Application of digital images processing for expanded gamut printing with effect of saving material resources

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Abstract

This work concerns expanding the capabilities of modern technologies for high-quality color reproduction of digital images on material media. The research focuses on replacing spot colors with classic four-color printing, with the addition of two or three colored inks. The Fogra 55 characterization data was processed for multi-primary printing with additional colors Orange, Green, and Violet. New methods of pre-press preparation were applied, which are based on the processing of the colors of the original in the ICaS color space. As a result of the analysis of the projections of the color gamut, the formulated principle of color division of the image with two color inks and black ink was confirmed. According to the analytical solutions of the Neugebauer equations, no more than two colors and black are defined for the reproduction of spot colors. The study compared the color differences of color separation by classical and ICaS-ColorPrint technology. The quality of color reproduction was evaluated regarding the color differences ΔE (CIE 2000) in CIE L*a*b* color space for selected PANTONE+ Solid Coated library sample colors. The small values of color differences when converting color information using the ICaS-ColorPrint technology shows that there is an alternative to the expensive process of spot color printing.

Keywords

Multi-primary Printing, Expanded Gamut, spot colors, additional inks, ICC profile, analytical solutions, color separation, color synthesis, saving color inks

1. Introduction

One of the most important tasks of modern printing is high-quality printing of color images as close as possible to the original in terms of color reproduction. The basis of modern printing technologies is printing with four process CMYK (Cyan, Magenta, Yellow, Black) colors. In most cases, four-color printing meets the customer's requirements. However, this printing process has a significant drawback: its color gamut is limited compared to the gamut of the monitor or the gamut of real colors. In this case, you can improve the quality of color reproduction by introducing additional spot colors. The primary US spot color specification tool is the PANTONE Color Formula Guide. The main component of this system is a fan decks with 2,161 samples of inks applied to coated and uncoated paper [1].

Spot inks are used in printing process in order to print a specific color on products, for example, the brand color of the logo: Starbucks Green, the iconic Red of Coca Cola, Cadbury's Purple Reign, McDonald's the Yellow arch on a Red background, Pepsi the Red, Blue and Background Blue [2]. For the purpose of reproduction a high-art and advertising publications, two or three additional spot colors are used to emphasize the expressive features of the products. The printing process with spot colors will ensure a more accurate reproduction of solid colors such as: Orange, Green, Purple. For example, Orange colors will appear purer when Orange ink is added to the printing process, instead of obtaining the corresponding color by mixing Yellow and Magenta inks [3]. Due to the fact that one color can be obtained not at the expense of applying four layers of ink, but at the expense of only one layer, when printing with spot colors. It is

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possible to achieve an accurate reproduction of the brand color and a more dense and uniform cover of the printed area with ink, avoiding the graininess characteristic of process colors [4]. Spot colors are generally used to reach colors that are outside the gamut of process CMYK printing. However, printing with spot colors requires estimating ink quantities, use of a separate printing unit with requirements for cleanup and changeover for the next print job. The excess of spot color inks must be stored, creating inventory, or discarded in an environmentally sound manner. The whole process of spot color printing is inefficient – It is expensive and arduous and represents custom manufacturing, which is difficult to justify in a challenged economy [5].

2. Literature Review

Therefore, in recent years, the popularity of research in the field of multicolor printing has increased. These studies concern the possibility of replacing spot colors with classic four-color printing with the addition of two or three color inks. Such printing was named: Extended Gamut Printing [3], Expanded Gamut Printing [5], Multi-primary Printing [6].

Expanded Gamut (EG) printing requires a new approach in terms of color management software and the number of colorants. Dr. Abhay Sharma in his research explains what results to expect from this new approach [7, 8, 9]. EG printing extends the color gamut of the conventional printing process by using additional inks such as Orange, Green and Violet (OGV). According to research by the Toronto State Research University, the Expanded Gamut seven-color printing system provides reproduction of a larger range of colors and 90% of spot colors from the PANTONE Solid Coated library [8]. Advantages of EG printing include the ability to reproduce a large number of spot colors without spot color inks, better print accuracy, batch job capability, and fewer ink changes and washes. Barbara Braun-Metz, CEO of ColorLogic GmbH, considers that basically, an expanded gamut system can skip the extra work of printing with spot color inks. Instead, it can use a set of fixed expanded gamut inks to match the color the customer wants [5].

The relevance of multicolor printing is confirmed by a research project from the Fogra Institute called “Professional color communication in multi-primary printing” [6]. This project, which was carried out in 2019-2021, developed FOGRA55 characterization data and an ICC-profile for multi-primary printing, which also uses seven colors: Cyan, Magenta, Yellow, Black, Orange, Green, Violet (CMYKOGV) [6].

Use of additional colors complicates the process of color separation of images for the output of printing plates. Because it increases the variability and ambiguity of the reproduction of a particular color in the image. It’s necessary during in the process of color separation of images to take into account the actual color characteristics of the inks and the technological conditions of the printing process as much as possible. This task is assigned to the ICC profiles. ICC profiles are used in the color management system, which are built on the characteristic data of experimental measurements. Output profiles explain how colors are represented in a specific printing method by establishing a link between the device and a standard color space like CIELAB or CIEXYZ. This connection is made using tables for mapping, which are then refined using interpolation, or through a series of parameters for transformations [10].

Equations proposed by physicist and researcher in image reproduction G. Neugebauer describe the principle of image synthesis on the imprint with colored inks. In his work [11], based on the International Commission on Illumination (CIE) XYZ color space, he formulated analytical equations for color synthesis in multicolor printing. The construction of the Neugebauer equations is based on the Demichel equations [12], which determine the relative areas of screen elements for all primary colors.

In conventional offset printing, the creation of different screen elements follows the principles of subtractive color mixing. This process involves working with three transparent ink layers: Yellow (Y), Magenta (M), and Cyan (C) [13]. When tiny color elements are combined together to form one complete color, it's known as spatial mixing. This process follows a law, which in vector color representation can be stated as: the resulting color vector from spatial mixing equals the sum of products of the color element vectors multiplied by the respective areas each color occupies. [14].

An illustration of the Neugebauer model begins by examining the simplest printing systems, which have two primary colors, F1 and F2. The printing area will be divided into four segments of primary colors (Figure 1): W (white), F1, F2, and F12.

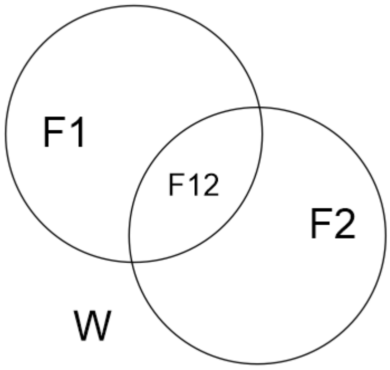


Figure 1: Schematic distribution of four colors W, F1, F2, F12 in a two-color printing system

The authors of the present paper have applied these equations for color conversion from the RGB model to CMYK through the orthogonal ICaS color space. It has been investigated the reproduction of colors on different paper types and determined that this process is non-linear. The non-linearity index is a parameter that takes into account the technological conditions of the printing process, such as the type of paper, the number of lines per inch, the type of the copy layer, the method of screening, the specifics of the printing process, and others. Thus made it possible to determine the optimal ink values for color reproduction by significantly saving color inks and develop the ICaS-ColorPrint information technology [15]. The overall objective is to perform analytical solutions [15, 16] and different image processing methods [17, 18] to evaluate spot color reproduction in multicolor printing.

3. Material and methods

3.1. Recalculating colors using orthogonal color space

Digital images consist of pixels that are defined by the amounts of Red, Green, and Blue light that make up their colors. On the other hand, printing devices use Cyan, Magenta, Yellow, and Black inks as their primary colors. There are different CMYK color spaces and gamuts that describe specific printing conditions.

Regardless of their source, all digital images are RGB color files. A color separation is needed to convert color information from RGB to CMYK or CMYKOGV. The authors generalized the characteristics of existing tangent color spaces to the additive and subtractive system to create a color space that will provide perfect conditions for recalculating colors [15]. The orthogonal condition of chromatic vectors results in a new color space. ICaS color space integrates two RGB and CMYK color representation systems on color charts. The transition to the ICaS color space is based on the Hartley orthogonal transformation [19, 20]. The formula for converting the coordinates R, G, and B into the coordinates of the space ICaS (I, C, S):

$$\begin{bmatrix} I \\ C \\ S \end{bmatrix} = \begin{bmatrix} 0.57735 & 0.57735 & 0.57735 \\ 0.57735 & 0.21132 & -0.78867 \\ 0.57735 & -0.78867 & 0.21132 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

The ICaS color space has a fundamental advantage as it uses three new coordinates to describe and quantify the colors of an image. These coordinates include an achromatic coordinate (I) and two chromatic coordinates (C) and (S). The achromatic coordinate (I) solely characterizes the neutral-gray colors of the original image. For any chosen color $\mathbf{F}_i(R_i, G_i, B_i)$, the chromatic coordinates (C) and (S) on the plane, known as the chromatic CaS-color diagram, depict the color characteristics of the chosen color (as shown in Figure 2).

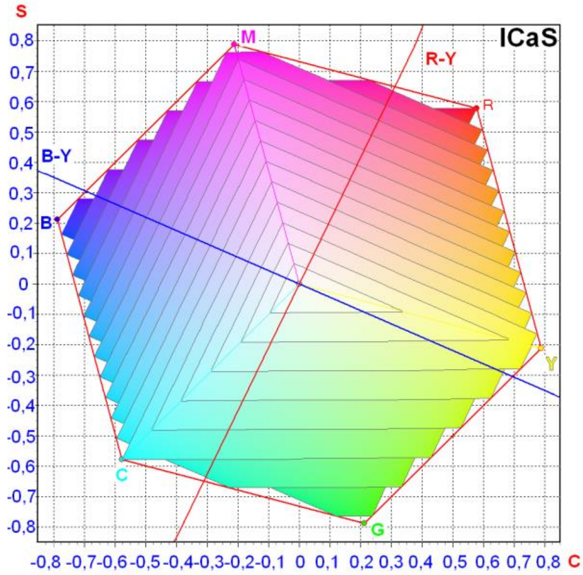


Figure 2: Planes of constant brightness of RGB colors on the CaS chromatic diagram

The placement of the color points on the CaS-color diagram and, accordingly, their coordinates in the ICaS color space will be analyzed for further research.

3.2. The method of determining the non-linearity of printing process

It was mentioned earlier that printing process is far-out from ideal one and has a certain amount of non-linearity, which distorts the reproduction of color. Therefore, it is important to get the parameter that will make it possible to compensate non-linearity on the stage of image preparation before printing.

In conventional offset printing, the different screen elements are formed strictly by the law of Subtractive Mixture. One works with the three transparent ink layers, which are Yellow (Y), Magenta (M), and Cyan (C) while maintaining the thickness of the ink layer. Tone values are simulated by screening. The size of screen dots can vary from zero (white paper) to 100% (full-tone ink layer). The index γ takes into account the various factors of influence on the amount of non-linearity of the particular color reproduction process. The dot gain mainly affects the non-linear color reproduction. In order to compensate for an increase in the size of the raster dots, a value of the dot gain quantity is performed on the value of the non-linearity index in the prepress stage.

The non-linearity of reproduction of Cyan ink gradations is determined by the color component R (Red). Similarly, the non-linearity of Magenta ink reproduction is determined by G (Green), and Yellow is determined by B (Blue). As for the additional inks OGV, we have analyzed that the nonlinearity should be calculated in the following way:

$$R = R_G + (R_0 - R_G)(1 - S_G)^{\gamma_G}; \quad B = B_{Or} + (B_0 - B_{Or})(1 - S_{Or})^{\gamma_{Or}}; \quad G = G_V + (G_0 - G_V)(1 - S_V)^{\gamma_V} \tag{2}$$

The nonlinearity parameter is determined by examining the curves depicting the relationship between the color value and the relative dot area of the printing ink. We opted for the Nonlinear Curve Fit Tool (NLFit) to assess the nonlinearity of the curves. The NLFit tool includes over 200 fitting functions that are utilized across various disciplines. Function Allometric2 is an extension of Classical Freundlich Model commonly employed to approximate growth curves and represented by the equation $y=a+bx^c$, where y is the dependent variable, x is the independent variable, and a, b, and c are model parameters [21]. The coefficient of determination (R^2) is utilized as a measure of how well the model accounts for the variability in the data. The values R^2 that are close to 1 indicates a better fit of the model to the data [22]. The coefficients of determination for the curves were computed, yielding an average value of 0.999.

According to this method, the value of the non-linearity γ parameter was determined for the standardized and production conditions for obtaining colored inks [15].

3.3. Equations for modeling the color gamut of inks

In CMY subtractive color model the basic process inks are selected as complementary colors to additive color system RGB. The theoretical model of multi-primary color mixing is described by the vector equation:

$$\mathbf{F}_{AU} = \mathbf{F}^{(0)} + \mathbf{F}^{(1)} + \mathbf{F}^{(2)} + \mathbf{F}^{(3)} + \ldots + \mathbf{F}^{(N)} \tag{3}$$

$$\mathbf{F}^{(0)} = \mathbf{F}_W \prod_{i=i}^{N} (1 - S_i) = \sigma_{min} \mathbf{F}_W, \qquad \mathbf{F}^{(N)} = \mathbf{F}_{1,2,\ldots,N} \prod_{i=i}^{N} S_i = \sigma_{max} \mathbf{F}_{1,2,\ldots,N} \tag{4}$$

where $\mathbf{F}_{AU}$ – vector of any color on the imprint in color space; $\mathbf{F}^{(0)}$– vector that is proportional to the vector of paper's color $\mathbf{F}_W$; $\mathbf{F}^{(N)}$– color vector, which is formed by mixing the N number of inks; $\mathbf{F}^{(1)}, \mathbf{F}^{(2)}, \mathbf{F}^{(3)}$– color vector, which is formed by mixing the inks of 1, 2 and 3 accordingly; S_i– relative dot area of the i-th ink; $\sigma_{min}, \sigma_{max}$– minimum and maximum dot area of mixing of inks; N – number of inks.

Based on the use of the color space ICaS, the Neugebauer equation for seven-color printing can be written down by the general vector equation:

$$\mathbf{F}_{AU} = \mathbf{F}^{(0)} + \sum_{n=1}^{N} \sigma_n \mathbf{F}_n^{(\mathbf{1})} + \sum_{n=1}^{N} \sum_{m=n+1}^{N} \sigma_n \sigma_m \mathbf{F}_{n,m}^{(\mathbf{2})} + \sum_{n=1}^{N} \sum_{m=n+1}^{N} \sum_{k=m+1}^{N} \sigma_n \sigma_m \sigma_k \mathbf{F}_{n,m,k}^{(\mathbf{3})} + \ldots + \sigma_1 \sigma_2 \sigma_3 \ldots \sigma_N \mathbf{F}_{\mathbf{1},2,3,\ldots,N}^{(\mathbf{3})} \tag{5}$$

$\mathbf{F}^{(0)}, \mathbf{F}_n^{(\mathbf{1})}, \mathbf{F}_{n,m}^{(\mathbf{2})}, \mathbf{F}_{n,m,k}^{(\mathbf{3})}, \ldots, \mathbf{F}_{\mathbf{1},2,3,\ldots,N}^{(\mathbf{3})}$ – vectors of the binomial decomposition are written by the sum of the base vectors $\mathbf{F}_n$ of color inks and vectors $\mathbf{F}_{n,m}, \mathbf{F}_{n,m,k,\ldots,N}$ of all combinations of mutual superimposition of different inks. To solve equation (5) it is necessary to have numerical values of 2^N base vectors. This is the fundamental complexity of the solution of the Neugebauer equations, since the same color $\mathbf{F}_{AU}$ can be practically synthesized by different ratios of colored and black inks.

Modified Neugebauer equations in the color space ICaS have certain properties:

1) The index (γ) is a characteristic of the nonlinearity of the printing process, in which single-color images with sufficient accuracy are described by the linear equation:

$$\mathbf{F}_{ICaS}^{(1)} = \widehat{\mathbf{H}} \mathbf{F}_i + \sigma_i \widehat{\mathbf{H}} (\mathbf{F}_W - \mathbf{F}_i), \quad \boldsymbol{i} = 1,2,3, \ldots N \tag{6}$$

where $\mathbf{F}_{ICaS}^{(1)}$ – vector of color in color space ICaS; $\widehat{\mathbf{H}}$ – operator of the unitary transformation of Hartley; $\mathbf{F}_W$– vector of color paper; $\mathbf{F}_i$–vector of color of i-th ink; $\sigma_i = (1 - S_i)$, S_i – relative dot area of the i-th ink.

2) All the colors of the image which synthesized by black ink will be placed strictly on the achromatic coordinate (I) in the ICaS color space;

3) The chromatic coordinates of two colors are proportional to the coefficient equal to the scalar value σ_K, in case of characteristic by the same color tone and difference in achromatic proportions:

$$\mathbf{F}_{ICaS}^{(3)} = \sigma_K \left[\widehat{\mathbf{H}} \mathbf{F}_{ij} + \sigma_i \widehat{\mathbf{H}} \left(\mathbf{F}_j - \mathbf{F}_{ij} \right) + \sigma_j \widehat{\mathbf{H}} \left(\mathbf{F}_i - \mathbf{F}_{ij} \right) + \sigma_i \sigma_j \widehat{\mathbf{H}} \left(\mathbf{F}_W - \mathbf{F}_i - \mathbf{F}_i + \mathbf{F}_{ij} \right) \right] \tag{7}$$

4) The general modified Neugebauer vector equation of color synthesis is reduced to a system of three nonlinear equations with three unknowns, which has analytical solutions in accordance with the formulated principle of color reproduction.

3.4. Test chart of spot colors

A color chart consisting of 22 PANTONE+ Solid Coated library color samples was created using Adobe Photoshop. Each sample has its CIE L*a*b* values that must be followed during the printing process. In the case of printing with spot colors, the accuracy of PANTONE color reproduction will be high. However, if spot color reproduction is done with CMYK or CMYKOGV process inks, it may not be possible to avoid color differences. The main objective of the study was to determine the ink values of the seven-color printing process required for reproducing the spot colors of the PANTONE Matching System. Additionally, the study aimed to calculate the color differences between the original CIE L*a*b* values of spot colors and analytical solutions of the modified Neugebauer equations that are used for image separation in ICaS-ColorPrint information technology [15]. The selected colors were closely distributed in hue and chroma. In Figure 3 the selected colors and their respective hue values are shown.

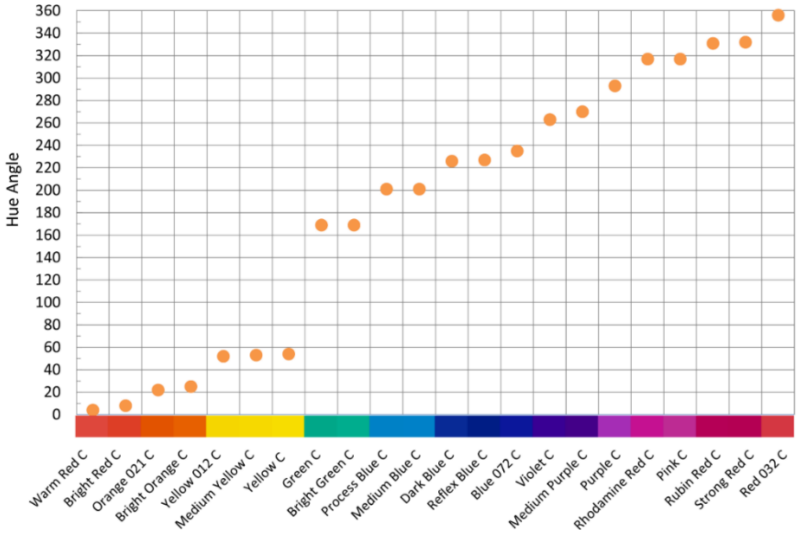


Figure 3: Hue angle distribution for 22 PANTONE+ Solid Coated library color samples

The image of test chart colors was converted to multichannel ICC profile FOGRA55-beta-TAC300-CL.icc based on FOGRA55 characterization data. As a result, we obtained seven channels CMYKOGV instead of the three RGB ones. Thus, we received new CIE L*a*b* values and relative dot areas of printing inks. We used the Color Picker panel and window Info in Adobe PhotoShop software to determine the required values.

The second stage of our research was processing a test chart with color samples in the ICaS-ColorSynthesis software [16]. First, it is necessary to enter values of the basic vectors (in color space) of the primary and secondary colors of extended gamut printing and the non-linearity indices. The method of determining the non-linearity of printing process was highlighted in the chapter 2.2. From Figure 4 it can be seen the user interface of the ICaS-ColorSynthesis software: data entry area (right panel) and modeling of the color gamut of inks (graph on the left).

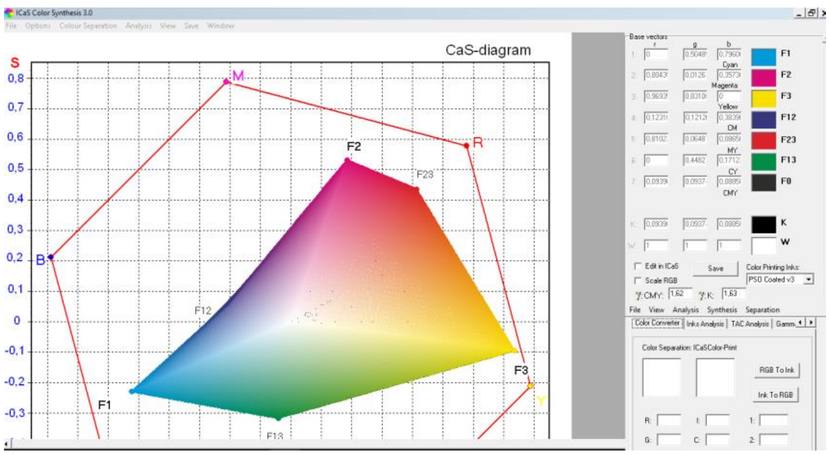


Figure 4: The ICaS-ColorSynthesis software for image color separation

The Color Picker tool is used to set the color. The Color Converter palette shows the results of color separation based on analytical solutions of the equations of color synthesis. As a result, we obtained the relative dot areas of process inks. The process of modeling color synthesis is also shown.

4. Results and Discussion

4.1. Modeling the color gamut of inks

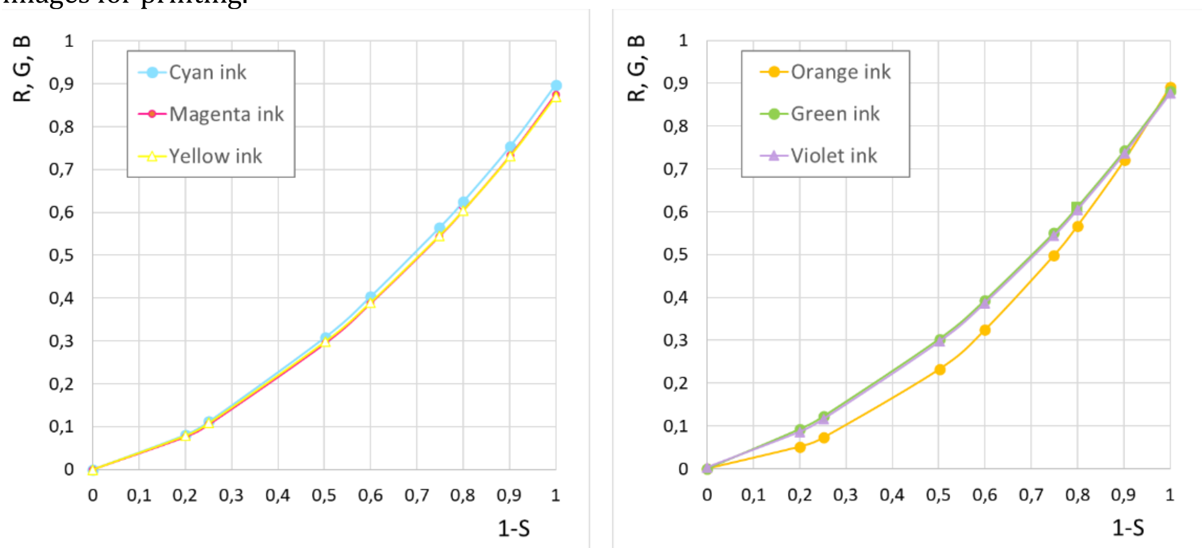
The CIE L*a*b*, XYZ and RGB values were recalculated using chromatic adaptation, which takes into account the color of the paper and the light source. Fogra 55, the characterization data, contains the CIE L*a*b* colorimetric measurements of scale patches obtained under standardized printing conditions, namely, offset printing on coated paper with CMYKOGV inks.

Table 1

Input data for plotting curves and calculated numerical values of the non-linearity γ parameter

(1-S)	R_{CYAN}	$G_{MAGENTA}$	B_{YELLOW}	R_{GREEN}	G_{VIOLET}	B_{ORANGE}
1	0.89701	0.875329	0.869968	0.881894	0.872785	0.89147
0.902	0.753952	0.732769	0.73083	0.742872	0.733763	0.721304
0.8	0.624219	0.603766	0.603665	0.61091	0.6018	0.567003
0.749	0.564092	0.544304	0.545472	0.549996	0.540886	0.497691
0.6	0.403011	0.387562	0.389167	0.392947	0.383837	0.32403
0.502	0.308377	0.294554	0.29801	0.303161	0.294051	0.232559
0.251	0.112094	0.105386	0.10847	0.121898	0.112788	0.072472
0.2	0.080972	0.07636	0.078672	0.092362	0.083252	0.051508
0	0	0	0	0	0	0
non-linearity parameter	1.61923	1.65693	1.6332	2.07319	1.70881	1.70881

The non-linearity of the gradation reproduction of the printouts of CMYK inks was determined, which on average is 1.64 for CMY and 1.63 for Black. The non-linearity indices for Cyan are 1.62, Magenta is 1.66, Yellow is 1.63, Orange is 2.07, Green is 1.7, and Violet is 1.7 (as shown in Figure 5a, 5b). The values obtained indicate the increase in screen dots for printing inks. In order to compensate for this increasing, we need to consider the non-linearity index when preparing images for printing.



a) b)

Figure 5: Non-linearity of each color inks CMY (a) and OGV (b) for the printing conditions Fogra 55

Based on the Fogra 55 colorimetric data and the calculated non-linearity indices, the coordinates of the basic color vectors of printing inks in the RGB space and, accordingly, in the ICaS color space were determined. To ensure that the previously formulated principle of reproducing an arbitrary color on the image with a maximum of two colored and black inks was followed, we modeled the color gamut of a seven-color printing process and compared it with four-color printing process. When modeled the color gamut of the printing process (as shown in Figure 6b) we used modified Neugebauer equation (5, chapter 2.3), characterization data Fogra55 and non-linearity indices of printing inks.

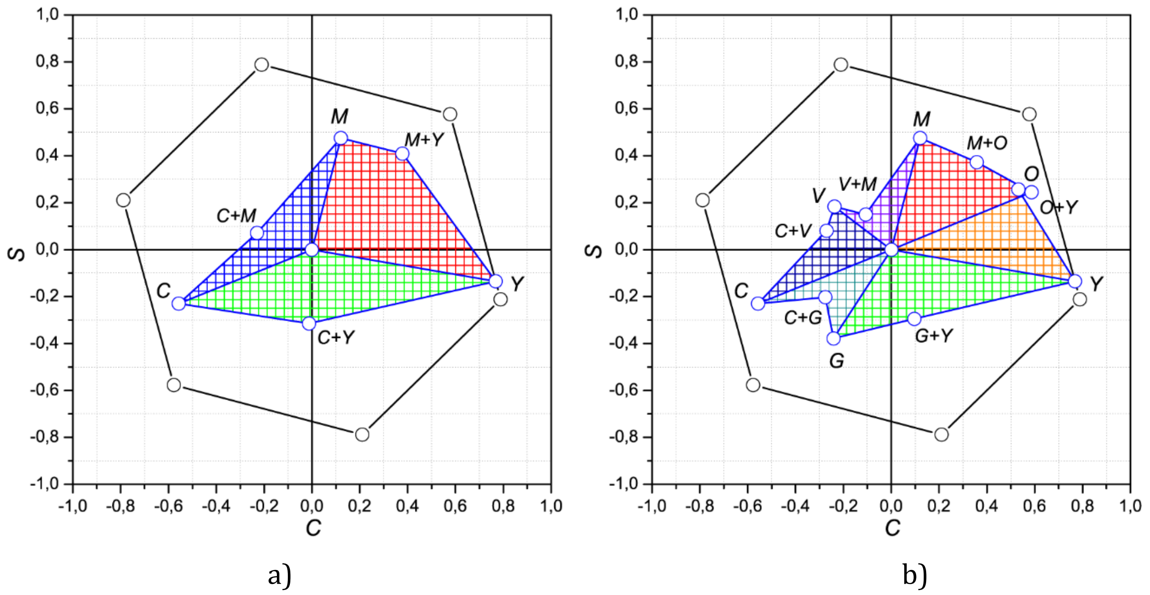


Figure 6: Model of color gamut of printing with four CMYK (a) and seven CMYKOGV (b) inks on the chromatic CaS-diagram

Based on the analysis of color gamut projections (as shown in Figure 6a, 6b), the color representation is reduced to six-color segments in the seven-color CMYKOGV printing process, depending on the hue. In the ICaS color space, the achromatic coordinate *I* of any arbitrary color in the digital image corresponds to the printout of the black (K) ink. Therefore, regardless of the number of *N* color printing inks, the ICaS color space completely separates the black (K) ink from the remaining *N* colored inks. This method offers the optimal color ink ratio for reproducing any color in the image. The use of additional colorants does not complicate the process of color separation, but only increases the number of areas of paired overlapping of inks.

As is well-known, RGB images displayed on a computer screen offer a wider range of colors compared to those printed using CMYK. To compare the color gamut of four and seven-color printing, we utilized a three-dimensional image, as projections of the color gamut onto a plane may not provide a comprehensive view. Figure 7**:** illustrates the comparison of color spaces between the original and printing processes. Gamut volume was determined using the online service Chromachecker [23]. Gamut volume quantifies the size of the color space. For AdobeRGB, the gamut volume is 1,325,000, for CMYK it is 405,912, and for CMYKOGV it is 570,877. The obtained values confirm that seven-color printing will enable the reproduction of more colors compared to four-color printing.

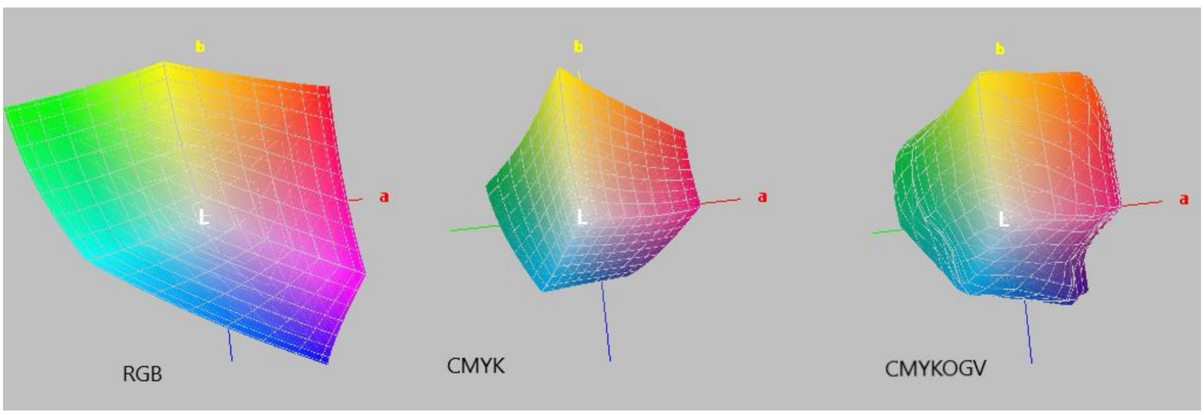


Figure 7: Three-dimensional images illustrate the color gamuts of RGB display colors, four-color CMYK, and seven-color CMYKOGV printing processes

4.2. Comparison of color differences

Thus, we have received the RGB values of spot color reproduction. Nevertheless, to calculate color differences, we needed CIE L*a*b* values. For this case, the CIE Color calculator was used [24]. The quality of color reproduction was evaluated in terms of the color differences ΔE (CIE 2000) in CIE L*a*b* color space for selected PANTONE+ Solid Coated library sample colors. Modern printing technologies ensure that the color of the print and the original match within ΔE = 1.5–6 units CIE L*a*b*. The color differences of spot colors given from ICC profile and calculate from ICaS-ColorPrint information technology based on analytical solutions. The value of ΔE > 6 CIE L*a*b* corresponds to a significant noticeable difference between the two colors. Despite additional inks, color differences exceed acceptable limits. This means that it is not possible to achieve accurate reproduction the colors from the PANTONE library with Fogra55 conditions. There is a certain dependence between the color tone and the difference ΔE (CIE 2000). The largest value of color differences was obtained for samples of PANTONE colors of purple, violet and blue shades. The average value of color differences is 7.47 for ICC-profile and 6.13 for ICaS-ColorPrint information technology.

The Figure 8 shows the value of color differences of Pantone+ Solid Coated library color samples for which the reproduction process was simulated using the ICC profile and ICaS-ColorPrint information technology. In both cases, the Fogra55 characterization data for multi-primary printing were used. Obtained values of color differences from ICaS-ColorPrint of such color samples as: Bright Orange, Warm Red, Red 032, Rubine Red, Strong Red, Rhodamine Red and Process Blue, are smaller compared to the same colors from ICC profile. Among the 22 tested spot colors, only eight of them have smaller color differences of reproduction simulated using the ICC profile. As we can see, such color differences of spot colors is related to different ways of solving the problem of color synthesis, that is, with which inks and in what ratio.

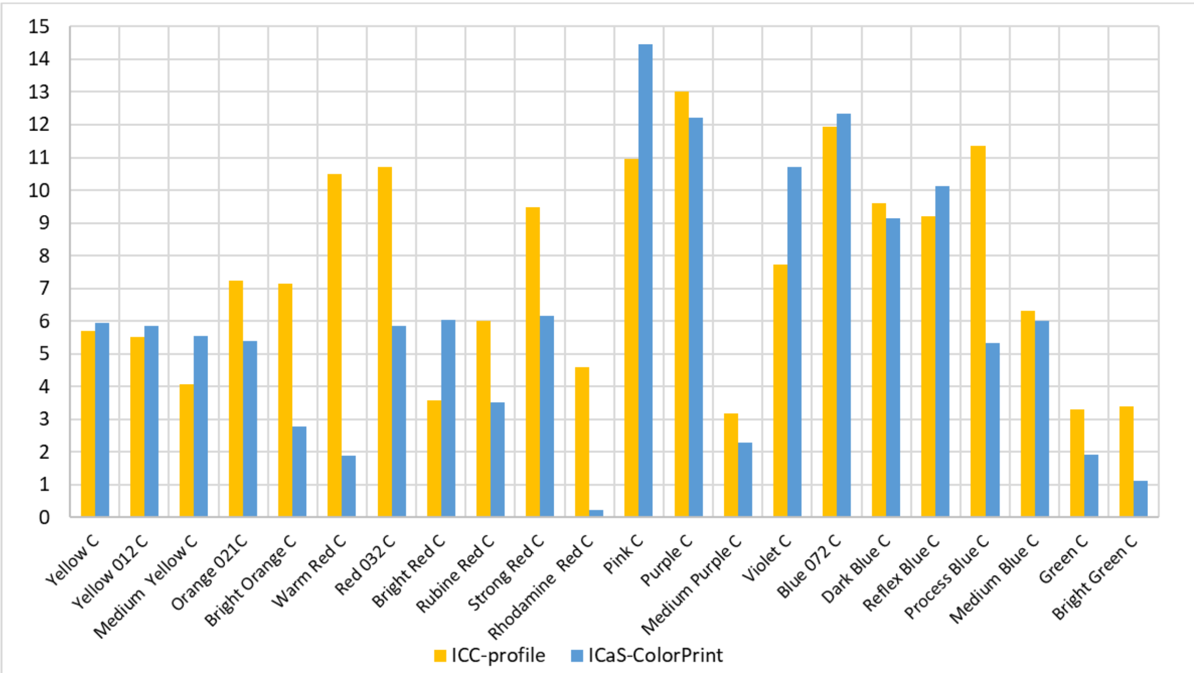


Figure 8: The color differences of the reproduction of spot colors when printing with an extended gamut using ICC profile and ICaS-ColorPrint information technology

4.3. Comparison of ink values

During the prepress stage of printing, it is crucial to consider the color reproduction characteristics of the printing process that will be used to print a digital image. To achieve this, a set of parameters must be established that takes into account the types of paper, inks, printing conditions, printing plates, and presses. These parameters are adjusted in the dialog box of standard programs that generate profiles. Initially, an algorithm must be chosen to replace a certain amount of color inks with black. This is realized through the Gray Component Replacement (GCR) method, which replaces gray components with a specific percentage of black ink. GCR offers various options, including light, medium, heavy, and maximum. The selection of the Total Area Coverage (TAC) parameter depends on the type of paper being used. For offset printing, the TAC value ranges from 300-330%. Choosing a smaller TAC value is not recommended when using classic technology for color separation as it can lead to a decrease in color gamut during printing, resulting in lost contrast and reduced quality of the reproduction. However, lower TAC values can lead to a more stable printing process.

ICaS-ColorPrint is a color separation technology that replaces colored inks with black ink using the Maximum GCR algorithm. This means that for a given color, only two of the three color inks will be used along with black ink, depending on the color's position on the chromatic CaS-diagram. As a result, the TAC parameter will automatically be much lower than the permissible limits. We have determined the percentage of inks required to reproduce spot colors from the PANTONE+ Solid Coated library. With ICaS-ColorPrint technology, the reproduction of color is limited by its position on the CaS-diagram. This means that if a color coordinates between the base vectors of Magenta and Orange inks in the ICaS color space, the third ink used will always be black. The ICC-profile follows a different principle of color formation with inks, where the achromatic component of the color can be matched with a third color ink. However, not all CMYK colors are used in the profile, only those adjacent in color tone. There are color samples that use basic CMYK instead of additional colors for their synthesis. For example, consider the Bright Green C color. According to the ICC profile, 24% of Cyan, 16% of Yellow, and 93% of Green are required for its reproduction. However, using the analytical solutions of autotype synthesis equations, which are the basis of ICaS-ColorPrint technology, only 12% of Yellow, 100% of Green, and 14% of Black are needed to reproduce the same color.

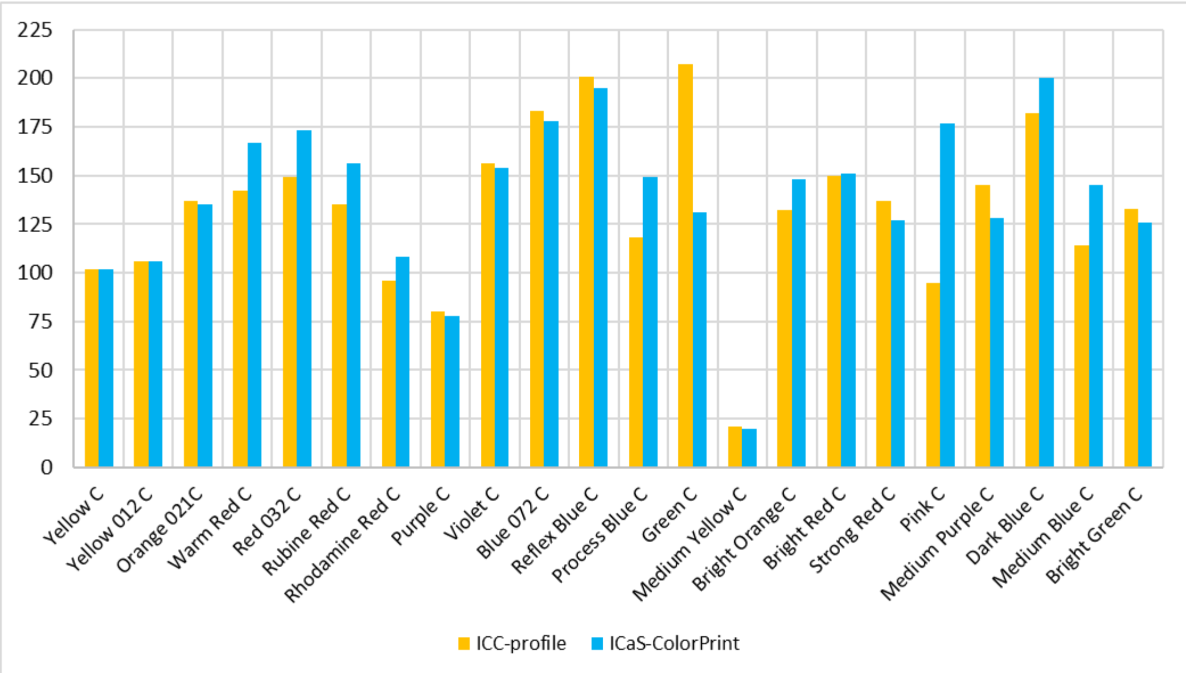


Figure 9: The total coverage of inks for spot colors reproduction in multi-primary printing

The study compared the dot areas of printing inks obtained from an ICC profile in Adobe PhotoShop with the values of inks obtained using the ICaS-ColorPrint technology (Figure 9). The analytical solutions of the equations reveal that spot colors can be reproduced using no more than two colored inks and black one. For instance, to reproduce Reflex Blue C Cyan, the ICC profile suggests using Cyan, Magenta, Yellow, Violet and Black inks. However, according to the ICaS-ColorPrint technology, only Violet and Black inks are required.

The average value required for total area coverage to reproduce the studied spot colors is 133% for the ICC profile based on Fogra55, and 139% for the ICaS-ColorPrint technology based on the analytical solutions. The maximum value of TAC is 207% and 200%, respectively. The minimum value of TAC is 21% for an ICC-profile and 20% for an analytical model. We have observed that the value of inks falls in the range of 1-3%, which makes the process of manufacturing printing plates and the printing process more complicated.

ICaS-ColorPrint is a technology that uses an optimal ink ratio to produce any color in an image. This is achieved by solving modified Neugebauer equations which take into account printing parameters such as basic colors, their combination, and the non-linearities of the printing process. The addition of extra colors in the printing process simplifies the color separation process and optimizes it, as evidenced by the results.

Previous research has demonstrated that four-color printing using ICaS-ColorPrint technology can save a significant amount of ink compared to traditional methods. In this study optimal values of colors are also obtained. The study confirmed that using ICaS-ColorPrint technology leads to smaller color differences. This is due to the fact that we calculated the non-linearity of additional color printouts, which we took into account when determining the base color vectors of colors

5. Conclusions

A study of the possibility of replacing spot colors with classic four-color printing with the addition of two or three color inks was conducted. For this, the latest characterization data of Fogra 55 were used. The Fogra 55 characterization data has been processed for multi-primary printing with three additional colors: Orange, Green, and Violet. Introducing this into the classic printing process provides an expanded color gamut and the reproduction of a more significant number of colors from the PANTONE color library. It is shown that the ICaS color space provides optimal conditions for converting the color information of a digital original from the RGB model to the CMYK ink model. The use of modified Neugebauer equations for color conversion from RGB to CMYK through the orthogonal color space ICaS is substantiated.

The basic color vectors of pure inks in vector space and their double blends are defined. The indices of non-linearity of prints of additional inks have been determined. The non-linearity indices for Green and Violet are 1.8, and for Orange it is 2.07. The measured values indicate an increase in screen dots for printing inks. To compensate for this, must be considered the non-linearity index when preparing images for printing. We performed the analysis of the projections of the color gamut and confirmed the formulated principle of color separation of the image with two colored inks and black one. Depending on the hue, the color representation is reduced to six color segments in the seven-color CMYKOGV printing process (plus Orange, Green, and Violet).

The test chart image of 22 spot colors was generated for the investigation. The ICaS-ColorSynthesis software was used to separate colors using ICC profiles and analytical solutions of equations. This led to new CIE $L^*a^*b^*$ values for color samples, which could then be compared to the original values. The color differences obtained from ICaS-ColorSynthesis for colors such as Bright Orange, Warm Red, Red 032, Rubine Red, Strong Red, Rhodamine Red, and Process Blue were smaller than those obtained from ICC profile. The relative dot areas of the printing inks obtained from the ICC profile were analyzed and compared with the corresponding values obtained by solving the modified Neugebauer equations. According to the analytical solutions of the equations (ICaS-ColorPrint technology), it was found that no more than two colored inks and black one are defined for the reproduction of spot colors. The study confirmed that using the ICaS-ColorPrint technology for spot color reproduction will provide smaller values of color differences.

Thus, increasing the color gamut of the printing process through the addition of extra colors does not complicate the process of color separation of the image, but rather improves the accuracy of color reproduction, including spot colors. The color separation technology developed by the authors solves analytical solutions of the modified Neugebauer equations in a new orthogonal color space. This ICaS-ColorPrint technology takes into account new methods of determining the nonlinearity of the printing process, resulting in accurate color reproduction and saving of colored inks. The obtained solutions were compared with FOGRA experimental data from printing, produced under standardized conditions. A matching accuracy to experimental data ranging from 0.35 to 8.6 (ΔE), affirming the reliability of the developed ICaS-ColorPrint technology. A promising direction is the application of developed separation technology for digital and flexographic printing. In digital printing, ink is supplied in a controlled manner, making efficient use of color inks crucial. In flexographic printing for labeling and packaging, substituting costly spot inks with triad inks and a few additional ones can conserve resources without compromising color reproduction quality.

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