to the reproduction quality q, i.e.

$$\eta \equiv q \qquad (4)$$

The reproduction quality q defines practically the quantity of information of the reproduction which originates directly from the original.

Printing processes are within close limits isothermal processes. In this case information is proportional to energies

$$H = \frac{1}{T_0} \cdot e \qquad (5)$$

The flow diagram of information therefore differs from the flow diagram of energies only by the scale.

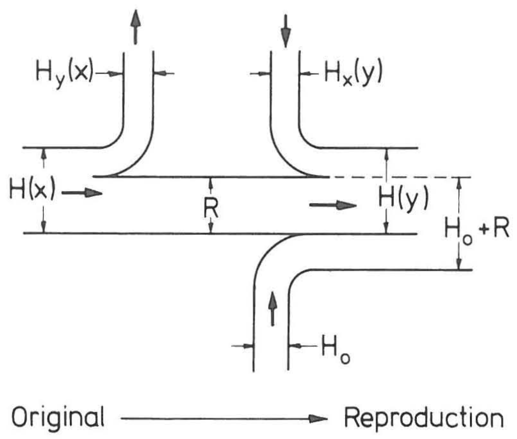

Fig. 1

From the diagram (Fig. 1) the reproduction quality can directly be derived

$$q = \frac{H_0 + R}{H_0 + H(y) + Hy(x)} = \frac{H_0 + R}{H_0 + H(x) + Hx(y)} \qquad (6)$$

where

H_0 = Entropy of an ideal (white) solid (H_0 is an arbitrary constant. In the case of a reproduction of a half tone picture $H_0=0$ may be a favourable choice).

R = transinformation

H(x) = information of the original

Hx(y) = noise

$H(y)$ = information of the reproduction

$H_y(x)$ = loss of information

In these terms x and y are the signals which are distinguished by an observer i.e. colours or densities. By colour measurement and density measurement the probabilities p needed to compute the reproduction quality q can easily be found. An exemplary description of the proceeding is represented in [3] . The definition of the reproduction quality q is of universal nature. It may not only be useful with respect to printed products.

The reproduction quality q may find an especially interesting application in describing the fidelity of any subprocess of a reproduction process, as for example positive-negative photographic processes etc. In a sequence of subprocesses the input information of a next following process is identical with the output information of it's preceding process (Fig.2).

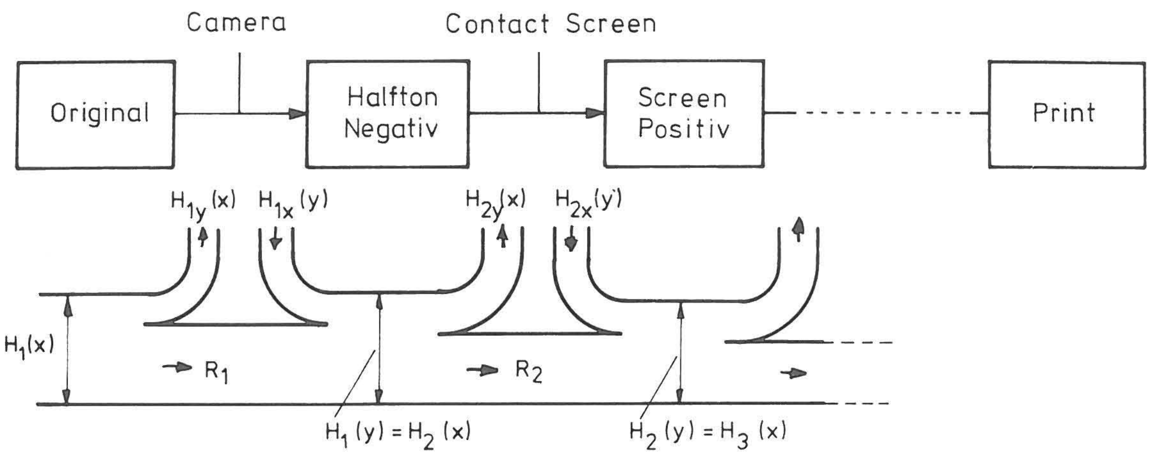

Fig. 2

The analysis of subprocesses is a mean to recognize those processes which are decisive for the quality of the reproduction process as a whole. It discloses possibilities to specific improvements with respect to apparatus, machinary and materials.

These considerations will be fully conclusive, if the reproduction quality q as derived from information theory and thermodynamics corresponds with the subjective quality perception of a mean observer comparing a reproduction with it's original.

The basis of a definit proof is a sufficient number of psychophysical experiments [4] covering finally the whole field of monochrome and colour reproduction. One experiment and its results will be now disclosed.

From a monochrome photograph (Fig. 3) as original 23 prints were produced. By carefully directed variations of the reproduction and the printing processes the prints became different with respect to their quality.

Original and prints were then scanned by a modified scanner at about 30 lines/cm. The measured values, densities of discrete image spots of a size of 0,136 square millimetres, were stored on tape. Each picture contributed 100 000 values. Computer processing of these values according to the beforementioned principles yielded the q-values for each one of the 23 prints. With that the objective quality rank is given.

The rank of the subjective quality perception is obtained with the aid of the statistical method of the "Paired Comparison" [5, 6] . For the purpose of easier comparing the 23 prints were grouped into sets of n_R = 6 to 8 objects. The comparison was then accomplished by 69 judges, namely 52 experts and 17 laymen. Each judge had to compare any object with any other object of the set and with the original. Preference criterion was the supposed higher fidelity of one print of a pair of prints with respect to the original.

Ties were not permitted, so that the results might be expressed in a two-way preference table of 1's and 0's. The objects might be ranked according to the values of the average preference frequencies of all judges.

Fig. 3

Three questions that come to mind on inspecting the test data are:

1) Had the judges been consistent in their preferences ?

2) Are there significant differences between the objects ?

and 3) Is a sufficient degree of agreement of all judges ascertained ?

The questions 1) and 2) are closely related; for if there is no difference between the objects, a judge cannot reasonably be expected to be consistent, while it is easy for him to be consistent if the differences are great.

The consistence of a judge is checked by the coefficient of consistence ζ [5, 6]. If $\zeta = 1$ there are no inconsistencies

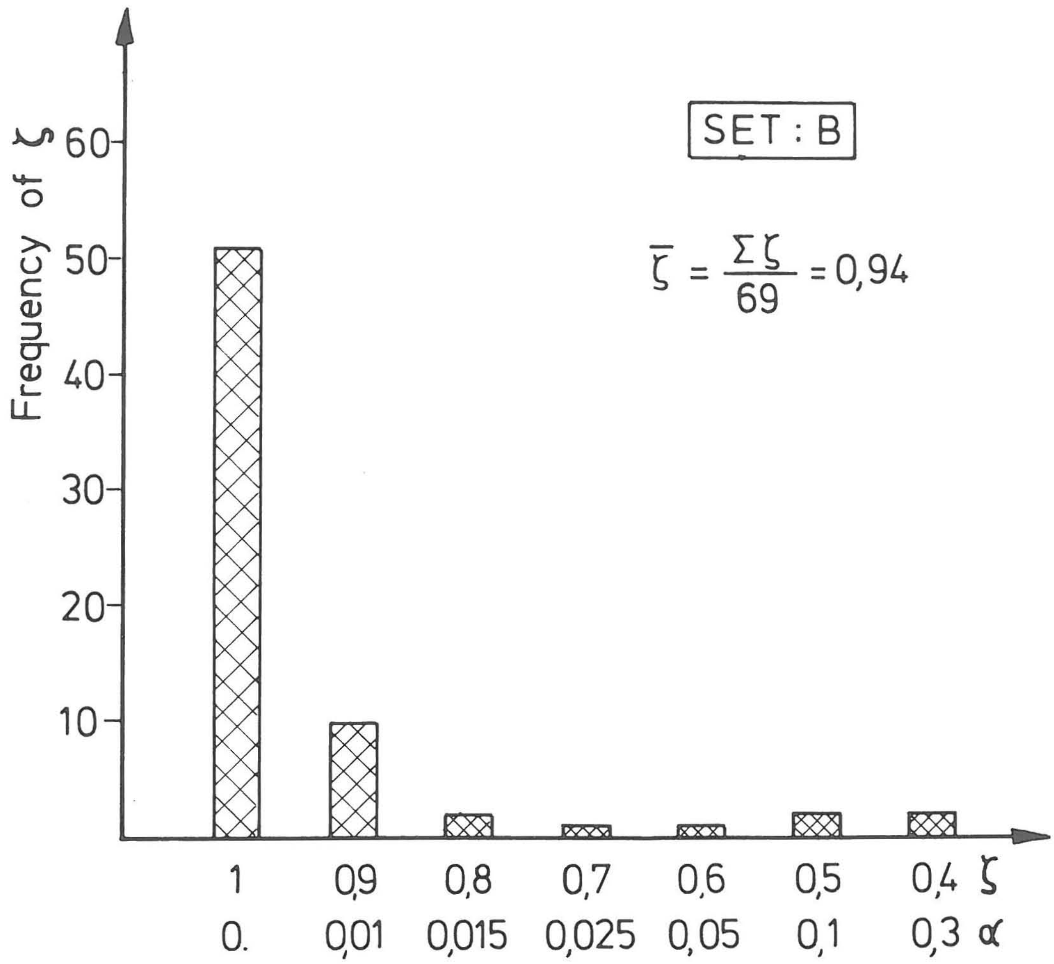

Fig. 4

in the configuration of preferences which is therefore immediately expressible as a ranking. As ζ decreases to zero the inconsistencies increase. The significance of a value of ζ may be tested by χ^2 with $n_R - 1$ degrees of freedom. In Fig. 4 and Fig. 5 the frequency distributions of ζ of set B and set C are shown. Further the probabilities α that the judges allotted their preferences only at random are indicated. The values of α are sufficiently small to demonstrate that the decisions were not at random.

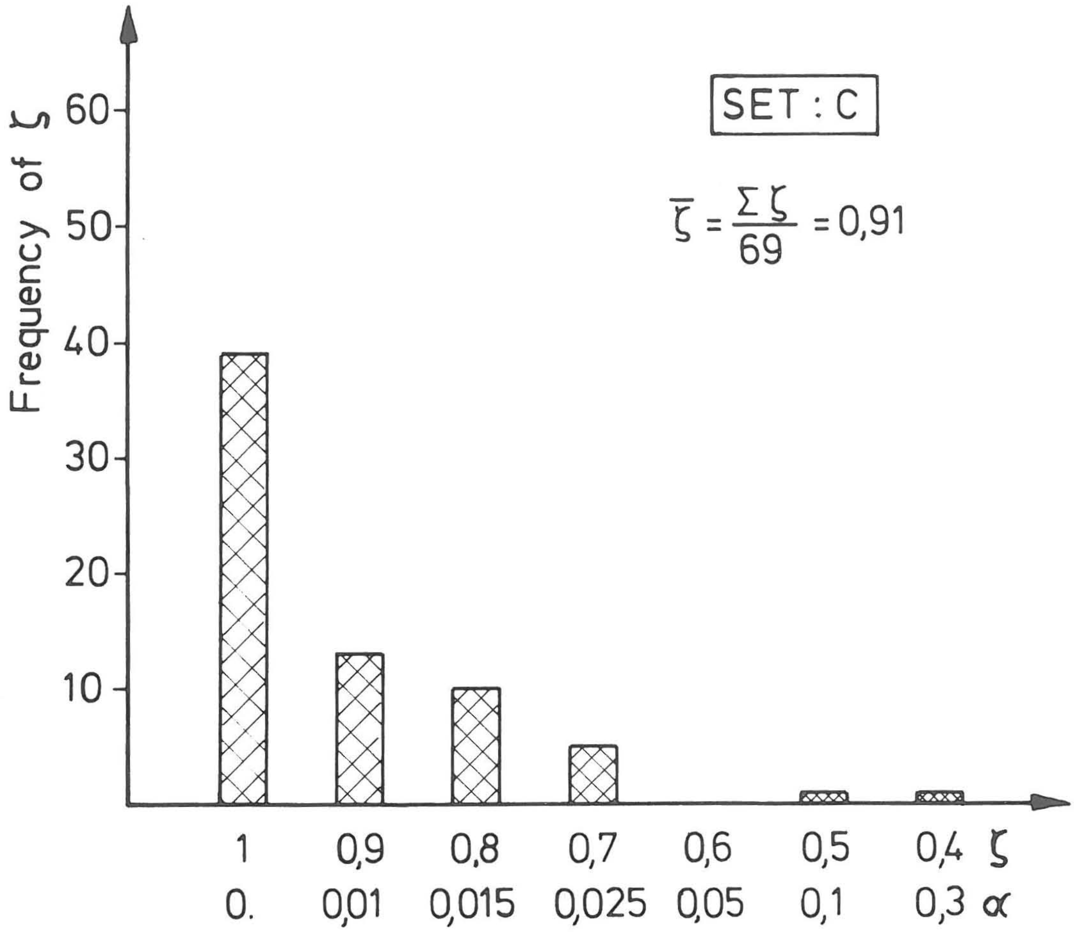

Fig. 5

The frequency distribution shows that most of the judges allotted their preferences nearly consistently. So the conclusion is admissible that there are significant differences between the test objects.

The greater average ζ ($=\bar{\zeta}$) of set B allows the supplementary conclusion that the quality differences of the prints of set B are more distinctive than those of set C.

The degree of agreement of all judges or different groups of judges as asked in question 3) is tested by the coefficient of agreement u.

For complete agreement u = 1; for complete disagreement u = -1. Furthermore it is possible to test u for significance with the χ^2-test with ν degrees of freedom, the null hypotheses H_0 being that all the judges allot preference at random. The probability α specifies whether H_0 is maintained or not. In table 1 the results are presented.

	SET : B			SET : C		
	All	Experts	Laymen	All	Experts	Laymen
u	0,49	0,57	0,26	0,49	0,58	0,27
ν	29	29	33	29	29	33
χ^2	991,4	882,9	166,6	998,1	892,9	168,8
α	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$

Table 1

The data of χ^2 are far beyond any ordinary significance point so that all probabilities $\alpha < 10^{-3}$. This means that the observed u could not have arisen by chance from a population in which all the judges allotted preferences at random.

Now as the consistency of each individual judge and a sufficient degree of agreement of all of them are ascertained and the significance of the differences between the objects is confirmed, the ranks of the average preference frequencies are conclusive and it is possible to prove the correspondence of these ranks obtained by the visual quality test with the ranks of the reproduction quality q. In Fig. 6 and Fig. 7 the corresponding quality values of set B and set C are figured in form of block diagrams. In both cases a correspondence is even recognizable by visual comparisons. The accuracy of this impression must be ascertained by statistical considerations.

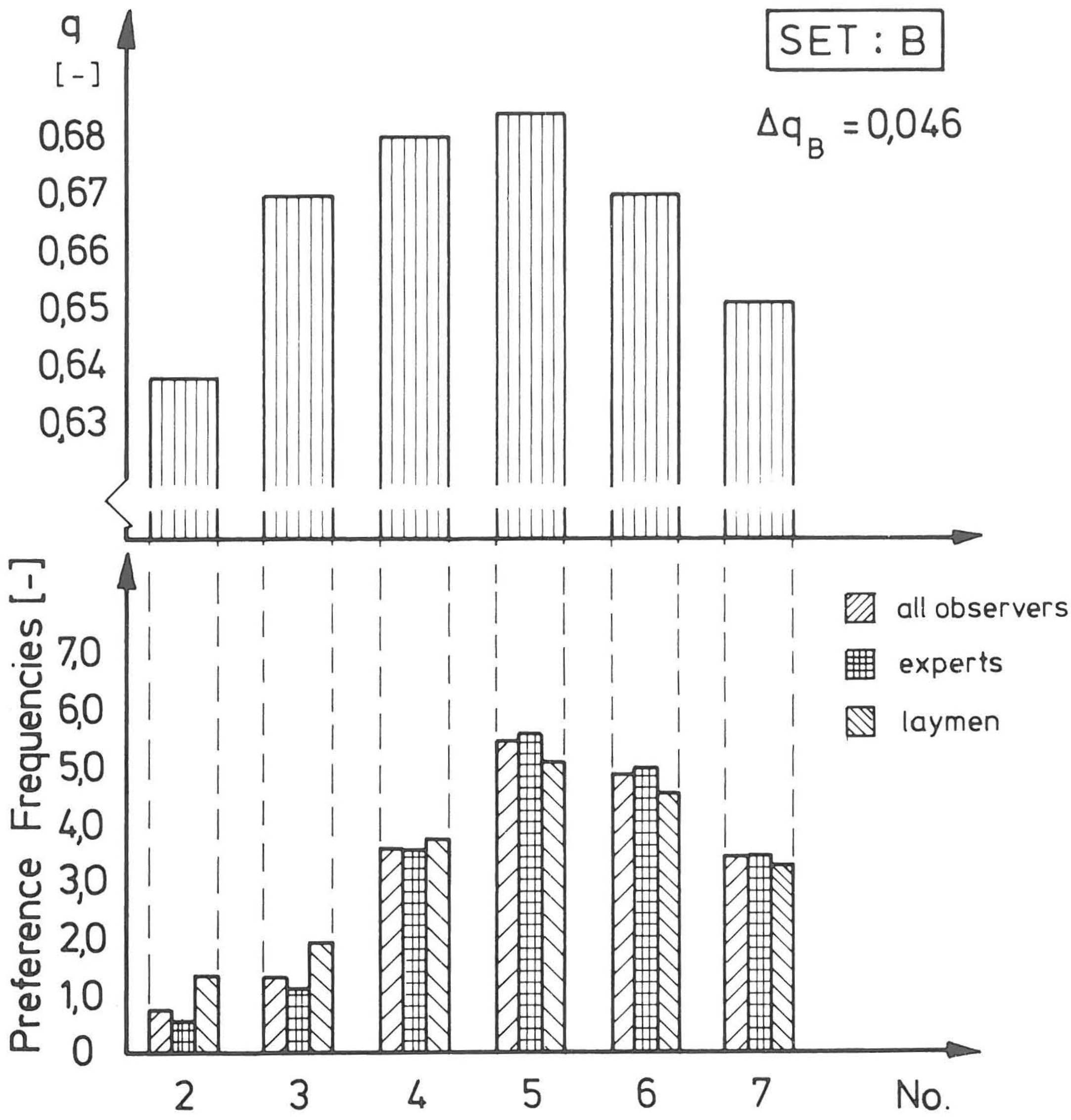

Fig. 6

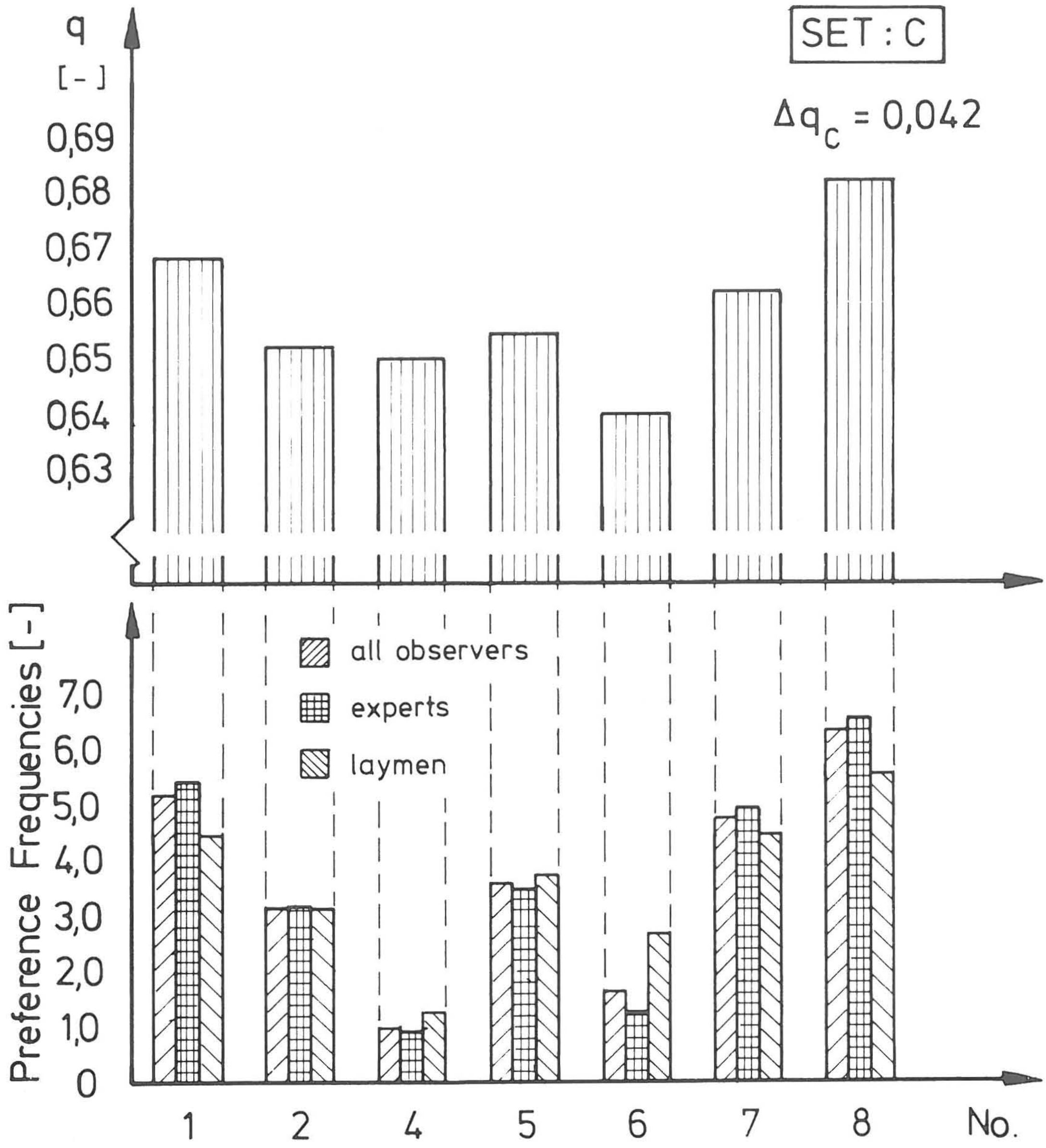

Fig. 7

The degree of the correspondence is checked by the rank correlation coefficient r_S [7] , where r_S = +1 if the two ranks are completely corresponding and r_S = -1 if there is a totally contrary tendency between the two ranks. The probability $\beta \doteq F(n_R, r_S)$ checks the significance of r_S. In table 2 the rank correlation coefficient r_S and the probabilities β of their significances are presented.

	SET : B			SET : C		
	All	Experts	Laymen	All	Experts	Laymen
r_s	0,8	0,8	0,8	0,96	0,96	0,93
β	0,957	0,957	0,957	0,999	0,999	0,995

Table 2

In Fig. 6 and Fig. 7 the value of $\Delta q = q_{max} - q_{min}$ is specified. (Δq_B=0,046; Δq_C=0,042). The greater Δq_B confirms the before--mentioned conclusion that the quality differences of the prints of set B are more distinctive than those of set C.

With this result the correlation is proved and thus the conformity of the quality evaluation on the basis of information theory with the quality judgement by human beings is demonstrated. It is understood that the validity of the foregoing proof is restricted on the described experiment. Much more experiments must be accomplished to confirm the general validity not only for monochrome but also for colour reproduction.

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