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Development of Information Model of Color Reproduction Process in Polygraphic Systems

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Abstract. Color calibration is a common procedure in polygraphic reproduction, and there are enough tools to guarantee accurate digital or analog reproduction (printing on paper, screen or display projectors, etc.). The topical task is to achieve the correspondence of colors formed on different devices of the printing process. The color on the monitor screen must match the color on the printer print. In addition, if there are several monitors and printers at the enterprise, it is necessary to ensure color matching between them. The aim of the article is to develop a model of step-by-step conversion of color images in order to achieve high quality reproduction in reproduction systems. The methods of automatic algorithmic conversion (using Convert to Profile in Adobe Photoshop) and conversion by the color separation operator were used in the work. Conversion of the image from the LAB color space to the CMYK color space was carried out using various conversion methods: Relative Colorimetric, Absolute Colorimetric, Perceptual, Saturation. This sequence of actions allowed to identify the nature and level of change of color coordinates. The maximum saturation reduction is observed when using the Relative Colorimetric and Absolute Colorimetric conversion algorithms. The minimal one – when using Saturation and Perceptual algorithms. Thus, the use of different conversion algorithms to varying degrees affects the saturation of different colors. The practical significance of the study is that the information model has been developed which will make it possible to implement the technology of priority color reproduction, depending on the purpose of the reproduction process, which increases the accuracy of the conversion of color information of the originals and, accordingly, the quality of production of printed publications

Keywords: color space, color management system, data flow model, color coordinate conversion algorithms

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INTRODUCTION

There is a massive introduction of computer systems into polygraphic prepress processes.The author, the publishing house and the printing house started performing technological operations in different proportions. There is a lack of regulations for the performance of operations [1]. These and other reasons led to the violation of established industrial relations. As a result, the quality of printed products often does not satisfy the customer, especially in terms of color.

Reproduction of color images involves the transition from colorimetric models to printing space. In this case, information is compressed from the color coverage of the original to the reduced color coverage of the print.

This situation has created the prerequisites for the creation of color management systems (CMS – Color Management System) [2] designed to solve the problem of ensuring the quality of color reproduction in the conditions of modern territorial openness of the production cycle. The International Color Consortium (ICC – International Color Consortium) in the mid-nineties proposed a standard [2] that allows to determine the color parameters of various devices involved in both prepress and printing processes.

The color management system copes well with the task of accurate color reproduction if all equipment is well calibrated and the output signal is greater than or equal to the input signal.

Thus, the task of achieving the correspondence of colors which are formed on different devices of the printing process is relevant. The color on the monitor screen must match the color on the print obtained on the printer. In addition, if there are several monitors and printers at the enterprise, it is necessary to ensure color matching between them. Without CMS, this situation is extremely difficult and time-consuming to correct.

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Color calibration is a common procedure for photographing natural objects and there are enough tools to guarantee an accurate digital image or analog reproduction (printing on paper, screen or display projectors, etc.). Color models, obtained both photogrammetrically and by scanners, have not yet reached such level of development and are often built without attention to the colorimetric quality of the result [3-5]. The color information of the original usually exceeds the amount of information that can be reproduced in the reproduction process, so information compression is performed [6]. But in these studies there is no algorithm for color conversion depending on the properties of the original.

When reproducing multicolor halftone originals, the choice of color transformation parameters is determined mainly by the experience and artistic taste of the operator [7]. At the same time, the possibilities of the reproduction process are often not fully used due to the lack of complete information about the optimal transformation of color information of a particular original [8; 9]. However, these works do not take into account the fact that since the choice of control objects is determined by the semantics of the original, an information classification of fine art originals for polygraphic reproduction is necessary.

The distribution of color fields of information within the gradation interval, the contrast in the plot-important and background areas of the gradual interval lead to the need to develop some additional requirements for the parameters of color originals. [10]

The CMYK color space (Cyan, Magenta, Yellow, Key color – a subtractive color model used in printing) has a limited color gamut, which depends on the applied components of polygraphic production – paper, inks and on the process settings in general – the parameters of the printing process, which must be taken into account when information about the real CMYK used in this process is entered into the processing system [11-13].

The developed HiFi-technologies [11; 12], which use from 5 to 8 synthesis inks, combined as a rule with stochastic rasterization, have limited application for technological and economic reasons. This makes it impossible to accurately reproduce pictorial originals, which are slides or photographic prints of natural scenes [14-16].

Thus, *the aim of the work* is to build a model of step-by-step transformation of graphic objects in order to achieve high-quality color reproduction characteristics in reproduction systems.

The novelty of the work lies in the construction of a model of data flows in the reproduction system, which allows to analyze information about the parameters of the polygraphic process and to adjust the equipment settings to achieve the required quality of color images.

MATERIALS AND METHODS

The process of developing an information model is to obtain a system object of modeling as well as a model of data flows. This approach will allow to analyze and generalize information about numerous parameters of the reproduction process and identify those of them by changing which it is possible to achieve the required quality of color information reproduction.

In colorimetric calculations, it is customary to express the values of RGB color coordinates as decimal fractions from 0 to 1, where 0 corresponds to black and 1 to white, while in digital image processing systems these coordinates are usually stored as 8-bit integer variables in the range from 0 (black) to 255 (white). The values of color coordinates of an image in the internal CMS color space, on the contrary, are stored as fractional variables in the range from 0 to 1. To get the value of XYZ coordinates in the usual units, they must be multiplied by 100 and vice versa, when entering XYZ color coordinates for color calculations based on color profiles – they must be divided by 100.

Compression of information at the stage of prepress processes can occur both automatically (with the help of algorithms for recalculation of color spaces, the so-called Rendering Intents, built into the software) and manually by the color correction operator.

The following methods are considered as comparative methods of conversion: automatic algorithmic conversion (using Convert to Profile in Adobe Photoshop) and conversion by the operator of color separation.

The original image and the image converted from LAB color space to CMYK color space are compared using different methods. The psychological accuracy of color reproduction of images obtained using the following conversion algorithms is evaluated: Relative colorimetric, Absolute colorimetric. Perceptual, Saturation, and on images subjected to address transformations by the color separation operator who controls the changes using the "Info" panel in Adobe Photoshop.

The methodology of the experiment was to control the color coordinates of real objects with the highest saturation in the LAB space. Automatic transformations using compression algorithms in Adobe Photoshop were performed according to the scheme below.

Then the image was converted from LAB color space to CMYK color space using the necessary parameters (target color space and conversion algorithm). Immediately after conversion LAB – CMYK using different conversion methods: Relative Colorimetric, Absolute Colorimetric, Perceptual, Saturation, the image was again subjected to CMYK – LAB conversion. This sequence of actions allows to identify the nature and extent of changes in color coordinates.

RESULTS AND DISCUSSION

The set of color information conversion operations can be represented in the data flow model (Fig. 1) [10; 17]. The original image in the input device is element by element transformed into an array of discrete values of color characteristics – first in the RGB space (Red, Green, Blue), then in LAB, which ensures consistency with the subsequent stages of the color reproduction process and the correct output of the print. At the same time, the method of determining the correspondence of color coordinates of hardware-dependent and hardware-independent spaces ensures the accuracy of color information conversion.

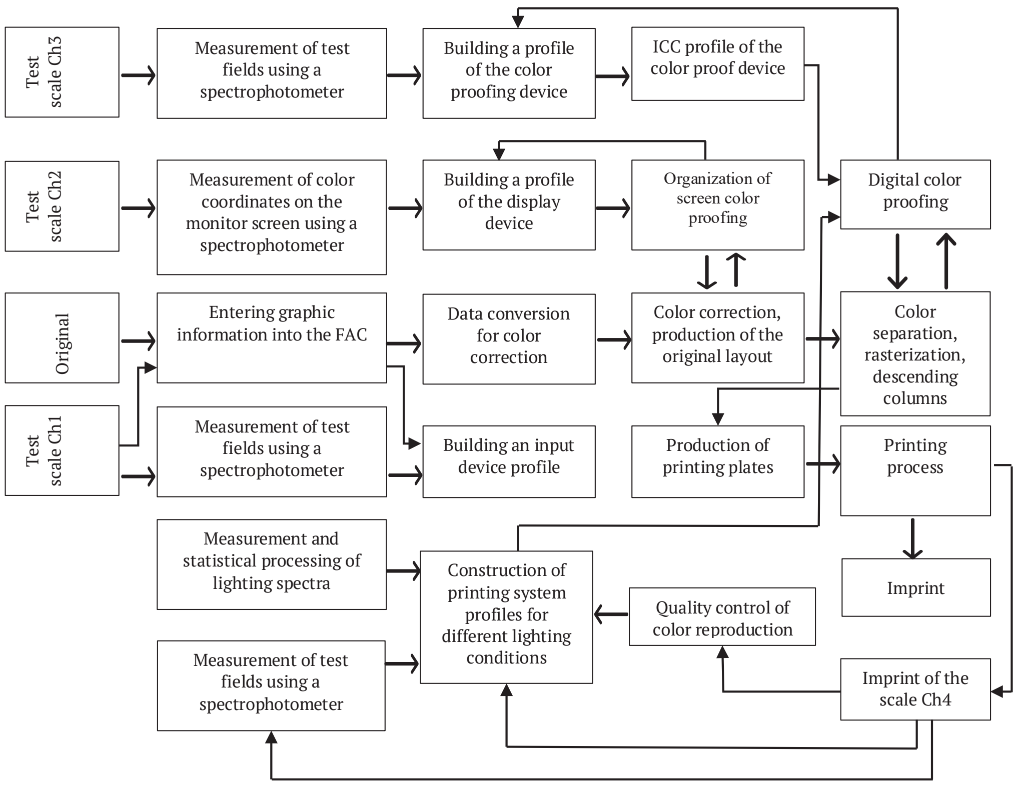

Figure 1. Information flows of color characteristics in the reproduction system

Information conversion in color image processing can be described by a system of equations that contains a set of functions and can be represented as the following relations:

The first equation describes the coordinates of the image elements that characterize the print:

$$X = F(O, v, U, C, M)\ . \quad (1)$$

The coordinates of image elements *X* are a function of *F* operators describing the technological process of reproduction in the polygraphic system and include such variables as: a set of coordinates of image pixels, characteristics of the original *O*; device profiles *v*; gradation transformations *U*; viewing conditions of the polygraphic product (spectral characteristics and color coordinates of the white emitter point) *C*; characteristics of ink and paper *M*.

A set of pixel coordinates of an image *O* is described by a set of coordinates in the *RGB* color model system:

$$O = \{R_i, G_i, B_i\}_{i=1,\dots n}\ , \quad (2)$$

where R_i, G_i, B_i – elements of the additive color model, which describes the way of color coding to reproduce colors using three colors (*R* (red) – red; *G* (green) – green; *B* (blue) – blue), which are called primary colors.

Device profiles *v,* given by a set of mappings Φ_i^j and Ψ_i^j, which perform the direct and inverse transformation between the hardware-dependent and hardware-independent color spaces of the *i*-th device for the *j*-th color rendering purpose:

$$v = \{\Phi_i^j, \Psi_i^j\}\ . \quad (3)$$

The conditions for viewing the printing product *C* include the lighting parameters determined by the spectral composition of the i-th radiation source

$$C_i = \{S_i(\lambda)\}\ , \quad (4)$$

where S_i is the spectrum of the actual radiation source in the visible wavelength range λ=380...720 nm.

The characteristics of ink and paper include the color coordinates of the white point M_1 and the spectral reflection coefficients M_2, which depend on the characteristics of polygraphic inks and the reflectivity of the printed material

$$M=(M_1, M_2). \quad (5)$$

The reproduction process aims to obtain the predicted colors on the print by solving the objective function

$$P(X, X^*) \to X_{min}\ , \quad (6)$$

where *P* is a color difference determined by a metric in the hardware-independent LAB space, *X* is the desired LAB values of the print coordinates for a given type of lighting.

At the stage of prepress preparation of images, it should be taken into account that the human eye perceives graphic information in the conditions of the existing light sources. The formation of the final image in the human visual system during the visual assessment of the final polygraphic product by the consumer is influenced by such factors as viewing conditions, as well as the characteristics of ink and paper [18; 19].

The change of color gamut occurs in distributed systems "computer – color information interpretation device". The differences between the configurations of input, display and output devices create many problems related to the coordination of color gamuts and the same color interpretation. At the same time, device profiles are the main elements of the system since all computer color conversions are performed using profiles.

The main function of the CMS is to convert the image from the hardware-dependent color space of the device to the hardware-independent internal color space of the CMS. And there is also the reverse conversion from the internal color space to the color space of a particular device in accordance with the selected color rendering algorithm. This conversion is performed based on data taken from the color profile of this device.

In general, the process of image visualization using CMS can be represented as follows. Conversion of the image from RGB color coordinate space to the internal CMS color space is carried out in two stages:

1. Linearization of the image (inverse gamma correction) as a result of which nonlinear distortions are compensated.

2. Conversion of the image to the internal CMS color space (XYZ or L * a * b *) with the recalculation, if necessary, of the color coordinates to the standard D50 emitter (adopted as a reference white light source in the internal CMS color space) [2].

To preserve the values of the nonlinear distortion gamut in the color profile file, image linearization is used, which is carried out by reducing to the power of γ the brightness values of the image pixel in three RGB channels:

$$r_0 = r_D^{\gamma_r}; g_0 = g_D^{\gamma_g}; b_0 = b_D^{\gamma_b}\ , \tag{7}$$

where γ_r=r*TRC*, γ_g=*gTRC*, γ_b=*bTRC* – gamma values (γ) for red, green and blue channels; r_D, g_D b_D – gamma-corrected coordinates of red, green and blue colors in the color space of the device, recalculated to the range [0 … 1]; r_0, g_0, b_0 – their linear values.

If gamma correction is used for any other function than the steady-state one, it is specified in the profile in a tabulated form as a one-dimensional matrix of п elements, the ordinal number of which determines the values of r_D, g_D, b_D and the values of the elements themselves – the values of r_0, g_0, b_0:

$$\begin{gathered} rTRC = [r_{01}, r_{02}, r_{03}, \dots, r_{0n}] \\ gTRC = [g_{01}, g, g_{03}, \dots, g] \\ bTRC = [b_{01}, b_{02}, b_{03}, \dots, b_{0n}] \end{gathered} \tag{8}$$

Thus, it is possible, if necessary, to set any non-linear transformations of color coordinates (for example, to strengthen or weaken certain tonal areas of the image without affecting others, to change the brightness and contrast of the image, and so on).

After linearization, the color coordinates of the image are converted to the internal CMS color space (XYZ CIE) by linear recalculation of color coordinates:

$$\begin{bmatrix} X_{pcs} \\ Y_{pcs} \\ Z_{pcs} \end{bmatrix} = \begin{bmatrix} rX & gX & bX \\ rY & gY & bY \\ rZ & gZ & bZ \end{bmatrix} \times \begin{bmatrix} r_0 \\ g_0 \\ b_0 \end{bmatrix} \tag{9}$$

where X_{pcs}, Y_{pcs}, Z_{pcs} – color coordinates of the image in the internal color space of CMS; r_0, g_0, b_0 – linear values of color coordinates; *rX, rY, rZ, gX, gY, gZ, bX, bY, bZ* – color coordinates of reference color-forming stimuli of this color space, defined in the tags rXYZ, gXYZ, bXYZ.

Particular attention should be paid to one important detail: the CMS internal color space almost always uses the standard D50 emitter as a reference white light. At the same time, a color profile describing a particular device (for example, monitor profile and printer profile) or an abstract color space (such as Adobe RGB and sRGB color profiles [14; 20]) may use a completely different standard emitter. Most monitors and desktop printers are calibrated to a color temperature of 6500K (D65 emitter), not 5000K (D50 emitter). And it is customary to calibrate equipment intended for use in poligraphy to a color temperature of 5000K. This means that in the process of recalculation of color coordinates from the color space of the device (for example, RGB) to the internal color space of CMS, not the values of color coordinates in the internal color space of CMS are obtained but the values calculated relative to another standard emitter (for example, D65), which will inevitably lead to errors.

According to the ICC recommendation, the conversion of color coordinates to the D50 standard emitter is carried out by the Bradford method, although different profiles may use other algorithms [2]. The coefficients of the chromatic color conversion matrix of the image from the standard emitter specified in the profile (the default reference white light source in this color space) to the standard D50 emitter are stored in the *chad* tag.

Most often, changes in color models consist of a chain of transformations: a graphic object from the color space of the scanner is converted to the working color space of image processing and its storage in a file; to display the image, it is converted from the working color space to the color space of the monitor; To obtain a replicated copy, graphic information is converted to the color space of the printing device, which is used for the final reproduction of the image. CMS allows image conversion from one color space to another and from this color space to a third any number of times.

Color discrepancies between different printing devices result in some colors not being reproducible. In this case, these colors are replaced with colors that can be reproduced on this device and that produce similar color sensations to the observer.

Therefore, the ICC standard provides for four different conversion algorithms that can be used to harmonize the representation of color between different color spaces.

The results of the experiment show that after the conversion from LAB to CMYK color space, there is indeed some loss in saturation, change in color tone and photographs. Experiments were conducted and measurements were made, based on which the following conclusions about the magnitude and nature of the change in information during compression (i.e. after conversion) were obtained.

Saturation. Converting image information from LAB color space to CMYK color space leads to loss of saturation. However, the degree of saturation change is not the same for different colors. The degree of saturation loss of a particular color depends on both the conversion algorithm used in the conversion process (Perceprual, Saturation, Relative Colorimetric, or Absolute Colorimetric) and the color tone.

Green and red colors lose saturation to the greatest extent. In yellow color, saturation is lost to a much lesser extent. When converting the same colors using different ICC profiles, saturation is lost to a greater extent when using the ICC profile for coated paper.

The maximum saturation reduction is observed when using the Relative Colorimetric and Absolute Colorimetric conversion algorithms. Minimal – when using Saturation and Perceptual algorithms. The use of the Peceptual and Saturation conversion algorithms leads to almost identical results, namely, to the preservation of maximum saturation. A slight difference is observed only in some cases in the area of green colors. Thus, the use of different conversion algorithms to varying degrees affects the saturation of different colors.

Lightness. Magenta color. Converting the original image from the LAB color space to the CMYK color space for magenta shows a characteristic decrease in the values of the photo. To the greatest extent, this situation occurs when using the Saturation method. To a lesser extent, the decrease in lightness is caused by the recalculation of the Perceptual algorithm. Such recalculation algorithms as Absolute Colorimetric and Relative Colorimetric show the least influence on the change of image lightness.

Red color. When converting saturated red colors, the greatest change in lightness occurs when using the Absolute Colorimetric conversion algorithm. To a lesser extent for saturated colors, changes are noticeable when using the Saturation algorithm. When converting unsaturated colors in shadows, the maximum changes in lightness are observed when using the Absolute Colorimetric conversion algorithm. Other conversion algorithms have practically no effect on lightness.

The application of the Relative Colorimetric conversion algorithm leads to a slight reduction of the photo, or does not affect it at all.

Blue color. For blue color, the lightness conversion process changes differently. In light ($70<L<100$) when using the Absolute Colorimetric algorithm, the lightness increases. In the case of using the Perceptual and Saturation conversion algorithms, the lightness is reduced. The Relative Colorimetric algorithm practically does not affect the lightness.

For coated paper, the Saturation and Perceptual algorithms lead to reduction of the photo. Relative Colorimetric and Absolute Colorimetric algorithms have almost no effect on lightness. In the shadows ($0<L<30$), after conversion, the lightness is basically unchanged.

Light blue color. After the conversion process, the lightness of the light blue color is mainly reduced. Lightness decreases to the greatest extent when using Saturation and Perceptual algorithms. In the case of conversion of unsaturated colors in light, lightness also decreases when using the Saturation and Perceptual algorithms. When using the Absolute Colorimetric algorithm, lightness, on the contrary, increases.

Yellow color. For yellow color, the use of the Absolute Colorimetric conversion algorithm leads to an increase in the photo. When using the Saturation and Perceptual algorithms, there is a decrease in lightness. The Relative Colorimetric conversion algorithm practically does not affect the lightness.

Green color. After the conversion process, the lightness of the image undergoes little change. In the case when an unsaturated color is converted, the lightness is reduced to the greatest extent when using the Saturation and Perceptual conversion algorithms. The use of Relative Colorimetric and Absolute Colorimetric conversion algorithms either does not affect the lightness at all, or leads to a slight change in one direction or another. If an unsaturated color is converted using the Absolute Colorimetric algorithm, the lightness increases. After the conversion process, the lightness changes to different degrees for different color ranges, i.e. it depends on the color tone:

– when converting dark colors of the image, the lightness is increased;

– in the light areas of the image the lightness practically does not change or decreases slightly;

– when using different conversion algorithms to perform the conversion, the results of the lightness change are basically the same (for dark areas of the image).

At the first stage of work with the image, the image was scanned in Lab color space. Then the color correction operator converted the images from Lab color space to Adobe RGB color space using the Convert to Profile function in Adobe Photoshop.

Then the resulting image is corrected in the raster image processing program Adobe Photoshop according to the following scheme:

1. The Curves command was mainly used for transformations.
2. In the dialog boxes, RGB colors were aligned using the curve.
3. In the situations where additional color correction was required (for example, for additional processing of natural colors, paying special attention to memorable colors), the Color Balance tool was also used.
4. Next, the Levels and Brightness/Contrast adjustment layers were added. When manually correcting the original image with the presence of grayscale (to achieve gray balance), 3-4 control points were used. Using the “Curves” tool, the areas of highlights, shadows and penumbra were adjusted by channels so that the RGB values were approximately the same.
5. At the final stage, the RGB image is converted to CMYK space.

During the experiment, the color coordinates of real objects with the highest saturation in the LAB space were controlled. Automatic transformations using compression algorithms in Adobe Photoshop were performed according to the following scheme. To set the conversion method in Photoshop, you need to enter the Convert to Profile window of the Image/Mode submenu, where you can change the appearance of the conversion algorithm (Rendering Intents).

Then the image was converted from LAB color space to CMYK color space using the necessary parameters (target color space and conversion algorithm). Immediately after conversion LAB – CMYK using different conversion methods: Relative Colorimetric, Absolute Colorimetric, Perceptual, Saturation, the image was again subjected to CMYK – LAB conversion. This sequence of actions allows to identify the nature and extent of changes in color coordinates.

The results of the experiment show that after the conversion from LAB to CMYK color space, there is indeed some loss in saturation, change in color tone and photographs. Experiments were conducted and measurements were made, based on which the following conclusions about the magnitude and nature of the change in information during compression (i.e. after conversion) were obtained.

Converting image information from LAB color space to CMYK color space leads to loss of saturation. However, the degree of saturation change is not the same for different colors. The degree of saturation loss in a particular color depends on both the conversion algorithm used in the conversion process (Perceprual, Saturation, Relative Colorimetric, or Absolute Colorimetric) and the color tone.

The maximum saturation reduction is observed when using the Relative Colorimetric and Absolute Colorimetric conversion algorithms. Minimal – when using the Saturation and Perceptual algorithms. Thus, the use of different conversion algorithms to varying degrees affects the saturation of different colors.

CONCLUSIONS

The model obtained in the work allows to analyze the information about the parameters of the reproduction process at all stages of the polygraphic process, from prepress directly to the printing process. This information provides high-quality conversion of graphic information with the required accuracy. With targeted correction in terms of saturation, the saturation is mostly slightly reduced, but sometimes significantly increased. After the conversion process, the color loses saturation. The more saturated the color is, the more it loses saturation. However, in some cases, targeted processing leads to an increase in saturation when processing images with a predominance of saturated colors. The nature of the change in lightness depends largely on the color, and either increases or decreases. After a series of transformations, the lightness and saturation of the image subjected to processing changed markedly. If the color is light and saturated, then its lightness in the process of transformation decreases significantly. If the color is saturated, but dark – lightness, on the contrary, increases.

The scientific result of the article consists in building a model of data flows in the reproduction system, taking into account the partial loss of graphic information at different stages of the reproduction process. Further work in this direction involves the development of regulatory documentation taking into account the quality of the original images and the specifics of printing equipment.

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Розробка інформаційної моделі процесу кольоровідтворення в поліграфічних системах

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Анотація. Калібрування кольору є звичайною процедурою при поліграфічному репродукуванні, водночас існує достатньо інструментів, що гарантують точне цифрове або аналогове відтворення (друк на папері, екранні або дисплейні проектори тощо). Актуальним є завдання досягнення відповідності кольорів, що формуються на різних пристроях друкованого процесу. Колір на екрані монітора повинен відповідати кольору на відбитку принтера. Крім того, за наявності на підприємстві кількох моніторів та принтерів потрібно забезпечити колірну відповідність між ними. Метою статті є розробка моделі поетапного перетворення кольорових зображень задля досягнення якісного відтворення у репродукційних системах. У роботі використовувалися методи автоматичного алгоритмічного перетворення (за допомогою Convert to Profile в Adobe Photoshop) та перетворення оператором кольороподілу. Конвертування зображення з колірного простору LAB в колірний простір CMYK проводилося за допомогою різних методів перерахунку: Relative colorimetric, Absolute colorimetric, Perceptual, Saturation. Така послідовність дій дозволила виявити характер і рівень зміни колірних координат. Максимальне зменшення насиченості спостерігається під час використання алгоритмів перерахунку Relative Colorimetric та Absolute Colorimetric. Мінімальні – при використанні алгоритмів Saturation та Perceptual. Таким чином, застосування різних алгоритмів перерахунку різною мірою впливає на насиченість різних кольорів. Практичне значення дослідження полягає в тому, що розроблена інформаційна модель дозволить реалізувати технологію пріоритетного відтворення кольорів, залежно від мети репродукційного процесу, що підвищує точність перетворення колірної інформації оригіналів і, відповідно, якість виробництва друкованих видань

Ключові слова: колірний простір, система управління кольором, модель потоків даних, алгоритми перерахунку кольорових координат