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CONTRAST DETERMINATION OF THE DEMODULATION OF OPTICAL DENSITY IN LIGHT IMAGES

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A mathematical model of the relative contrast of demodulated optical density based on the Yule-Nielsen equation has been developed, which makes it possible to quantify the response of the light-toned image perception system for typical relative areas of raster elements and their optical density, which increase the information content of the reproduction, allowing the operator (technologist) of a computer publishing system to make correct decisions regarding further processing of images when preparing them for printing. On the basis of the object-oriented programming paradigm in MATLAB:Simulink package, the following was developed: a structural diagram of the relative contrast simulator model, with the help of which typical characteristics of raster conversion, optical density and relative contrast graphs were calculated and constructed.

Using a power transformation with the exponents r = 1.5, 2.0, 2.5, typical relative areas are formed, which are curved curves in which an increase in the exponent "compresses" the characteristic. It was found that the maximum value of the optical density. As well, it was found that the maximum value of the optical density D_H *= 2,5 units and does not depend on the power law and corresponds to the relative areas. The optical density graphs at the beginning of the range have a low steepness, and in the middle tones their steepness gradually increases, which improves the image contrast.*

The low initial steepness of the optical density causes jumps in the relative contrast, which quickly tends to the maximum value of K_d *= 0.63, 0.77, 0.85 units, after which it gradually and smoothly tends to the final zero values. The initial and final zero values of the relative contrast are due to the peculiarities of the Yule-Nielsen equation and its inaccuracy, as indicated by various sources.*

The results of the work and simulation modeling may be used by operators (technologists) of specialized computer systems when preparing images for printing.

Keywords: *model, relative contrast, demodulation, rasterization, optical density, simulator, characteristics, quantitative estimates.*

Problem statement. Existing methods of prepress image preparation are based on digital image processing, the analysis and synthesis of which consists of three main stages: data input to a computer, digital processing, and information output. In most cases, some images are lost due to unsatisfactory conditions of image acquisition, imperfections of individual parts and devices, various kinds of interference, distortion and noise [1, 2, 3, 4, 6].

Specialized computer publishing systems and graphic editors do not have programs for building gradation characteristics, optical density and contrast graphs, so the operator has little information about the source image. In most cases, the designer (technologist) corrects the image in the absence of the original and evaluates it against a black monitor background, while the printed image is reproduced with black ink on white paper, so the quality of the image depends on their knowledge, creative imagination, skill and production experience. Consequently, the designer and technologist do not have enough information about the quality of image preparation for printing, so determining and analyzing the contrast of demodulation and optical density of images is a relevant task.

Analysis of recent research and publications. The traditional content of halftone originals is quite diverse. The originals may have different contrasts, different values of minimum and maximum optical densities, and their ranges can be shifted to the left or right at intervals of certain densities [2, 4, 6].

If these initial data are established, the second stage involves determining the characteristics of tone reproduction, optical density, and rasterization characteristics [1, 3, 4, 6, 7]. Classical methods for analyzing and synthesizing the tone reproduction of printed images are based on the construction of the dependence of the optical density on the relative area of raster elements, which is formed depending on the tone in the form of a gradation characteristic.

There are analytical expressions for determining the relative area based on the boundary values of the original tone and basic printing parameters, which correspond to the Yule-Nielsen formula [1, 7]:

$$S = F\left(D_{lp} D_{p}, n\right), \tag{1}$$

where D_{lp} – the optical density of the ink layer of the impression plate; D_p – the optical density of the paper; n – a coefficient that accounts for the influence of line screen and paper on demodulation.

It is known that expression (1) is inaccurate, but the available sources do not provide quantitative data on accuracy. In addition, the synthesis procedure depends on the adopted organization of the tone reproduction and takes into account the input and output gradation characteristics and the interconnection of the reproduction tone characteristics [4, 5, 6, 8].

The ratio of brightness in the image as a whole and in its individual parts is determined by contrast. In general, contrast is expressed by the ratio of reflectance. The overall contrast of an image is estimated [2, 5, 6, 8]:

$$K = \frac{\rho_{\max}}{\rho_{\min}}. \tag{2}$$

Instead, the local contrast is in the vicinity of a given point:

$$K_{лок} = \frac{\rho_{x,y}}{\rho_{x+\Delta x, y+\Delta y}}. \tag{3}$$

To determine the contrast according to expressions (2) and (3), it is necessary to have reflection coefficients and appropriate devices for their measurement, which significantly limits their definition and application.

To quantify the imprint, the print contrast is used, which is determined by the Schirmer coefficient [5, 6]:

$$K = \left(D_p - D_r\right) / D_p \cdot 100\%, \quad (4)$$

where D_p – the optical density of the plate and i D_r – the integrated optical density of the raster area of the control scale.

The contrast ratio is determined by the zonal optical densities of the 100% and 80% reflectance plate of the scale element. Its value depends on the type of paper and for chalky glossy paper k =0.50, for chalky paper – 0.43, and for nonchalky paper –0.25 [5].

Therefore, modeling the contrast of light image optical density demodulation, which makes it possible to calculate and build characteristics of raster transformation, optical density and relative contrast graphs, is a relevant task.

Aim of the Research: the goal of the publication is to develop a mathematical model of relative contrast of demodulated raster images and develop a block diagram of the simulator, to present and analyze the results of simulation modeling of raster conversion characteristics, optical density and relative contrast graphics.

The main part of the research. In general terms, image contrast is a function that analytically reflects the human response to visual perception of images, so determining contrast is important for image conversion and quality improvement. Different mathematical expressions are used to estimate contrast, which are applied to the selection and processing of information for different aspects of image processing, depending on the purpose of processing using different transformation models. There are dozens of different expressions for estimating image contrast that may be selected for a given task [2].

Specific traditional methods of analyzing and synthesizing image tone reproduction based on the relative area of raster elements and the optical density corresponding to it are used in printing, in the moment when images are preparing for printing. To determine the contrast estimate of the optical density demodulation, the relative contrast was used, which is analogous to the signal modulation coefficient [2, 5]. A two-element contrast description base, grounded on the optical linear scale and typical raster optical densities of images, is assumed. Subsequently, under the specified conditions, a quantitative assessment of the relative contrast of optical density demodulation is proposed:

$$C = \left(D_0 - D_r\right) / \left(D_0 + D_r\right), \quad f\ 0 \le D_r \le D_{\max}, \quad (5)$$

where D_o – the optical density of the linear scale, which varies linearly within the range $[0 \ldots D_{max}]$, D_r – the typical raster optical density of the image.

The raster optical density corresponds to the area of raster elements, for the formation of which a power function was used:

$$S = S_0^r, \quad if\ 0 \le S_0 \le 1, \quad (6)$$

where S_0 – the relative area, which varies linearly within the range [0...1], r – the transformation rate.

For example, let us create three typical options for the relative area of raster elements for light colors.

$$S_1 = S_0^{1,5};\ S_2 = S_0^{2,0}; S_3 = S_0^{2,5}; \quad if\ 0 \le S_0 \le 1, \quad (7)$$

Based on the Yule-Nielsen formula, let us determine the raster density for three variants of the relative area of raster elements (7) [1]:

$$D_{ri} = -nLg\left[S_i \cdot 10^{-\frac{D_{lp}}{n}} + (1 - S_i) \cdot 10^{-\frac{D_p}{n}}\right], \quad (8)$$

where $D_i = D_1, D_2, D_3$ – the optical density of the plate ink layer, D_p – the optical density of the print paper, and n – a coefficient that takes into account the effect of paper and line quality on demodulation.

On the basis of the above and expressions (5) to (8), we are able to calculate the characteristics of contrast, optical density, and raster transformation. To facilitate the resolution of this problem, object-oriented programming was employed within the MATLAB:Simulink environment. Based on the preceding information and expressions (5) to (8), a block diagram of the relative contrast simulator model was developed, the schematic of which is presented in Fig. 1.

The Ramp operating unit generates the relative area S_0, which varies linearly within [0...1] and is fed in parallel to the inputs of the blocks of the first column of mathematical functions F_{cn}, accordingly in the dialog boxes there are programs for calculation of expressions (7) of typical variants of relative areas of raster elements.

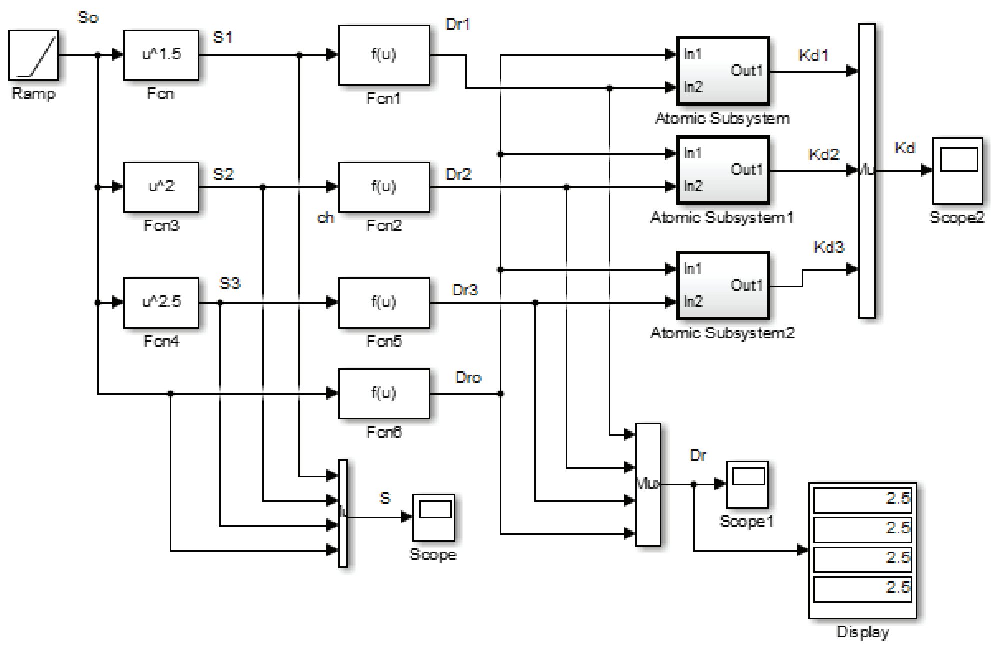

Fig. 1. Block diagram of the relative contrast simulator model

The calculated areas of the raster elements S_i are fed to the input of the multiplexer MUX and visualized by the Scope blocks. The calculated areas are fed in parallel to the inputs of the operating blocks of mathematical functions F_{cn} of the second column, accordingly in the dialog boxes of which a program with expression (8) is written to calculate the densities D_{ri}, which are fed to the input of the second multiplexer and visualized by the Scope1 and Display blocks. For comparison, the optical density D_{r0} of the linear scale S_0 is additionally determined in the block $F_{сп6}$.

The relative contrast is determined in the Atomic Subsystem blocks, the block diagram of which is shown in Fig. 2. The relative contrast is determined by expression (5). The inputs of the Atomic Subsystem block In1 and In2 are fed with the calculated values of the optical densities D_0 and D_r and are fed to the inputs of the Add blocks, and their outputs are connected to the inputs of the Divide operating block, at the output of which the relative contrast K_d is obtained. The calculated contrasts are fed to the inputs of the next multiplexer and visualized by the Scope2 block.

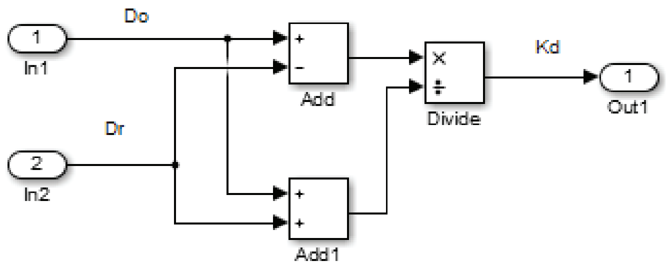

Fig. 2. Block diagram for determining relative contrast

The simulator is configured for the specified power factors r = 1.5, 2.0, 2.5. We set the optical density of the paper D_p = 0,02 units, the plate D_{lp} = 2.5, and the coefficient n = 3. The results of simulation modeling of the scribing characteristic are shown in Fig. 3.

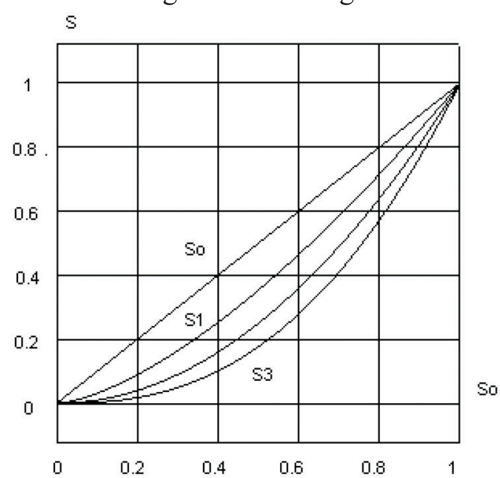

Fig. 3. Rasterization characteristics for typical relative area options

For comparison, the figure shows the characteristic of a linear raster scale S_0. Rasterization characteristics are concave curves with initial values of zero and final values of one. Increasing the power factor shifts the characteristic downward. The first upper characteristic S_1 corresponds to the exponent r = 1.5, and the lower one S_3 corresponds to the exponent $r = 2.5$. Note that the shape of the rasterization curve is the main carrier of image information, including its contrast.

The results of modeling in the form of the dependence of the optical density of a raster image on the relative area of a raster element for typical variants of the power transformation are shown in Fig. 4.

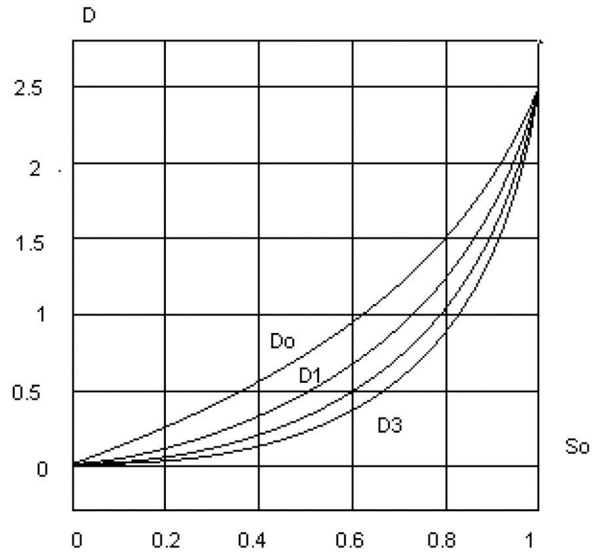

Fig. 4. Graphs of optical density of a raster image for typical variants of the power transformation

The characteristics of raster optical density are concave curves. At the beginning of the range, the characteristics of light colors have a rather small slope, especially the third and second curves, which correspond to exponents $r = 2{,}5$ and $r = 2{,}0$. After that, the characteristics gradually increase, and the final values are 2.5 units. Comparing the characteristics of the optical density with the characteristics of the raster transformation (Fig. 3), we conclude that the optical density to some extent corresponds to the characteristics of the rasterization. The upper curve D_0 corresponds to the linear raster scale S_0 and darkens the image the most. In contrast, the lower curve D_{r3} corresponds to the value of the exponent $r = 2{,}5$, which results in the maximum image brightness.

The results of the simulation of the relative contrast of optical density demodulation are shown in Fig. 5. The initial values of all contrasts are negative and equal to $K_d = -1$. The contrast sign indicates which of the optical densities prevails, D_0 or D_r. At the beginning of the range, there is a contrast jump and a change of sign. The contrasts attain their maximum values in the range of $0.1 \le S_0 \le 0.2$, which are K_d 0.63, 0.77, 0.85, and two boundary properties of the contrast are preserved, namely $K_d(D_r, D_0) = 1$ and $K_d(D_r, D_0) = 0$, if $D_r = D_0$ and equals an extremum value. After the extremum, the contrast is described by convex curves that tend to a zero final value.

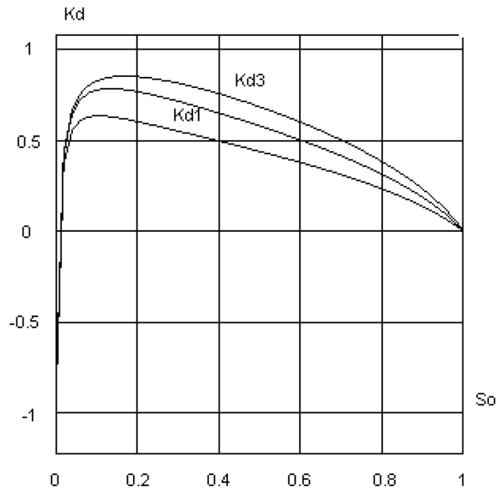

Fig. 5. Graphs of relative contrast of optical density

In summary, the proposed contrast of light image optical density demodulation has the properties of a contrast metric [2] and provides a reliable quantitative assessment of the visual system's response to light-colored images, so it can be used in preparing images for printing in computer publishing systems.

Conclusions. A mathematical model of relative contrast based on optical density has been developed, enabling the quantitative assessment of the perception response to light-tone images for typical optical density variants. This enhances the informational content of the reproduction and allows the operator (technologist) of a computer publishing system to make informed decisions regarding the further processing of images during their preparation for printing. A structural diagram of the relative contrast simulator model has been developed in the MATLAB:Simulink environment, which facilitates the calculation and construction of raster transformation characteristics, optical density, and relative contrast graphs.

The results of the simulation modeling of raster transformation characteristics and optical density are presented. It was found that at the beginning of the range, the optical density curves have a low slope, with the optical density values at S_0 = 0,2 being D_r = 0,123; 0,065; 0,039, after which the slope of the characteristics gradually increases, and their final values reach 2.5 optical density units.

It was established that the initial values of all contrasts are negative and equal to K_d = -1, where the sign of the contrast indicates the predominant optical density. At the beginning of the range, a contrast jump occurs, resulting in a sign change, with the maximum values in the range $0,1 \leq S_0 \leq 0,2$ being K_d = 0,63; 0,77; 0,85. After the extremum, the contrast is described by convex curves that approach a zero final value. It has been proven that the proposed optical density demodulation contrast for light-tone images possesses the properties of a contrast metric and provides a reliable quantitative assessment of the visual system's response to image perception.

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ВИЗНАЧЕННЯ КОНТРАСТНОСТІ ДЕМОДУЛЯЦІЇ ОПТИЧНОЇ ГУСТИНИ СВІТЛИХ ЗОБРАЖЕНЬ

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Розроблено математичну модель відносного контрасту демодульованої оптичної густини на основі формули Юля-Нільсена, який дає можливість кількісно оцінити реакцію системи сприйняття зображення світлих тонів для типових відносних площ растрових елементів та їх оптичної густини, які підвищують інформативність репродукції, що дають змогу прийняти коректні рішення оператору (технологу) комп'ютерної видавничої системи щодо подальшої обробки зображень при їх приготування до друкування. На основі парадигми об'єктно-орієнтованого програмування в пакеті MATLAB: Simulink розроблено структурну схему моделі симулятора відносного контрасту, за допомогою якого розраховані і побудовані типові характеристики растрового перетворення, оптичної густини і графіки відносного контрасту.

За допомогою степеневого перетворення з показниками степені r = 1,5; 2,0; 2,5 сформовано типові відносні площі, які є вгнутими кривими, у яких збільшення показника «стискує» характеристику. Встановлено, що максимальне значення оптичної густини $D_н$ *= 2,5 одиниць і не залежить від показника степені та відповідають*

відносним площам. Графіки оптичної густини на початку діапазону мають малу крутизну, а на середніх тонах їх крутизна поступово збільшується, що покращує контрастність зображення.

Мала початкова крутизна оптичної густини викликає стрибки відносного контрасту, який швидко прямує до максимального значення K_d = 0,63; 0,77; 0,85 одиниць після чого поступово і плавно прямують до кінцевих нульових значень. Початкові і кінцеві нульові значення відносного контрасту обумовлені особливостями формули Юля-Нільсена і її неточністю, на що вказують різні джерела.

Результати роботи та імітаційного моделювання можуть бути застосовані операторами (технологами) спеціалізованих комп'ютерних системи при приготуванні зображень до друкування.

Ключові слова: *модель, відносний контраст, демодуляція, растрування, оптична густина, симулятор, характеристики, кількісні оцінки.*

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