Optica Applicata, Vol. XXVIII, No. 3, 1998

Optimization of the optical granularity measurement conditions of model photographic layers

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Computer results of the model dependence of the measured optical granularity on the area of the measuring aperture are presented. The optical granularity is expressed as a standard deviation of the optical density fluctuations. A spherical shape of the silver grains was assumed in the theoretical model of the developed photographic layer. The microdensitometric measurements were simulated assuming various conditions. This model and the results obtained are intended to help to further develop an integrated simulation system for research on the structurometric properties of silver-halide photographic layers.

1. Introduction

The light-sensitive photographic materials are composed of gelatine layers in which the silver halide crystals are suspended. These crystals play the part of radiation detectors but they cause some discontinuity of the photographic layer structure due to their nonuniform spatial distribution within the layer region. The consequence of this discontinuity of the radiation detectors location in the light sensitive media used to image information recording is the corresponding nonuniformity of the image obtained with such carriers. This nonuniformity is called optical granularity. The following three aspects of granularity are well known:

1. Structural granularity comprising the average grain size and the grain size distribution, the spatial distribution of grains and the due optical properties.
2. Optical granularity comprising statistical description of the optical density fluctuations in a uniformly exposed and developed photographic layer.
3. Subjective granularity corresponding to optical granularity determined subjectively, *i.e.*, on the basis of its action on the observer's consciousness.

The optical granularity plays the most essential part in the systematics of the granulometric properties of the silver halide layers. Its measurement is performed using the microdensitometric scanning of the photographic sample with the help of a suitable optical system. As a result of recording, the function of the optical density fluctuation is obtained which occurred along the scanning path. Next, from this function the average value and the standard deviation of the optical density is determined. The granularity measure is just the value of the standard deviation which is proportional to the magnitude of the blackening fluctuation. The equation describing the above formulated conclusions has been given by SIEDENTOPF [1] and takes the form

$$\sigma_D = \text{const}\sqrt{\frac{\bar{a}\bar{D}}{A}\left(1+\frac{\sigma_a^2}{(\bar{a})^2}\right)} \tag{1}$$

where: σ_D – standard deviation of the optical density fluctuation, $\bar{a}$ – average magnitude of the projection area of the silver grains, σ_a – standard deviation of the grain projection area, A – area of the measuring aperture surface, $\bar{D}$ – average optical density of the sample area.

From Equation (1) it follows that the optical density expressed as the standard deviation is reversely proportional to the square root of the surface area A of the measuring aperture. This means that if a sufficiently large measuring diaphragm is used to observe the nonuniform structure of the photographic image, the relatively small fluctuations of the optical density are subject to optical integration due to which only a relatively uniform gray field is observed. If, however, the measuring diaphragm area is diminished so much that the magnitude of the diaphragm is comparable with the spatial size of the optical density fluctuation, the magnitude of the standard deviation determined from Eq. (1) will no more characterize correctly the relevant photographic layer. Thus, the preservation of the correct proportions between the silver grain sizes and magnitude of the surface area of the measuring aperture is very important. However, an invariance of the product defined by the equation

$$G = \sigma_D\sqrt{A} \tag{2}$$

is observed within some limits of the surface area of the measuring aperture. This relation is called Selwyn's law, where the value G expresses the optical granularity in accordance with Selwyn approach [2], [3]. The optical granularity of the photographic layers expressed in this way is widely applied in the practical estimation of the optical granularity of the black-and-white photographic materials since the value G is independent of measuring conditions within certain limits. In Figure 1, the experimental illustration of the Selwyn granularity dependence versus the measuring aperture area is given [5]. For the case of small measuring area, a great contribution of the high diffraction occurs mainly at the measuring diaphragm, while for great surface of the diaphragm the measurement noise as well as calculational noise appear. Hence, the presented curves show some deviation from the Selwyn law. Thus, the estimation of the optical granularity of the photographic layers should take place only within the range of the straight line fragment of the presented dependence. Generally, the circular apertures of diameters 24 and 48 μm are used to measurements, which corresponds to the following magnitudes of the measurement areas: 452 and 1810 μm^2, respectively. These conditions as well as the others related to the properties of the optical system of the microdensitometer are defined by standard [6]. The magnitudes of the measuring aperture area are fully justified by the results illustrated in Fig. 1.

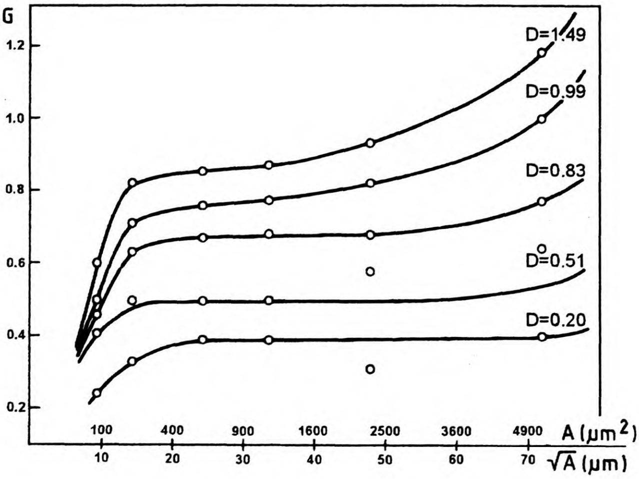


Fig. 1. Dependence of optical granularity G (due to Selwyn approach) on the square root of the measuring aperture area applied to determination of the optical density fluctuation function. The values of the optical density areas on which these densities were determined are given above the particular curves

The significance of the above considerations for the problems of optimizing the conditions for optical granularity measurement of the model layers is high when aiming at construction of a mathematical model describing the phenomenon of the optical granularity. This must be obviously preceded by examination of the theoretical dependence of this granularity upon the magnitude of the measuring area. For this purpose, a suitable model has been built and statistical examinations of the dependence of the current value of the standard deviation, which occurs along the scanning path, upon the magnitude of the scanning aperture area have been carried out.

2. Model examinations

Taking advantage of the silver halide photographic layer model presented in the work [6], the possibilities of the latter have been widened by adding the estimation of the optical granularity, assuming definite conditions of its measurement. These are determined by the size of the measuring aperture A for which the following values have been established: 50, 100, 200, 400, 800, 1600 and 3200 μm^2 and the number of measurements which was established at the level of $N = 2^{18}$. Besides, the examinations were carried out for four hypothetical layers containing the same spherical silver halide grains of diameters $d = 10.0$, 5.0, 2.5, 1.0 μm.

As already mentioned, the starting point for the estimation of the optical density of the model photographic layer is the photometric measurement of the optical density fluctuation function along the scanning path. For this purpose, a number of hypothetical layers have been generated containing identical spherical silver grains distributed at equal distances such that they get in touch with each other only at their borders. Schematic construction of such a layer as well as the principle of granularity measurements are illustrated in Fig. 2. In each case of the model layer, its

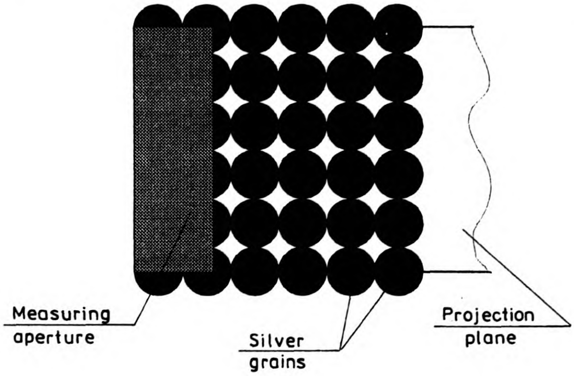
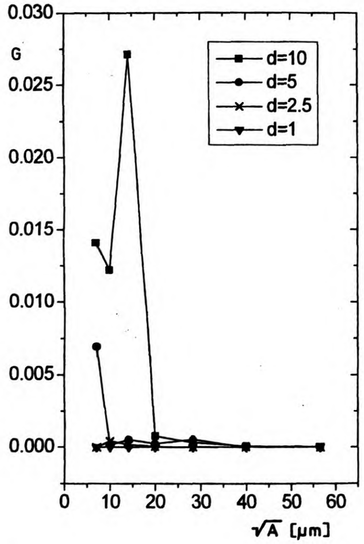


Fig. 2. Scheme of the hypothetical photographic layer structure and the optical density measurement principle when applying the measurement aperture of established surface. After each measurement the measuring slit was shifted to such a distance that the subsequent measurements showed no spatial correlation

optical density should amount to $D = 0.6667$. The deviations from this theoretical value allowed us to establish the influence of the particular elements of the model on the accuracy of the optical granularity estimation. Determination of the optical density of layers under test was carried out by estimating the coverage degree of occupation of the surface by the crystals as related to the covered surface. The model examinations of the optical granularity were carried out for the above determined measuring apertures, silver grain diameters, and the measuring resolution which defines the possibly least measuring step in order to identify the coverage area of the photographic layer by a silver grain. In the first phase of the simulations carried out two resolutions have been applied $\rho = 1.0$ and 0.1 μm.

The performance of several preliminary simulations for a small number of measurements equal to $N = 256$ allowed us to find the relations between the simulation parameters and the accuracy of the results obtained. In Figure 3, the dependences of the average optical density, and in Fig. 4 the dependences of the Selwyn granularity on the square root of the area of the measuring aperture are shown. The results obtained indicate a distinct stabilization of the optical density value as related to the measuring field. A stabilization of the value of Selwyn granularity is observed as well; the latter appears to be independent of the measuring area value. However, it is worth noting that the essential error in determining the average optical density occurs which does not achieve its theoretical value for all the given sizes of crystals. When analysing the plots in Figs. 3 and 4, it should be stated that in both cases of the greatest and the smallest silver grains the applied measuring resolution appeared to be insufficient.

In order to verify the correctness of these suppositions, the simulation was repeated to estimate the measuring resolution as $\rho = 0.1$, 0.05 and 0.01 μm, respectively. The results obtained are presented in Fig. 5, where the average density dependence on the measuring area determined for three different resolutions is illustrated. The application of the measuring resolution amounting to $\rho =$



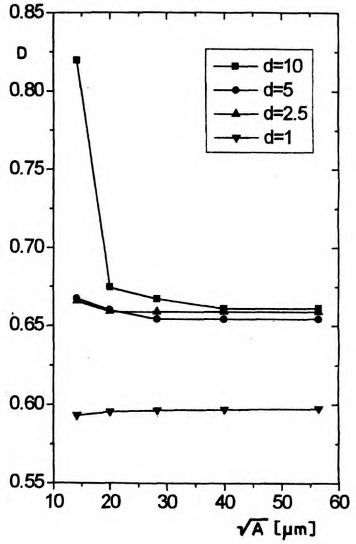


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Fig. 3. Dependence of the average optical density on the square root of the measuring aperture area determined for four model photographic layers containing spherical silver grains of diameters 10.0, 5.0, 2.5 and 1.0 μm, respectively

Fig. 4. Dependence of the standard deviation of the optical density fluctuation function on the square root of the measuring aperture area determined for four model photographic layers containing spherical silver grains of diameters: 10.0, 5.0, 2.5 and 1.0 μm, respectively

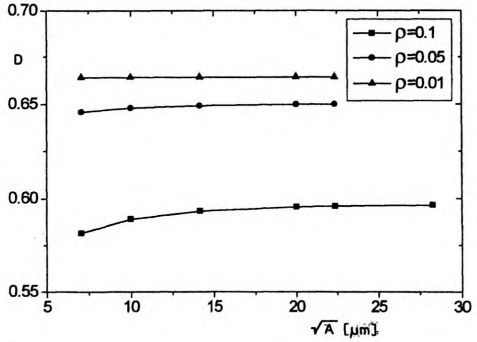

Fig. 5. Dependence of the average optical density on the square root of the measuring aperture areas determined for the model photographic layer containing the spherical silver grains of diameter 1.0 μm when applying three different resolutions for the optical density fluctuation measurement

= 0.01 μm allowed us to obtain the optical density value close to its theoretical value. Thus, it can be stated that the spatial resolution of the measurements should be less, at least, by one order and better by two orders of magnitude than the size of the silver grains contained in the analysed photographic layer. In the further calculations the applied measurement resolution of the optical density fluctuation function was $\rho = 0.01$ μm because the smallest silver grains in the model photographic layers were of 1 μm diameter.

3. Optical granularity in the polydispersive systems

The correctness of the results obtained for the systems containig nondispersive sliver grains encouraged us to carry out the simulation examinations for standard model layers of determined surface concentration of silver. For this purpose several models of the photographic layers have been developed, being characterized by the following parameters:

— average size of the crystal $d = 1.0$ μm,

— standard deviation of the average size of crystals $\sigma_d = 0.1$ μm,

— contents of the silver halides in a unity surface of photographic material (m^2) as recalculated to the metallic silver equivalent $s = 1.0$ g/m^2, 3.0 g/m^2 and 5.0 g/m^2.

Next, a random distribution of the crystals population across some surface has been generated so that the latter be sufficiently numerous to satisfy the accuracy requirements for a series of statistical measurements. The model layers obtained in this way were subject to an analysis in order to determine the optical density fluctuation function and, consequently, the optical granularity. In Figure 6, the images of projection of fragments of the particular model layers on a plane for three examined surface concentrations of silver are shown.

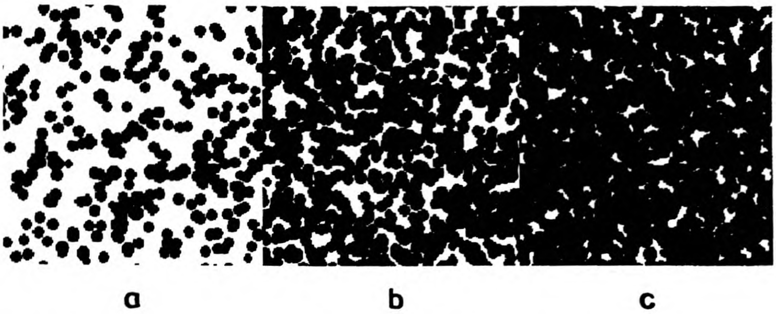

Fig. 6. Image of the projection of fragments of the model photographic layer on a plane. The layers are characterized by content of the polydispersive population of silver grains for three surface concentrations: **a** — $s = 1.0$ g/m^2, **b** — $s = 3.0$ g/m^2, **c** — $s = 5.0$ g/m^2

In the figures, a great degree of coverage of silver grains is quite visible. In the first case, for surface silver concentrations amounting to 1.0 g/m^2 the ratio of the grain surface projection to the total surface of the layer was less than unit and amounted to $P1 = 0.393$. This means that the layer covers 39.3% of its silver grain surface. In the second case for $s = 3.0$ g/m^2 the coverage ratio of the surfaces was greater than unit and $P2 = 1.185$, while in the third case for $s = 5.0$ g/m^2 the coverage ratio was $P3 = 1.971$. In the last two cases a total coverage of the layers

Table. Average optical density and standard deviation of the analysed model layers

Crystal diameter $d = 1$ µm, standard deviation $\sigma_d = 0.1$ µm, surface concentration of silver [g/m^2]	Average value of optical density	Standard deviation
1 g/m^2	0.171	2.43×10^{-8}
3 g/m^2	0.514	1.74×10^{-5}
5 g/m^2	0.856	7.51×10^{-5}

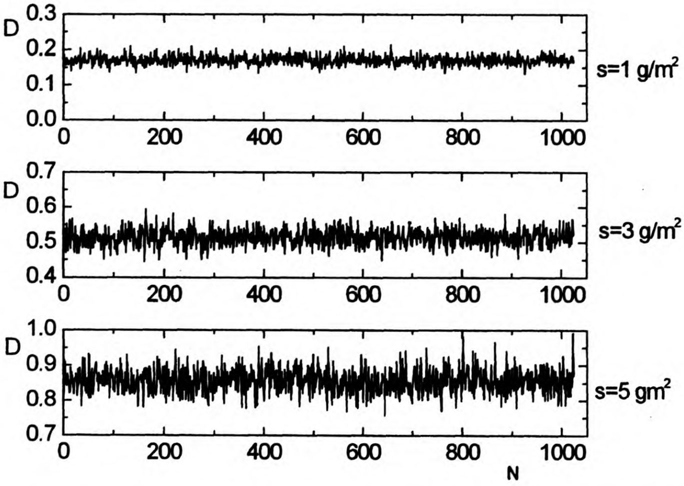

Fig. 7. Optical density fluctuation function for the model layers of surface concentration of silver $s = 1$, 3 and 5 g/m^2

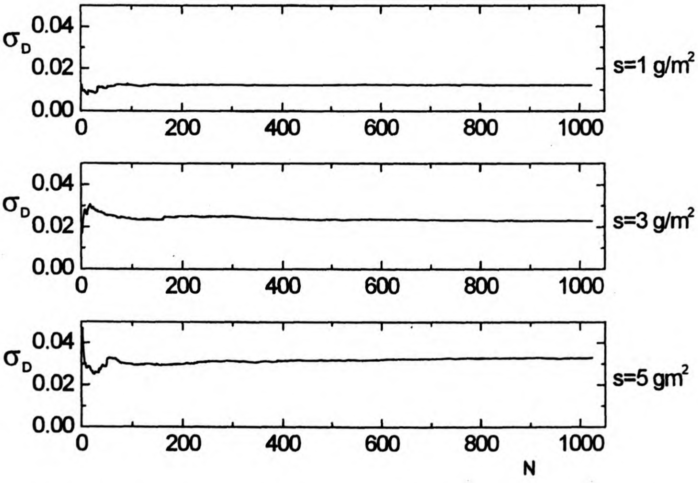

Fig. 8. Current value of the standard deviation of the optical density fluctuations determined along the scanning path for a layer of silver surface concentration $s = 1$, 3 and 5 g/m^2

should be expected which was not observed in the images presented. In the case of $P3$ it may be assumed that there exist two almost completely covered layers. In the cases of $P2$ and $P3$ the optical density of the layers should tend to infinity, while in the first case $P1$ (Fig. 6a) it should amount to $D = 0.217$. These layers were subject to analysis at the measuring resolution $\rho = 0.01$ μm. The results are illustrated in Figs. 7 and 8, while the average optical density and the standard deviation are listed in the table.

4. Concluding remarks

The results of our work on the optical granularity modelling for the photographic layers allow us to conclude that both the accepted concept and its implementation provide a chance of obtaining much more accurate results of the simulation. However, a necessary condition for it is to take account of a number of factors connected with the structure of the photographic layer itself, the optical properties of the silver grains suspended in a dry gelatine layer and a number of other factors following from the accepted measurement method for determination of the optical density fluctuation function. An important advantage offered by the constructed model is the possibility of a simple analysis of the relations following from the Siedentopf and Selwyn equations describing the granulometric properties of the black-and-white photographic layers. This possibility can also be exploited in teaching lectures on photographic structurometry.

Besides, the results obtained from examinations of the granulometric properties of the model photographic layers allow us to formulate the following conclusions:

1. The elaborated computer model of the optical granularity phenomenon occurring in silver photographic images renders it possible to obtain the qualitatively correct results for the model layers built of a population of spherical silver grains, both in the monodispersive and polydispersive systems.

2. Stabilization of the current value of the standard deviation of the optical density fluctuation function occurs after about 600 measurements. The further increase of the measurement number has no influence on the change of the standard deviation and by the same means on the value of the optical granularity of the model photographic layers.

3. Average optical density determined by measuring the optical density fluctuation function differs significantly from the expected values and thus the model used should be improved in this respect, especially so far as the range of light scattering by the silver photographic layers is concerned.

The preliminary version of this paper has been presented in the Proc. of III Local Conference KOWBAN, Wrocław – Polanica Zdrój, October 1996, pp. 165–170.

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Received April 21, 1998