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Model examination of the influence of edge effects on the acutance of photographic image

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In the paper, the results of simulation model examination of the influence of edge effects connected with both inhibiting and accelerating the photographic development process on the sharpness of images recorded on light-sensitive silver halide materials are presented. In the examination, a three-stage model of the photographic recording of image information was used, which was been worked out by the Imageing Science Group of the Wrocław University of Technology. The functioning of this model was compared to that of the well known Nelson's model.

1. Introduction

The sharpness of a photographic image is closely related to the density distribution at the border between the dark and bright image fields (image and its background). The spatial distribution function of density at the border between the photographic image and its background is called edge function. The slope of its quasi-rectilinear segment provides the basis for quantitative expression of the sharpness, also called acutance. Actually, many methods of expressing the photographic image sharpness are known. One of the more important measures of acutance which is in accordance with the psychophysical perception of sharpness perceived by human beings is the r.m.s. of the edge function [1] expressed by equation

$$G_x^2 = \frac{1}{x_b - x_a} \int_a^b \left(\frac{\mathrm{d}D}{\mathrm{d}x}\right)^2 \mathrm{d}x \tag{1}$$

where: x_a and x_b – positions (distances) of points a and b at which the slope of edge function reaches the minimal value of spatial contrast perceived by human being, D – optical density of image.

The acutance may be changed by suitable deformation of the spatial density distribution at the border of differently exposed fields. In the process of photographic recording of image information, these deformations can occur during both the exposure of the image and chemical processing of an exposed light-sensitive layer. Therefore, it is believed that the acutance depends on the course of these processes.

During the exposure light scattering takes place which is caused by heterogenic structure of the light-sensitive layer being composed of silver halide crystals suspended in binding gelatine medium. This phenomenon is disadvantageous to the quality of optical information recording which is manifested mainly by the lower information capacity of such a type of recording media. On the other hand, a selective reaction occurs during the development process of light-sensitive materials in wich only exposed silver halide crystals are reduced to metallic silver. At this stage, advantage of various physical effects can be taken in order to improve the structurometric properties of image. The edge effects appearing at the border of fields of low and high exposure (low and high density) can be considered among the most essential phenomena. Taking into account their nature we can distinguish two kinds of edge effects that are connected with either inhibition or acceleration of the photographic development processes. Depending on their nature a local increase or decrase of contrast occurs at the border of fields of different exposure which the human eye interprets as an increase or decrease in sharpness.

2. Model examinations

In order to examine both the nature of the edge effects and their influence on the photographic image acutance computer simulations were carried out in which the edge functions performed without any contribution on the part of edge effects and with the edge effects connected either with inhibition or acceleration of the development process were calculated. Two methods of modelling were used which allowed us to obtain results that were complementary to one another. The first one was Nelson's empirical model [2], in which a linear dependence of the optical density on the surface concentration of the metallic silver was assumed.

In the first stage of this model, the input distribution of exposure $H(x)$ in the sharp image edge is transformed into the real spatial distribution of exposure $H_r(x)$. This stage is accomplished by the convolution of the input signal function being the exposure function $H(x)$ with the line spread function $L(x)$. This relation is expressed by the following equation:

$$H_r(x) = \int_{-\infty}^{+\infty} L(x')H(x-x')\mathrm{d}x' \tag{2}$$

where: $H(x-x')$ – input exposure distribution without contribution of the scattered light, $H_r(x)$ – real distribution of the exposure including the scattered light, $L(x')$ – line spread function.

In the second stage of simulation, the real distribution of exposure $H_r(x)$ of the recording layer is counted over into the spatial distribution of the density $D(x)$. For that purpose, the macroscopic characteristic curve is used which expresses the dependence of the optical density D on the logarithm of exposure $\log H$.

The density distribution obtained in this operation takes no account of edge effects appearing during development. In the third stage, the spatial distribution of the density is modified in such a way that the edge effect is encountered. In simulation examinations this operation consists in performing convolution of real density function $D(x)$ with the chemical spread function $L_C(x)$. If the edge effects are connected with inhibition of the photographic development process, the convolution function obtained is subtracted from the spatial distribution of the density produced after an infinite time of developer action (equation below). On the other hand, if the edge effects are associated with acceleration of the development process, then both components of the real distribution of optical density are subject to the following addition

$$D_C(x) = D(x)+BD^2(x)-D(x)\int_{-\infty}^{+\infty} L_C(x')D(x-x')\mathrm{d}x' \tag{3}$$

where: $D_C(x)$ – function of the spatial distribution of density for the case of the development process including edge effects, $D(x)$ – function of the spatial distribution of density obtained for the case of the development process without contribution of the edge effects, $L_C(x')$ – chemical spread function, B – value of the integral of the chemical spread function.

In these examinations, the line spread function, being described by the Frieser equation of first approximation [3], [4], has been applied which was also adopted to describe the chemical spread function. Here,

$$L(x) = \frac{2.3}{k_F}10^{-(4|x|)/k_F} \tag{4}$$

where: $L(x)$ – line spread function, x – distance from the plane of incidence of an infinitely narrow and long light beam, k_F – Frieser coefficient of the first approximation.

In this model the global contribution of edge effects to the shaping of the gradient profile of the edge function was regulated by changing the value of the parameter B_s scaling the normalized value of the integral of the chemical spread function

$$L_C(x) = \frac{2.3B_s}{k_C}10^{-(2|x|)/k_F} \tag{5}$$

where: $L_C(x)$ – chemical spread function, x – distance from the border between the image and the background, B_s – constant scaling the value of the chemical spread function integral, k_C – constant of the chemical spread function describing the range of the edge effect.

As the second way of modelling the results of edge effect action the method of summing up two experimental functions [4]–[6] is applied. The first is the edge function curve obtained due to exposure including scattered light and the development process without participation of the edge effects $rD(x)$, while the second is the chemical spread function $L_C(x)$. By putting both functions together a spatial distribution of the gradient of the edge function $rD_C(x)$ is obtained which is characteristic of the exposure including scattered light. This distribution appears in the process of photographic development at the presence of edge effects. In the presence of edge effects connected with inhibition of the development process the chemical spread function takes negative values whereas in the case of edge effects connected with acceleration of the development process the chemical spread function takes positive values. Intensity of the edge effect can be regulated in this model both by scaling the value of the integral of the chemical spread function (parameter B_s) and by changing its partial contribution in the function of gradient distribution of the edge function $rD_C(x)$. This relation is expressed by the following equation:

$$rD_C(x) = (1-\rho)rD(x)+\rho L_C(x) \tag{6}$$

where: $rD_C(x)$ – distribution of the gradient of the edge function modified by the action of the edge effects, $rD(x)$ – distribution of the gradient of the edge function obtained by exposure including scattered light but without contribution of the edge effects, ρ – dimensionless coefficient expressing the partial contribution of the chemical spread function in a modified gradient of the edge function.

In the model discussed, it has been assumed that the ratio of the edge effect action occurring in the fields of low and high exposure, respectively, is proportional to the ratio D_2/D_1 of the density of the dark and bright fields. Thus, the difference of the intensities of the edge effect action at the border of low and high densities is obtained due to proportional reduction of the chemical spread function share in the image field of low density. The integral of the distribution of the edge function gradient is proportional to the absolute difference of the densities D_2-D_1 of high and low exposure fields (between the upper and lower part of the edge function) independently of the appearance and intensity of the edge effects. In this model, the spatial distribution of the edge function gradient is described by adopting the exponential Frieser function of the first approximation which was modified by introduction of the constant $B1$ scaling the value of the integral of the distribution of the edge function gradient

$$rD(x) = \frac{2.3B1}{k_r}10^{-(|x|)k_r} \tag{7}$$

where: $B1$ – constant scaling the value of the integral of the gradient distribution function, k_r – constant of the modified Frieser function determining the range of the light diffusion inside the photographic layer.

Taking advantage of the above model three series of calculations were carried out. In the first one, the quantitative dependences of the r.m.s. of the gradient of the edge function G_x^2 are calculated as a function of intensity of the edge effects. The calculations were carried out for the constant values of the image field exposures using Nelson's empirical model. The results obtained are illustrated in Fig. 1.

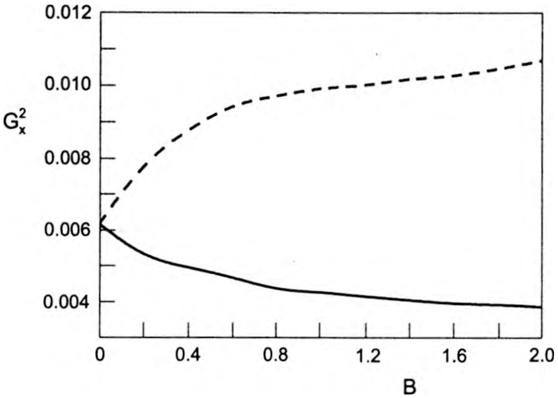

Fig. 1. Dependence of the r.m.s. gradient of the edge function on the intensity of the edge effect as defined by the value of the integral B of the chemical spread function. The solid line is used to mark the results of calculations of the edge effects connected with inhibition of the development process, whereas the broken line denotes the results obtained for edge effects connected with the corresponding acceleration process. The calculations were carried out for a constant value of exposure of the image fields when applying Nelson's model.

In the other series, similar dependences were determined for constant values of the densities of the image fields located outside the range of the edge effects. The decrease and increase of the density between the upper and lower parts of the edge function, resulting from both inhibiting and accelerating features of the products of chemical reactions taking place in the development process, was compensated by the change of the exposure values. In the examinations, both Nelson's model and the model of summing up the experimental functions were applied. The intensity of the edge effect action was being changed by varying the value of parameter B_C scaling the value of the chemical spread function in such a way that its value changed within the range from zero to two. The zero value of the integral of the chemical spread function denotes the course of the development process without the edge effects. The diffusion range of the scattered light inside the photographic layer for all the simulation calculations was determined by means of the Frieser constant equal to 10 μm. The results obtained are illustrated in Fig. 2. It should be emphasized that Nelson's model admits the calculation of the edge functions for constant values of density within the image fields remaining outside the range of edge effects only for reaction products inhibiting the process of photographic development. For those reasons, the calculations carried out for edge effects connected with acceleration of the photographic development processes were carried out for one model only.

In the last series of calculations, the influence of the range of the edge effect on the acutance were examined. The calculations were based on two theoretical approaches to the modelling of edge effects in which the action range of these effects was controlled by changing the values of parameter k_C

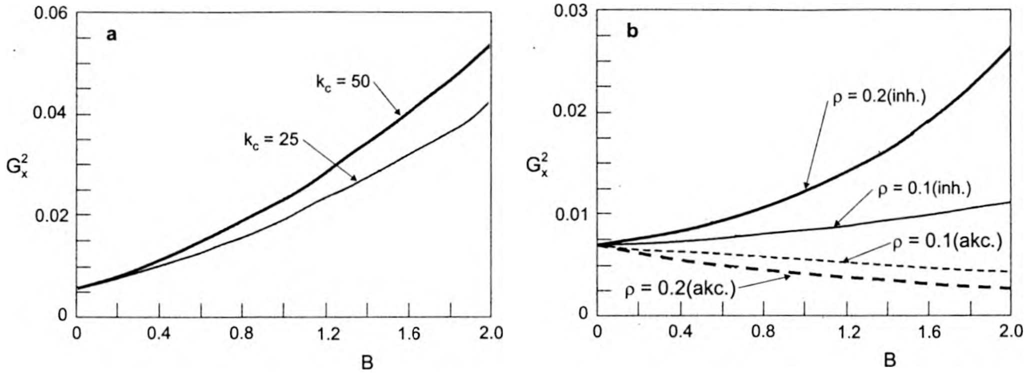

Fig. 2. Dependence of the r.m.s. gradient of the edge function curve on the intensity of the edge effect. The solid line is used to mark the results obtained for edge effects connected with inhibition of the development process while the broken line denotes the results obtained for the effects connected with the acceleration of this process. The model examination was carried out applying the empirical model of Nelson (**a**) and the model of summing up the exponential function (**b**) in which the exposure parameters were selected in such a way that the density of the image fields located outside the range of the edge effects was constant and amouted to $D_1 = 0.5$ and $D_2 = 1.5$ for the upper and lower parts of the edge function, respectively.

in the equation describing the chemical spread function. The results obtained in this series are illustrated in Fig. 3.

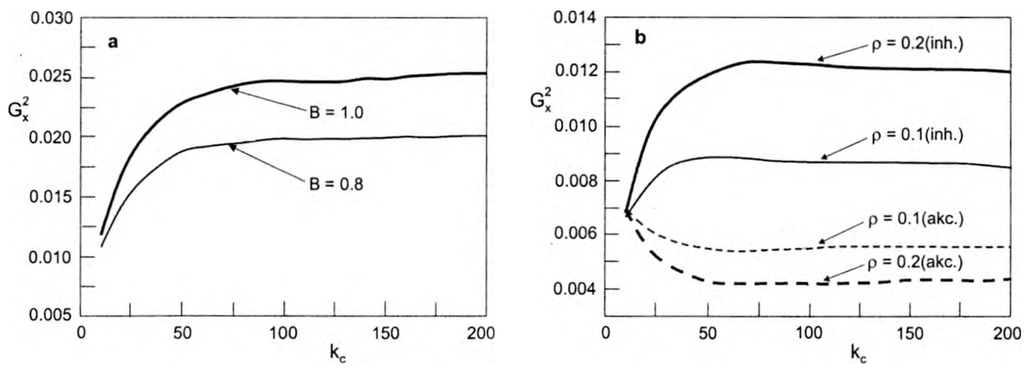

Fig. 3. Dependence of the r.m.s. gradient of edge function on the range of the edge effect. The model examinations were carried out applying both the empirical Nelson's model (**a**) and the model of summing up the exponential functions (**b**) in which the exposure parameters were chosen in such a way that the density of the image fields was constant and amounted to $D_1 = 0.5$ and $D_2 = 1.5$ for the upper and lower parts of the edge function, respectively.

3. Conclusions

While keeping the exposure of the image fields constant (Fig. 1), the increase of intensity of edge effect connected with the acceleration of the development process causes the increase of the r.m.s. value of the edge function gradient G_x^2. On the other hand, the increase of intensity of the edge effects connected with inhibition of the development process causes the decrease of the sharpness measures values. It can be concluded that in this case an essential factor influencing the estimation of the acutance of the image is either the increase or the decrease of the density difference ΔD determined in the image fields remaining outside the range of the edge effects which are caused by the action of the accelerators or inhibitors of the development process. The increase in the density at a constant exposure should be connected with the increase of effective photosensitivity, whereas the decrease of density – with the decrease of the photosensitivity of the layer. Therefore, the increase or decrease of the density difference between the upper and lower parts of the edge function resulting from the inhibiting or accelerating features of the reaction products occurring in this processes can be compensated by the change of the exposure value. In this case, the increase of intensity of edge effect action connected with inhibition or acceleration of the development process is interpreted respectively as an increase and a decrease of the acutance of image (Fig. 2). The results obtained prove that the influence of the range of the edge effect is essential as far as the acutance of the photographic images is concerned (Fig. 3). The course of the changes of the values G_x^2 as a function of the action range of the edge effect can be divided into two principal stages. In the first of them, the increase of the range of the edge effects causes some rapid changes in the acutance of the photographic image while depending on the direction of action of the edge effects it is either an increase or decrease of the value of the sharpness measure. In the second stage, the increase of the action range of the edge effects causes, in principle, no essential changes in the acutance.

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