Characterization of Digital Silver Halide Printing Devices

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Abstract

Last years are characterized by increasing penetration of digital information registration and processing methods in silver halide photography.

The sphere of our interest is a hybrid photographic technology (see Ref.1), which permits to print digital image, obtained by digital camera or scanner, on the silver halide photographic paper. There are many problems in this sphere; tuning and calibration of digital silver halide printing devices cause the main of them.

One of the main problems, which rise on working with digital methods of image processing, is characterization (or calibration) problem of input and output devices. Characterization for RGB data dependent of device, and XYZ values independent of device has been investigated in Ref.2. For the similar studies see Refs. 3-6.

The goal of this paper is to develop the calibration methods for digital silver halide printing devices for further development of techniques for estimating the tone and color reproduction in process printing with digital image processing, taking into account the subjective (psychophysical) side of the process. This should shorten and simplify the process of calculating the quality parameters at each stage of image processing and make it easier to choose the optimum conditions for carrying out process printing, with the final result of improving the quality of photographic images.

Introduction

Quality Estimation

The problem of evaluating the quality of photographic images from their visual perception has a very long history. The problem is crucial, because in our daily life, at least within the limits of amateur photography, each of us has to evaluate the quality of photographic prints. The reason that this problem is difficult is that visual quality is an unformalized, psychophysical concept, developed by each individual on the basis of a generalization of his previous experience.

Jons' Conception

Questions of evaluating the quality of photographic images are dealt with in a section of scientific photography called the theory of tone reproduction. For many decades, this area of knowledge was dominated by the concept of L. Jones (see Ref. 7), which completely ignores the psychophysical aspects of the evaluation by an observer of the quality of a photographic positive. According to Jones's viewpoint, a specific subject and its photographic image are "rigidly" connected with each other, and the problem of tone reproduction is solved by comparing like characteristics of one or the other on the assumption that, ideally, the characteristics being compared are linearly related. Although this is obviously unrealistic because of the incompatibility of the topology, the brightness-light parameters, and the conditions under which one or the other is observed and photographed, decades were required to go from a comparison of the objective characteristics to a comparison of the individual subjective parameters that are significant for the evaluation of a photographic image by an observer (see Ref.8). In this connection, certain publiccations (see Refs.9, 10) have pointed out the impasse that is largely the result of the limitedness of the scientific approach of Jones's classical theory.

Referent Concept of Tone Reproduction

The appearance of the so-called referent concept of correct tone reproduction, which constitutes an important step on the path toward a psychophysical treatment of the problem of tone reproduction, should be singled out (see Ref. 10). By making the relative luminosities (or visible brightnesses) the characteristics to be compared and by placing the standard referent inside the photographic image itself, this concept in essence has prepared the ground for procedurally detaching the consideration of the subject from its photographic image. However, instead of surmounting this barrier and bringing to a logical completion the conclusions that follow from the physically based and valid starting prerequisites, the "referent" concept proposed to again return to a comparison of the initial subject and its photographic image in a generalizing reproduction cycle.

Psychophysical Hypothesis

A decisive breakthrough in this direction was made in Ref. 8, where, starting from iconic representations, the "psychophysical" hypothesis was first formulated, according to which it is not the objective subject and its image that are to be compared, but their psychophysical correlates, the relative intensities of the visual perception of certain tonal scales. One scale corresponds to the photographic image and is directly perceived by the observer. The second scale corresponds to the subject of the photography and is the sum of the person's generalized experience, extracted from his memory. According to this viewpoint, the image reaches the highest quality when the tonal scale of the image most

closely approaches some "ideal" scale of the subject stored in the observer's memory. This finally accomplishes the transition from a direct comparison of the objective characteristics of the subject and its image to a comparison of certain normalized sensory reactions of the visual analyzer as a measure of subjective perception. The formulation of the psychophysical hypothesis opened up new prospects in the study of the problem of correct tone reproduction. The main difficulty in putting it into practice was the necessity of finding the critical parameters and verifying the laws that directly affect the quality of subjective perception. Some progress in solving these problems was made in Refs.11-14; these, however, were not complete, because of difficulties in organizing an experiment. These difficulties can now be surmounted because of achievements in related disciplines: information and communication theory, informational esthetics, the psychophysics of complex-stimulus perception, and especially computer technologies. It is this that has largely promoted the solution of such an important aspect of the implementation of the psychophysical concept of hue reproduction as the possibility of obtaining photographic images with fixed parameters of the reproduction of various brightness details that ensure a given quality of the subjective visual perception.

Experimental Setup

The main goal of the study was to verify Bartleson and Breneman's hypothesis: "Is the main criterion of optimum tone reproduction the linear reproduction of luminosities, proportional to a reference white?" (see Ref. 9).

Originally, this goal was pointed for black and white portrait photocopies, it was necessary to examine revealed regularities for color photographic images at the second stage of research.

Black and White Photocopies

It is quite possible to determine the conventional quality index Q of black-and-white prints on the basis of their densitometry and by the computer processing of the corresponding data if one starts from a certain (see Ref.12) stagewise variation of the process of subjective perception of a complex stimulus of a given type. Five series of photographic prints were studied (one of the subjects is shown in Fig. 1 with the indexing points at which densitometry was carried out on the prints of the specific series) that differed from each other (within one series) in exposure during printing and consequently in macroscopic quality (see Ref.11). The prints were made on photographic paper of various degrees of contrast with three exposure levels (optimum and ± 10% from the optimum). The subjects of the different series differed both in the models, in the background, and in closeness (black-and-white positives of only close-up and medium shots were studied), with all of the photographic prints being portraits (Fig. 1).(see Ref.15).

Figure 1. Example of portrait subject studied in this paper.

Each photographic print was evaluated by at least thirty observers (the sum of the positions at which the observers placed a given photograph and the total index of the subjective quality on a scale of ten was determined for each print of a given series). Then the interval between the white and black elements of the observed semantic field was spontaneously broken down by an expert on a kind of scale of local stimuli, which is, ideally, of uniform contrast (see Ref.16), but in practice only approaches such. When the image quality Q is evaluated thus or by another means, it is necessary to identity the relative placement on such a scale of at least three elements of the image: white, black, and a characteristic gray. It is understood that, for portrait subjects, such a characteristic "gray" is the skin of the model's face, although, if there are more than three density-measurement points, other gray elements of the image can be adequately representative. In other series, the number k of such points varied from five to seven, with k = const for each separate series (i.e., for a given negative).

The luminosity function of Ref. 9, which represents the dependence of the subjective reaction Srel on the normalized visual stimulus expressed in optical density units, was used to convert the densitometric information into psychophysical form. The scale itself acquired an analog form in this case, and the local densities Di of the photographic print were used as a basis for calculating numerical analogs Ni of the scaled subjective reaction similar to the well-known Munsell numbers, but as applied to the optical densities being measured. The method of relative numbers or ratios

$$n_i = N/N_w, \tag{1}$$

was verified for each N_i to the same number N_w of a white field (element) of the given photographic print in combination with the intervals ΔN of the prints, which are the difference

$$\Delta N = N_b - N_w \tag{2}$$

between the N_i values of the black and white image elements.

The interval ΔN was subjectively broken down into some a priori given number m of gradations, identical for all the photographic prints of a series, on the basis of the same "reference" gray scale. The conventional number M_w of the white element was always considered the unit. It is easy to see that the M of the black element in this case will equal

$$M_b = m+ 1, \quad (3)$$

while the number of each of the gray elements of the image is obtained from the expression

$$M_i = m(N_i - M_w)/ \Delta N + 1. \quad (4)$$

To check the hypothesis that the scale is linear, the dependences of the relative luminosities and their intervals on the breakdown intervals were constructed in the best photographic prints for positives with different subjective quality indices (Fig. 2). The degree of linearity of the model was estimated by computing the correlation coefficients of the linear interpolation of the data to be analyzed.

Results for Black and White Photocopies

A relation is established between the correlation coefficients and the visual estimate of the quality (Fig. 3). The quality index has the best values in the photographic prints in which a proportional transfer of the subjective luminosities with respect to the reference white is observed. The subjective quality index falls off as the correlation coefficient decreases. (see Ref. 17)

An additional check of the linearity of the model was also carried out on the basis of a single-dispersion analysis by means of Fisher's statistical criterion. The calculation was done for groups of prints with different subjective quality indices. It was shown that the statistic of Fisher's criterion lies in the allowable zone with a significance level of a=0.01 and confirms the hypothesis that the scale is linear for prints with a subjective quality index no less than 6.0— these are the prints of the best and the good groups. For prints with $Q<6.Q$, the values of Fisher's criterion lie outside the allowable zone, and this indicates that the model is nonlinear. This undoubtedly confirms Bartleson and Breneman's hypothesis and provides a basis for developing an algorithm for calculating an index for the print that matches the expert rating.

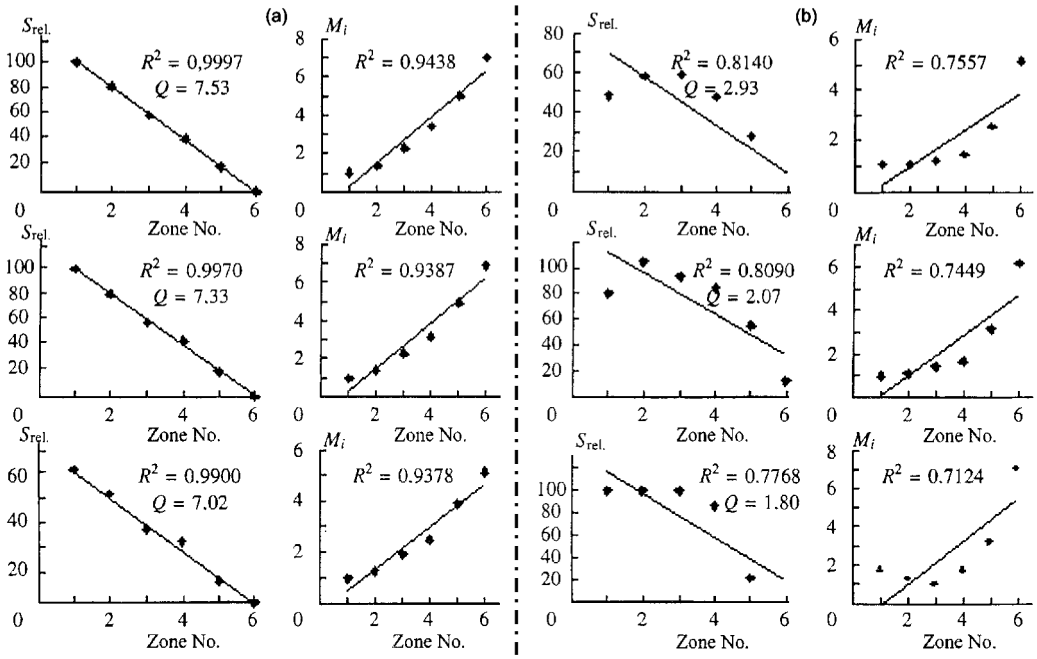

Figure 2. Checking the hypothesis of the dependence of the visual quality on the linearity of the increment of visual stimuli: (a) best series, (b) worst series.

Color Photocopies

It is necessary to examine the regularities revealed for black and white photocopies in applying to the color images. First of all, we ought to solve the compatibility of methods of densitometry for optical density estimation of photographic images and digital means of image brightness estimation (R, G, B) applied in the standardized graphic packets.

Calibration

The standardized scale “Barevna” which included 12 color samples and gray scale was applied for plotting the calibration curves. The scale negative image was obtained on the negative films and photoprints was obtained on the color photopaper of several types. The optical densities were measured for each color sample with densitometer Brumicro MPST and DO-1M (status A, status M). The transfer of photographic images into digital form was realized by scanning of photographic images with scanners: “Agfa DuoScan T 2000”, “Acer ScanWit 2720S”.

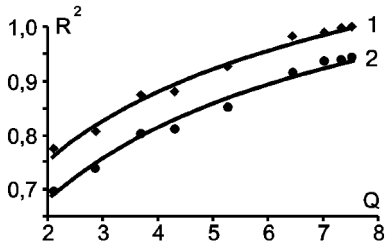

Figure 3. Correlation coefficients of the data versus visual evaluation of the quality: 1—scale of absolute values, 2—scale of relative increments.

The means of brightness of digital image for each color channel (RGB model) were determined according to the indication on the "Info" panel (the standard procedure of the program Adobe Photoshop. The function relations D^{RGB}=f(R, G, B) were plotted in graphic form by obtained means (fig.4).

Using these calibration curves we obtained means of D^{RGB} for the scaled places.

Results for Calibration

The RGB values were measured at the break intervals for the series of color portrait photoprints and were converted into optical density values behind the blue, green, and red optical filters with obtained calibration curves.

The relation between relative luminosity values and means of RGB was plotted (fig.5). Obtained relation was close to a linear relation with correlation coefficient of 0.9. It means that diagram of calibration function is almost the same as the diagram of relative luminosity function.

The hypothesis about the possible use of RGB values instead of relative luminosity values in referent conception of tone reproduction was drawn out on the base of obtained results. In order to check the hypothesis the comparative estimation of relative luminosity scale made by direct RGB measure at the breakdown intervals of portrait image. The obtained graphics were identical with almost the same correlation coefficients (fig.6) and confirmed the being of relation between subjective quality index Q and linearity of relative luminosity scale as well as RGB values scale (Fig.7).

Considering the linear fashion of the relation between S_{rel} and RGB these results once again showed the possibility to use the RGB values instead of relative luminosity characteristics.

The confirmation of the given hypothesis permits to realize a transition from calibration (characterization) to quality indexing of color photographic positives.

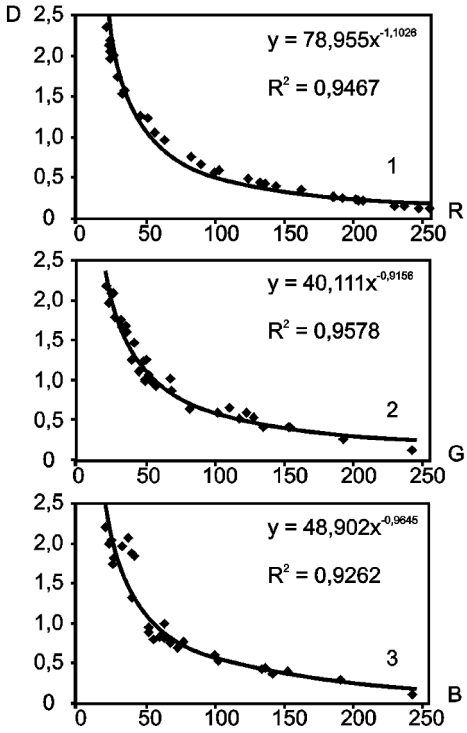

Figure 4. Calibration curves for converting RGB values into optical densities: 1-behind red filter, 2-behind green filter, 3-behind blue filter.

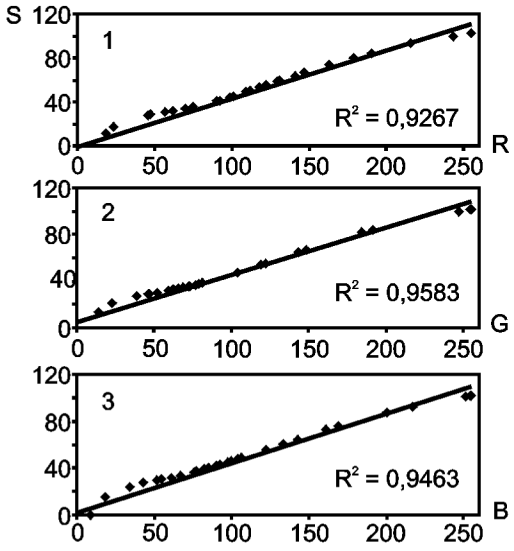

Figure 5. Calibration curves for converting RGB values into relative luminosities: 1-Red, 2-Green, 3-Blue.

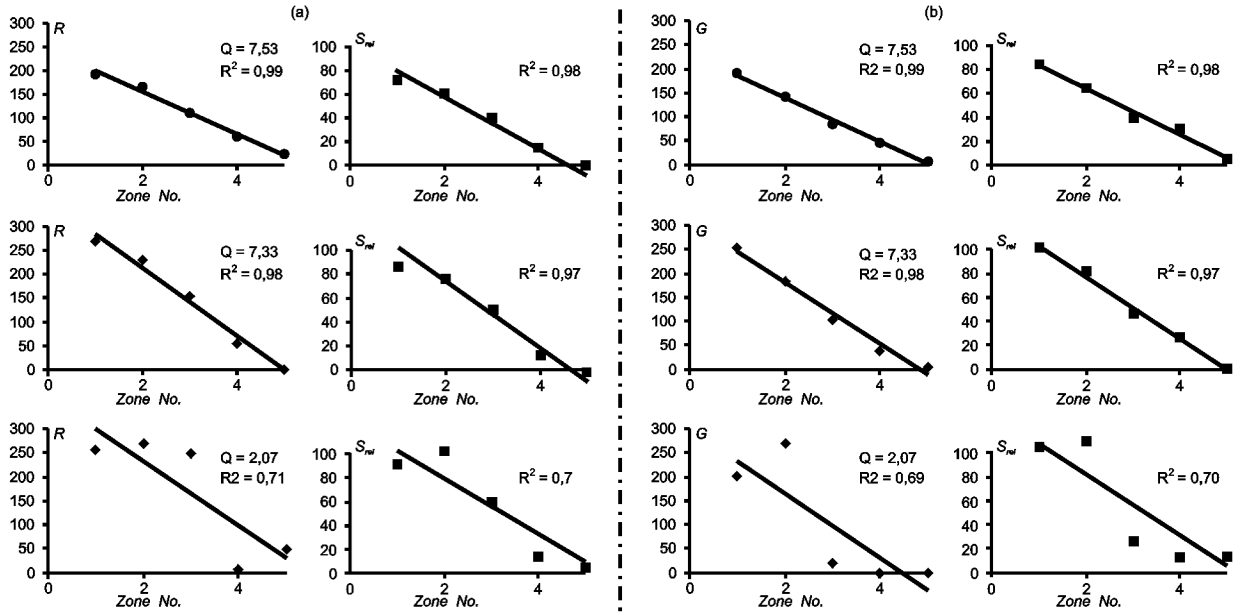

Figure 6. Checking the Bartleson and Breneman's hypothesis for color portrait images:(a)-Red, (b)-Green.

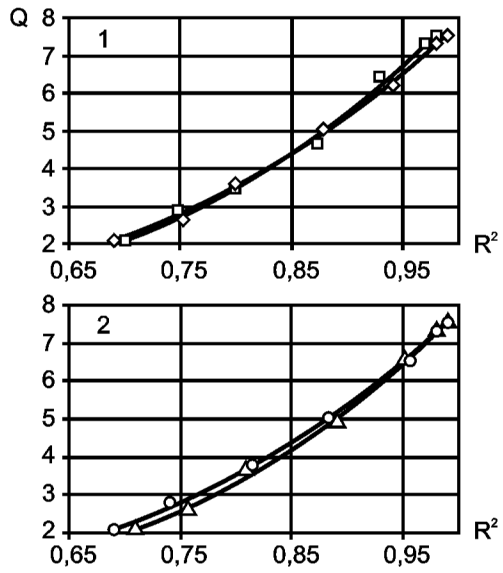

Figure 7.Visual evaluation of the quality data versus correlation coefficients: 1(○, ❑)—scale of RGB values, 2(Δ,✧)—scale of relative luminosity values.

Conclusions

1. A technique has been developed for evaluating the quality of photographic images in portrait photography by breaking down the density interval into some variable number of psychophysical levels and comparing the comprehensive subjective quality index with the quality with which the separate levels are rendered. This makes it possible to develop automatic indexing of portrait photographic prints.
2. A technique has been proposed for checking Bartleson and Breneman's hypothesis that the scale of luminosities proportional to the reference white is linear for the best photographic prints. It has been shown that the hypothesis is valid for portrait photographic prints. Relationships have been established between the parameters of the objective tonereproduction curve and the subjective quality, and this has made it possible to develop the entire concept of tone reproduction at a new level, taking into account the objective and subjective stages.
3. The optical densities of the key brightness details of photographic portrait prints have been determined, and their effect on the overall subjective quality has been established.
4. In the issue, upon done work we conclude that calibration of digital devices significantly ease, and simplify a procedure of tuning and managing of the last. Also, the calibration permits to automatisate process of quality indexing of output images.

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Biography

Helena Konstantinova received her B.C. degree in chemical sciences from the Institute of Cinema engineers at Leningrad in 1985 and a Ph.D. in technical sciences from the St.-Petersburg's state university of moving picture and television. Since 1985 she has worked at cathedra of photography of St.-Petersburg's State University of Moving Picture and Television as a lecturer. Her work has primarily focused on the problems of tone and color reproduction in silver halide photography and digital photographic systems.