Definition of Optical Density of Digital Images for Print Equipment Control Systems

BOHDAN DURNYAK[1], MYKHAILO NAKONECHNYI[1], MIKOLA LUTSKIV[1], VOLODYMYR POLISHCHUK[2] AND PETRO SHEPITA[1]

[1]*UKRAINIAN ACADEMY OF PRINTING, PID GOLOSKOM STR., 19, LVIV, 79020, UKRAINE*

[2]*UZHHOROD NATIONAL UNIVERSITY, NARODNA SQUARE, 3, UZHHOROD, 88000, UKRAINE*

Introduction

Optical density of digital images is a crucial parameter in the field of printing, as it indicates the concentration of ink or dye on a printing medium, such as paper or film. It is measured using a spectrophotometer or densitometer.

The optical density of an image can be defined as the logarithm of the ratio between the light intensity passing through the printed material and the light intensity on a white background. It is measured on a scale of 0 to 5, where 0 represents a completely transparent material (no ink present), and 5 represents a fully opaque material (maximum ink concentration).

In print management systems for graphic equipment, optical density is utilized for monitoring and calibrating the printing process. It enables the establishment of the desired printing intensity to achieve the desired levels of tone and color.

Optical density can be measured separately for each color, such as process colors like cyan, magenta, yellow, and black, or as the overall density of the image. Precise measurement of optical density requires calibrated equipment and standardized measurement methods.

It's important to note that optical density is one of several factors influencing print quality. Other factors, such as dot accuracy, dot size, halftone frequency, and the type of printing material, also play a significant role in achieving the desired outcome.

Problem Statement

To ensure high-quality reproduction of digital images in the field of printing, various adjustments are often required due to the imperfect conditions under which the images obtained. This includes imperfections in scanners, digital cameras, and non-professional equipment, as well as the presence of various artifacts and distortions. Therefore, most digital images require different corrections, including tonal adjustments [1, 3, 6, 7, 17-22]. When images are scanned in batches, they can be too light or too dark, with variations in the minimum and maximum values of optical density, which deteriorates the quality of the scanned images. As a result, nearly every scanned image needs digital processing in computer graphics software such as Photoshop [7, 8, 11]. It should be noted that optical density is not a measurement unit and is not applied in computer graphics software.

Proper quality of the final product achieved when the images and textual information reproduced in the print without significant losses, which is achieved through thorough control using step wedges, reference scales, standards, and measuring instruments. The primary instrument used is a densitometer, which employed to control printed reproductions, including the range of optical density, image contrast, relative area of halftone dots, and their spread [3, 9, 12-16]. The operator (designer) of the computer publishing system responsible for preparing images for printing often does not have a physical original and computer graphics software does not provide a means to determine optical density. Therefore, the operator has limited quantitative information about the image, and verbal descriptions such as "highlights" or "shadows" are insufficient for determining the gradation characteristics of the reproduction.

Hence, the determination of the optical density of digital images is a relevant task that allows for constructing the characteristics of optical density for the initial digital image after its adjustment.

Presentation of the main research material

To construct a mathematical model of optical density for digital images, we assume that the digital images are obtained through scanning originals, which is based on the phenomenon of light reflection from the image. The main physical parameter involved is the reflectance coefficient R, which is determined by the relationship [5, 9, 11, 24].

$$R = \frac{\Phi_0}{\Phi_1}, \quad (1)$$

The equation you mentioned describes the relationship between the intensity of the incident light (Φ_0) and the intensity of the reflected light (Φ_1). If the scanned original reflects 10% of the light, then the reflectance coefficient of the analyzed image would be 0.1. The main parameter for scanning is optical density, which is measured in logarithmic units [5, 9, 11].

$$D = \frac{lg1}{R}, \quad (2)$$

After substituting the reflection coefficient in (1) optical density.

$$D = lg\frac{\Phi_1}{\Phi_0}, \quad (3)$$

In scanners, the intensity of reflected light is measured by photosensitive elements (e.g., CCD), and their output electrical signal corresponds to the brightness L of the image. Through analog-to-digital conversion (ADC), it is transformed into a corresponding number of gray levels within the range of 0 to 255 (an 8-bit representation of black pixels). The optical density of scanned digitized originals (digital image) is then determined by the number of gray levels that correspond to light intensity.

$$D = lg\frac{L_0}{L}, if\ 0 \leq L \leq 255, \tag{4}$$

Where L_0 represents the nominal number of gray levels of the ADC and L corresponds to the brightness level of the image

The optical density of a digital image is determined by the expression:

$$D = lg\frac{255}{L+1}, \tag{5}$$

The unit is introduced to account for the first level of black.

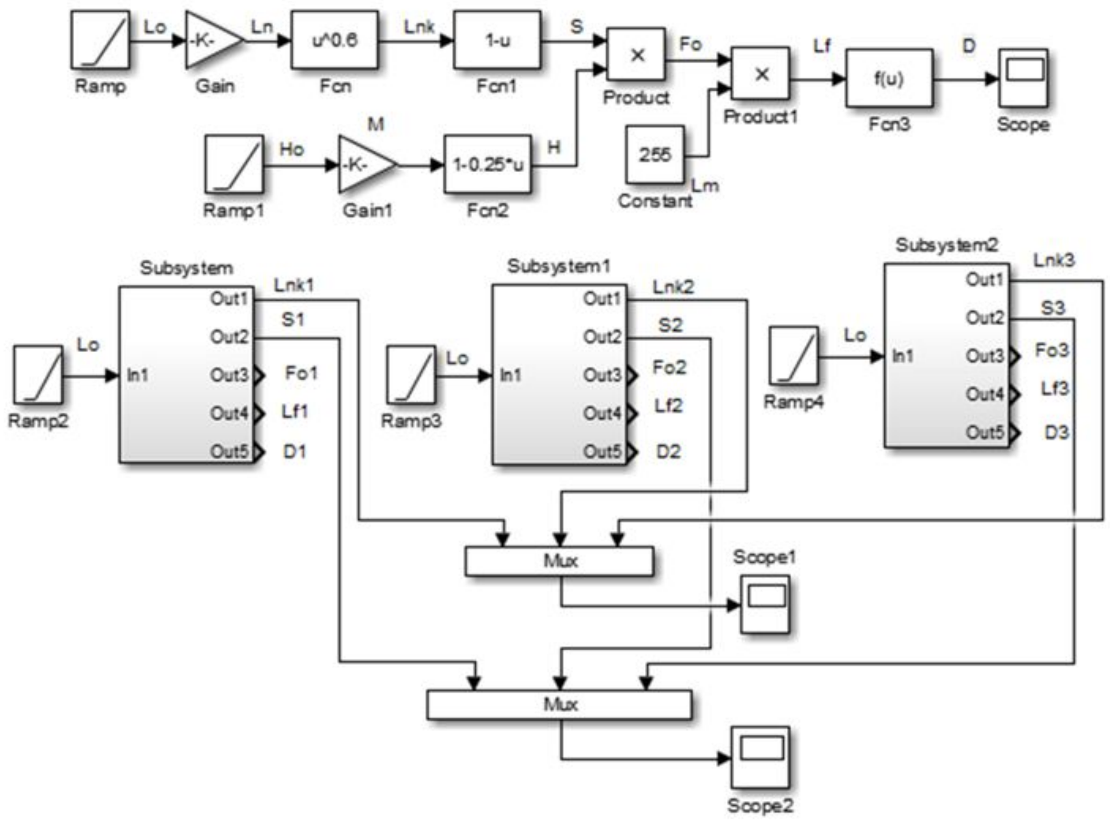
If we linearly change the amount of gray in the range of $0 \leq L \leq 255$ in equation (5), we can calculate and construct the optical density characteristic of the digital image on a linear scale. In most cases, digital images have low quality and require adjustments, which can be done using computer graphics software such as Photoshop [6, 7, 8, 18, and 25] in a dialog window. Various standard functions are used for adjustments. Let us consider an example of a popular gamma correction defined by the formula [4, 7, 19, 18, and 26].

$$L_{out} = (\frac{L_{out}}{L_0})^r * L_0, \tag{6}$$

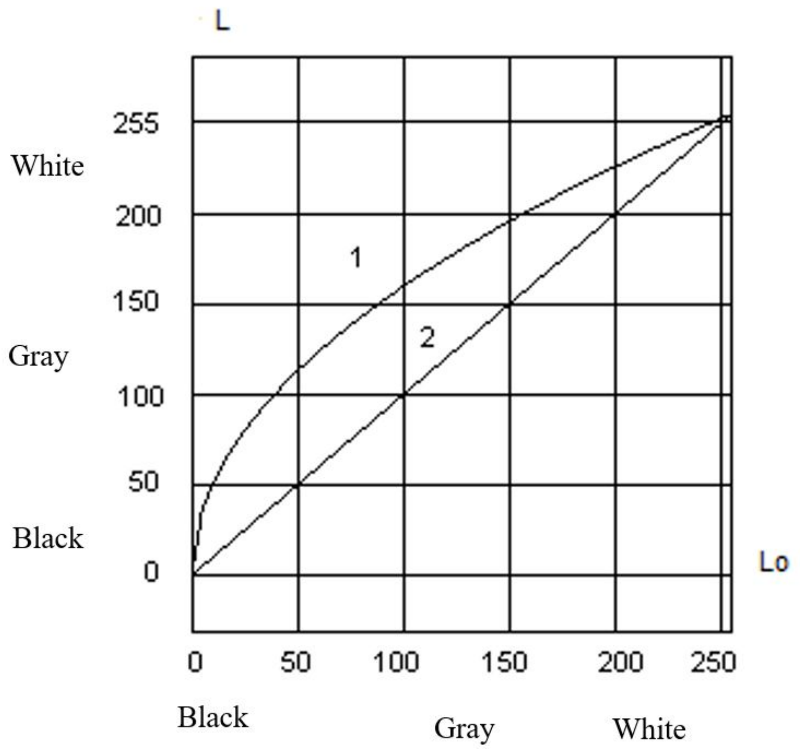
Where L_{out} – is the output brightness value, $L_0 = 255$ – is the number of gray levels, and r is the exponent that determines the desired correction of the digital image. Then, using equation (5), we can determine the optical density of the corrected image.

$$D_1 = Lg\frac{255}{L_{out} + 1}. \quad (7)$$

To simplify the task of determining the optical density of a digital image, an imitation modeling approach was applied using the MATLAB Simulink package. Based on the available blocks from the Simulink library, a structural diagram of the simulator model for optical density of digital images was constructed, as shown in Figure 1.

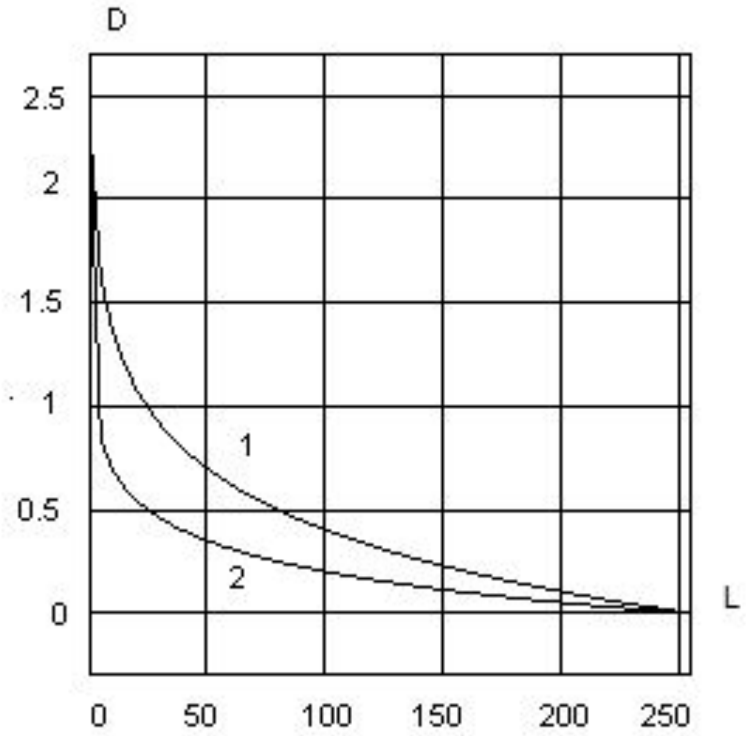


The results of the simulation, depicting the gradient characteristics of the digital images, are presented in Figure

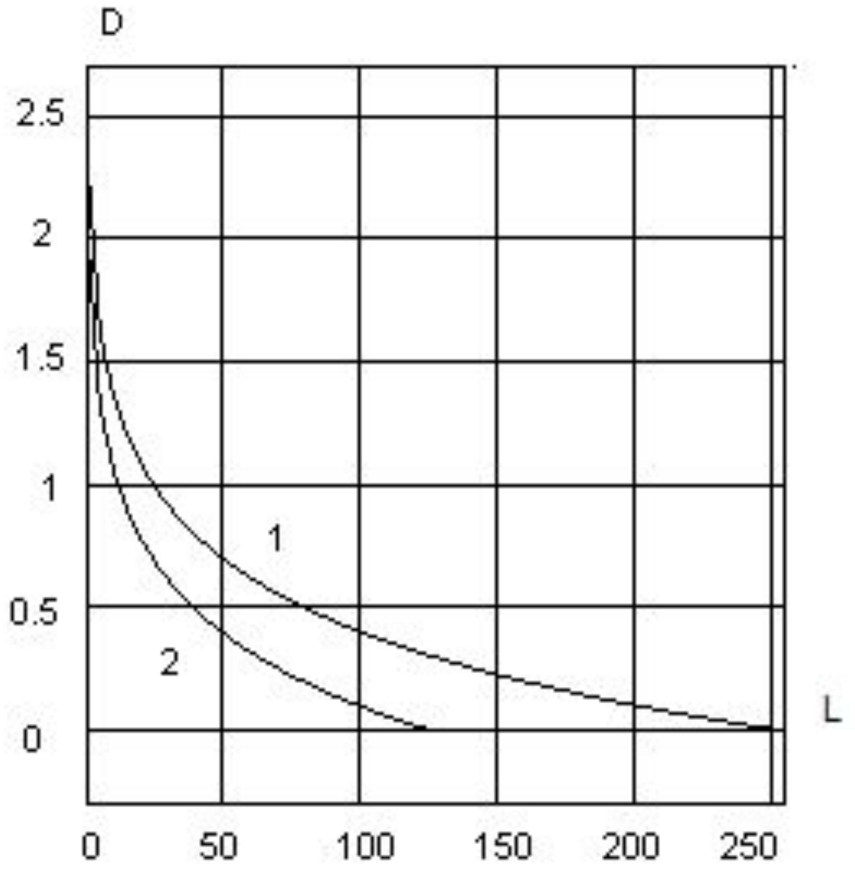


The second characteristic is a straight line and corresponds to a linear digital scale with 256 levels of gray. The image exhibits more or less uniform information content and has a constant contrast value of 1. The first gradient characteristic of the corrected image is a convex curve. Shifting the characteristic curve upwards increases the brightness of the image, enhances contrast, and improves the visibility of details in darker areas of the image, but may lead to the loss of details in brighter areas. Shifting the characteristic curve downwards results in image darkening, increased color saturation, better visibility of details in brighter areas of the image, but at the expense of losing details in the shadows.

The results of the simulated modeling of the optical density of digital images are presented in Figure



The maximum deviation of optical density occurs at low gray levels, with a maximum value of 30%. It gradually decreases and approaches zero at the end of the interval.
Let's examine the influence of the number of gray levels on the optical density. As an example, we set the number of gray levels to 128. The simulator was adjusted accordingly to have 128 levels (see equation 7). The results of the simulated modeling of optical density for different numbers of gray levels are shown in Figure



Conclusions

A mathematical model of optical density for digital images has been developed, expressed logarithmically as the ratio of the nominal number of gray levels (255) to the given digital image. A structural scheme of the accumulator model for optical density of digital images in the MATLAB package Simulink has been constructed, which allows for computing and generating characteristics of optical density for specified digital images and analyzing their properties.

The presented results of simulation modeling are in the form of optical density characteristics for typical digital images with linear scales and convex gradation characteristics. It has been established that the optical density characteristic for a linear digital scale has a maximum value of Dm=2.5 and gradually approaches zero for gray tones. The characteristic for the adjusted image is positioned below the previous one, resulting in a decrease in optical density and image brightening. The deviation of optical densities has been determined, with the maximum value occurring at low gray levels and reaching 30%.

The influence of the number of gray levels on optical density has been examined. It has been found that with 128 gray levels, there is compression of the optical density characteristic, a reduction in tonality, and image brightening. Consequently, the adjusted image will have fewer details in the dark areas.

It has been established that the optical density characteristic of a digital image is inversely related to the gradation characteristic provided by gray levels, which is due to the logarithmic algorithm for calculating optical density. Optical density and brightness describe images in different planes. The optical density characteristics more fully describe the black tone of digital images compared to gradation characteristics.

The results of this work enhance the informativeness of digital images and can be used in computer publishing systems to select optimal gradation characteristics for reproduction at different stages of image preparation for printing.