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APPLICATION OF THE NEURO-FUZZY SYSTEM FOR DATA INTERPOLATION DURING METAMERIC COLORS REPRODUCTION

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The article deals with improving the corporate colors reproduction accuracy during printing. The proposed approach is based on the phenomenon of metamerism — visual impression of similarity simultaneously with the difference of the colors spectral nature. Images in printing production are subject to transformations using color management system, data for transformations are contained in a special file named the profile of the output device. To reduce the amount of storage memory a color data is generated for a small number of colors, remaining are calculated by interpolation. During color transformations for printing the change in data dimension space occurs and the resulting space is formed by an irregular grid data points. The paper offers to use the neuro-fuzzy system for interpolation calculations in an irregular grid to accurately reproduce colors inside the color gamut. For colors that do not match to the device color gamut a tentative projection onto the gamut near limit plane followed by irregular interpolation is offered.

Keywords: *neuro-fuzzy system, irregular interpolation, metameric color, color fidelity, color gamut*

Introduction. Today, the most rapidly developing market segments include publishing and advertising products, an important element of their design are branded (corporate) colors. In 80% of cases, these colors are not designed specifically, they are picked from a color atlas, for example, the most common is the Pantone atlas. Logo placed on promotional products that can be printed on different materials (paper, cardboard, film, polyethylene, fabric, plastic) by different printing technologies (digital printing, offset printing, screen printing). However, the creation of such a promotional products set, it is important to ensure constancy of corporate logo colors.

Problem formulation. In a constantly changing variety of goods and services promotional kits are printed in small parties, and the best solution is the use of digital printing. This method (electrophotography) suggests that the image on the print is formed using toner of four colors CMYK. As a result, corporate color on prints often does not match the reference. The variance entails economic losses and the company's image disruption.

The purpose of this study — the development of the layout preparation procedure for digital printing, which provide accurate reproduction of corporate colors specified on any paper.

To meet the challenges of maintaining a stable color on different devices the use of color management systems (CMS) became a world practice. They unify the color description and color reproduction for any device that allows a qualitative color transfer from one to any other device [1, 2, 3].

As part of the CMS basic color conversion algorithms were developed that can be used to conform representation of colors between different color spaces.

Information about the device color spaces is represented in the form of lookup tables, which are stored in the device profile. To reduce the amount of memory and computational costs sizes of tables are limited, so the data form a lattice structure with nodes (fig. 1).

Let some color coordinates $[c, m, y]$ in color space CMY are known. Using the lookup table define the coordinates of the nearest grid point $[C][M][Y]$. If the color $[c, m, y]$ coincides with the node $[C][M][Y]$, the output values are coordinates $[L][a][b]$ of the output space grid node, which corresponds to node $[C][M][Y]$. However, if the specified color gets between the nodes of the initial CMY grid, resulting point in CIELAB space would be interpolated between the CIELAB nodes. Therefore, in the general form of the color data conversion problem can be formulated as follows. There is a set of T m -dimensional device-dependent color samples $\{d_i\} \in R^n, i=1, \dots, T$ measured during the color profiling [3].

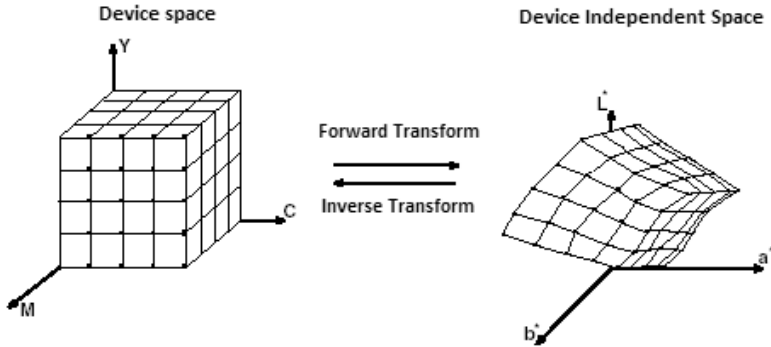


Fig. 1. An example of a three-dimensional lattice in the spaces CMY and CIELAB

We define a corresponding set of n -dimensional device-independent samples as $\{c_i\} \in R^n, i=1, \dots, T$. A couple $(\{d_i\}, \{c_i\})$ can be seen as training samples set. From this set it's need to evaluate one or two of the following transforms:

- $f; F \in R^m \rightarrow R^n$ - hardware-specific data mapping within the gamut F to the device-independent space;
- $g; G \in R^n \rightarrow R^m$ - device-independent data mapping within the gamut G to hardware-dependent space.

The error is identical to zero in all training samples in interpolation scheme, so that is $f(d_i) = c_i$, and $g(c_i) = d_i, i = 1, \dots, T$.

A common approach is to write a parametric form for f or g and minimize the squared error given by equation

$$E = \frac{1}{T} \sum_{i=1}^T \|c_i - f(d_i)\|^2 \tag{1}$$

Then, the interpolation function evaluation in an input space regular grid points and the construction of a multi-dimensional lookup table performed. After that, fast interpolation method applied to convert the image data using the table.

For regular three-dimensional data lattices there are some effective interpolation methods: trilinear, tetrahedral, prismatic and pyramidal interpolation [2]. More

complicated is the case of the inverse transform, when the input domain partition function is irregular.

In the most general case, when the grid is an arbitrary set of points, you can make a tetrahedral division of space using an algorithm tetrahedrization. The advantage of this approach – the flexibility with which the grid nodes can be positioned within the color space. However, the covering tetrahedron recovery step becomes much more complicated compared with the case of a regular lattice. Moreover, the interpolation step is also more complex, including a tetrahedral inversion. For this reason, the Delaunay partition is rarely used in real time applications.

Interpolating neuro-fuzzy system. To solve this problem the use the neuro-fuzzy system [4] is offered. They combine the neural networks learning capabilities with transparency and interpretability of fuzzy inference systems. In general, neuro-fuzzy systems are fuzzy models, trained by algorithms adopted in the theory of neural networks, and using one-dimensional membership function that is much easier from a computational point of view.

Among the neuro-fuzzy systems is the most popular adaptive neuro-fuzzy inference system ANFIS [5], which has a multi-layer architecture with direct information transfer, weights and membership functions of which are adjusted by the consistent optimization of some preassigned learning criterion.

Consider a two-dimensional problem projection. Let the nodes with coordinates $\{x_j, y_j\}$, $j=1,2,\dots,l$; located on the plane randomly; $f(x_j, y_j)=f_j(x, y)$ are the function values. It is necessary to construct an estimation $F(x, y)$ of the original function, strictly coincide with function values $f_j(x, y)= F(x_j, y_j)$ in the nodes $\{x_j, y_j\}$.

These training sample $\{\tilde{x}_j, \tilde{y}_j\}$ form the set of membership functions μ_{x_i}, μ_{y_i} ($i=1,2,\dots,l$, and generally does not coincide with j), so that their center points are determined by \tilde{x}_j, \tilde{y}_j .

The functioning process of interpolating the neuro-fuzzy system is illustrated by the example in Fig. 2, where the upper part shows three interpolation nodes $\{x_1, y_1\}, \{x_2, y_2\}, \{x_3, y_3\}$, with the known values $f(x_1, y_1), f(x_2, y_2), f(x_3, y_3)$ and the point with coordinates $\{x_p, y_p\}$ in which to interpolate.

Projections of points $\{x_j, y_j\}$ on the axis x and y arranged such that $x_1 < x_3 < x_2$ and $y_3 < y_2 < y_1$. In the lower part of the figure the same nodes are defined as $\{\tilde{x}_1, \tilde{y}_1\}, \{\tilde{x}_2, \tilde{y}_2\}, \{\tilde{x}_3, \tilde{y}_3\}, \{\tilde{x}_7, \tilde{y}_7\}$, and may be located either at the vertices or sides of a unit square on. With nodes $\{\tilde{x}_j, \tilde{y}_j\}$ projections on the axis \tilde{x}, \tilde{y} the center of the membership functions connecting such that $c_{x1} = \tilde{x}_1 = 0$, $c_{x2} = \tilde{x}_3$, $c_{x3} = \tilde{x}_2 = 1$, and $c_{y1} = \tilde{y}_3 = 0$, $c_{y2} = \tilde{y}_2$, $c_{y3} = \tilde{y}_1 = 1$. With each center, in turn, connect its membership function μ_{x_i}, μ_{y_i} , ($\mu_{x1}, \mu_{x2}, \mu_{x3}, \mu_{y1}, \mu_{y2}, \mu_{y3}$) as shown in Fig. 2.

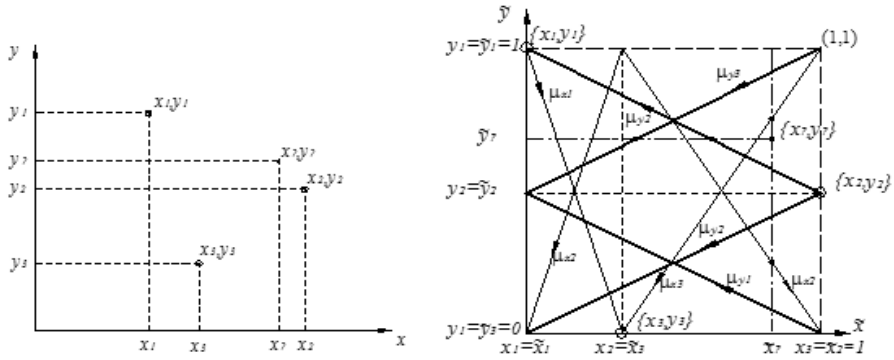


Fig. 2. Example of interpolation

As a result of the system at the point with coordinates $\{\tilde{x}_\gamma, \tilde{y}_\gamma\}$ value determined by the closest to the $\{x_j, y_j\}$ interpolation nodes will be calculated [6]:

$$F(\tilde{x}_\gamma, \tilde{y}_\gamma) = \frac{\sum_{j=1}^3 f(x_j, y_j) \mu_{x_j}(\tilde{x}_\gamma) \mu_{y_j}(\tilde{y}_\gamma)}{\sum_{j=1}^3 \mu_{x_j}(\tilde{x}_\gamma) \mu_{y_j}(\tilde{y}_\gamma)}, \quad (2)$$

This method is especially useful for the direct and inverse transforms between CIELAB and CMYK calculation, when due to space dimensions mismatch the unit cell dimension changes. For this reason, the unit cells are converted into hypercubes in CMYK space, which have an irregular shape and an irregular profile data acquiring structure.

It was noted above that profile lookup tables use the set of T m -dimensional device-dependent color samples. Typically, they are collected as test charts, and the number of fields in the test chart can be hundreds. Among them are those that limit the gamut – that is, it is assumed that richer colors are not available for this device. Profiling test charts are different, but their diversity is low. Typically, the same set of fields may be used in practice for different applications and devices. Therefore, for such sets is impossible to accurately describe the device gamut boundaries – if the colors set is standard, then it does not provide the construction of the expanding gamut boundaries. Then there are situations in which colors beyond the gamut, built by the standard test chart, may be available for the device.

Non-gamut color case. In order to control the device color reproduction outside of gamut (it is important to remember that the gamut has been built by a standard typical test chart), enterprises often use a sample prints fit: sets of test samples, similar to the logo color, are printed on edition paper and offered the customer to choose the correct one. This empirical approach does not guarantee an optimal solution, and, moreover, includes a subjective visual estimation, significantly reduces the solution quality.

To improve the constancy of non-gamut corporate colors it is offered to use a method that is as follows. Let the device color gamut is represented by a set of the

device profile data. As already noted, these data for the output devices form a regular mesh structure which shell is an aggregate of plane fragments. It is necessary to find the three gamut points, closest to non-gamut input color, which form the bounding plane fragment (Fig. 3).

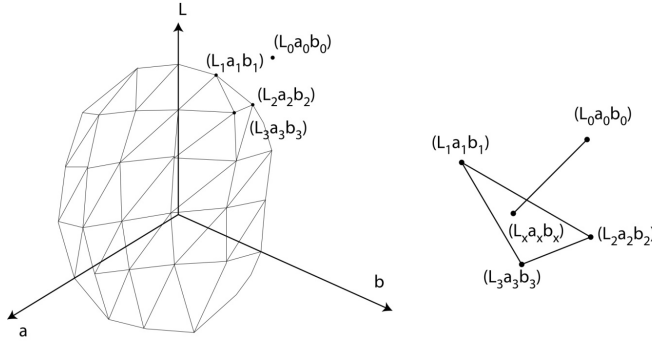


Fig. 3. The three closest gamut points from profile, which forms the bounding plane fragment

Defining the closest gamut points whose coordinates are stored in the profile based on the use of the color differences metric [7]:

$$\Delta E = \sqrt{(L_0 - L_i)^2 + (a_0 - a_i)^2 + (b_0 - b_i)^2}, i=1, \dots, T. \quad (3)$$

Then, across the points (L_1, a_1, b_1) , (L_2, a_2, b_2) , (L_3, a_3, b_3) passes the plane described by the equation [8]:

$$\begin{vmatrix} a_1 & b_1 & 1 \\ a_2 & b_2 & 1 \\ a_3 & b_3 & 1 \end{vmatrix} x + \begin{vmatrix} b_1 & L_1 & 1 \\ b_2 & L_2 & 1 \\ b_3 & L_3 & 1 \end{vmatrix} y + \begin{vmatrix} L_1 & a_1 & 1 \\ L_2 & a_2 & 1 \\ L_3 & a_3 & 1 \end{vmatrix} z - \begin{vmatrix} L_1 & a_1 & b_1 \\ L_2 & a_2 & b_2 \\ L_3 & a_3 & b_3 \end{vmatrix} = 0 \quad (4)$$

Onto this plane the projection from a predetermined non-gamut point (L_0, a_0, b_0) can be built that gives the closest point (L_x, a_x, b_x) on the border of gamut. The equation for the line $[L_1, a_1, b_1, L_x, a_x, b_x]$:

$$\frac{L_x - L_0}{\begin{vmatrix} a_1 & b_1 & 1 \\ a_2 & b_2 & 1 \\ a_3 & b_3 & 1 \end{vmatrix}} = \frac{a_x - A_0}{\begin{vmatrix} b_1 & L_1 & 1 \\ b_2 & L_2 & 1 \\ b_3 & L_3 & 1 \end{vmatrix}} = \frac{b_x - B_0}{\begin{vmatrix} L_1 & a_1 & 1 \\ L_2 & a_2 & 1 \\ L_3 & a_3 & 1 \end{vmatrix}} \quad (5)$$

Now to convert CIELAB to CMYK relation (2) can be used, which is based on irregular interpolation and allows to calculate the CMYK coordinates of the non-gamut point projection on the device gamut boundary.

Thus, the color coordinates calculating algorithm based on the profile data consists of the following stages:

- printing profiling test chart;
- measuring test chart by spectrophotometer and profiling of the output device;
- measuring the coordinates of input non-gamut corporate color (L_0, a_0, b_0) ;
- finding the coordinates of the closest gamut nodes from the profile data (accounting the condition $\min(\Delta E)$);

- constructing of the plane through the found nodal points (equation (4));
- defining the projection of (L_0, a_0, b_0) formed on the plane (point (L_x, a_x, b_x) in accordance with (5));
- the direct conversion of CIELAB→CMYK according with (2), based on the interpolation method using neuro-fuzzy network, will provide CMYK-coordinates (c_x, m_x, y_x, k_x) of the projection (L_x, a_x, b_x) of the non-gamut point (L_0, a_0, b_0) on the gamut border;
- designing of a test layout containing fields obtained with color coordinates (c_x, m_x, y_x, k_x) ;
- printing a test layout with applied profile and spectrophotometric measuring of printed samples;
- calculation of the color difference ΔE (3), between obtained color samples and input non-gamut corporate color (L_0, a_0, b_0) .

If necessary, the algorithm can be repeated until a predetermined value of color difference achieved.

Experimental results. The basis for the experiment was the task of accurate reproduction of corporate logo color, which is described as Pantone 185C, using electrophotography on the digital press Konica Minolta Bizhub PRESS C7000 on glossy coated paper A3 size, density of 170 g/m² (Lomond). According to the Pantone Color Bridge Coated set 185C color can be reproduced using CMYK offset printing and has the following formulation: C = 0, M = 91, Y = 78, K = 0 and spectrophotometric measurement of the Pantone 185C color correspond to the following LAB coordinates: L = 49,1; a = 75,5; b = 46,1.

According to the results test chart ECI 2002 printing on the target machine her profile was built. Fig. 4 shows a gamut cross-section and input non-gamut corporate color with its original coordinates. This color is beyond the boundary of the used printing press gamut.

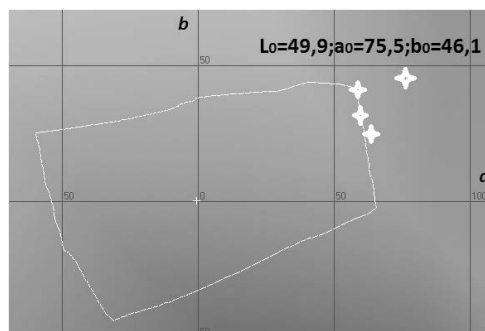


Fig. 4. The two-dimensional cross-section of the gamut (with L = 49,9) and the location of the test colors

Accordingly with the offered procedure the calculation of the nearest gamut color based on the profile data was carried out: three gamut points and LAB-coordinates that form the bounding plane fragment were found (Table 1). These points are also shown in Fig. 4.

After substituting these coordinates into equation (4) and (5) the coordinates of the given color (L_0, a_0, b_0) projection on the facet, described by equation (4), were found.

Table 1

LAB-coordinates of the nearest (to the test color) metamer gamut points

Color name	LAB-coordinates		
	L	A	B
Pantone 185 C (reference color)	49,9	75,5	46,1
Nearest gamut point 1	49,3	61,21	33,02
Nearest gamut point 2	48,91	60,81	39,59
Nearest gamut point 3	44,65	59,7	36,65
Nearest gamut point 4 (Input point projection onto gamut boundary plane)	53,8	62,1	45,8

To find the CMYK-coordinates of non-gamut point projection on the gamut boundary the 8 nodes for device-independent space in the device profile were found. These points form a three-dimensional body, inside which is a reference color (Fig. 5).

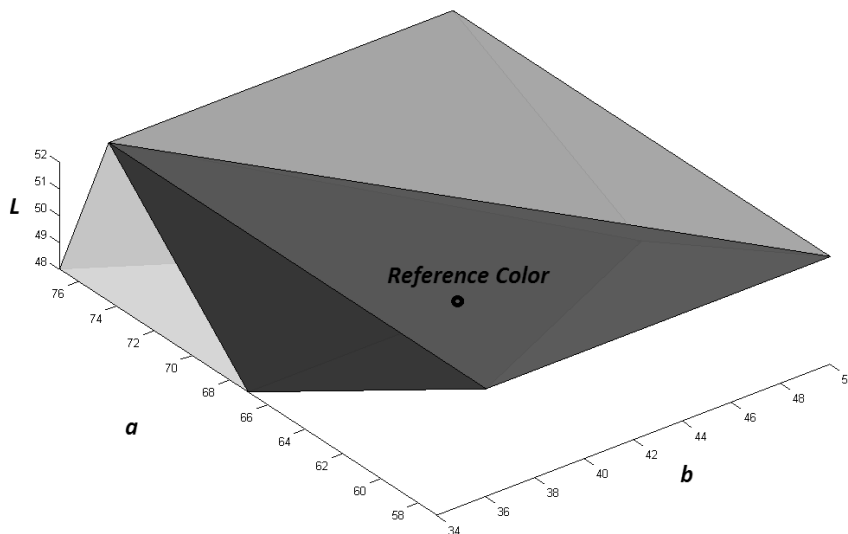


Fig. 5. Detail of the device gamut created by the found 8 points

LAB-coordinates of these 8 points and corresponding CMYK-values found by interpolation based on a neuro-fuzzy network are summarized in Table 2.

The test layout containing the fields with the obtained color coordinates was developed. After printing, the spectrophotometric measurements of samples received color value were made and the color difference ΔE relative to a given corporate color was calculated. The measurement results are listed in Table 2.

Table 2

The points coordinates and results of color samples spectrophotometric measurements and the color difference

Point number	Coordinates before printing							Coordinates after printing			Color error ΔE
	L	A	B	C	M	Y	K	L	A	B	
1	48	67	34	9	99	79	1	45,2	60,3	34,2	19,87
2	48	67	50	9	99	100	1	45,6	60,4	39,7	16,95
3	48	77	50	3	100	97	0	46,1	63,6	42,6	12,97
4	48	77	34	4	100	74	0	46,5	63,8	33,3	17,67
5	52	57	36	10	87	78	1	48,5	55	37,3	22,35
6	52	57	50	9	87	98	1	48,1	54,9	43,3	20,87
7	52	77	50	0	100	89	0	48,1	64,9	41,7	11,62
8	52	77	36	0	100	70	0	48,3	65,7	32	17,25

The resulting color differences exceeded the normative tolerance $\Delta E = 6$ CIELAB units. This is explained by that the given corporate color is non-gamut for test printing method, and the best approximation is within gamut.

Conclusions. Thus, the layout design procedure for digital printing, which increases the constancy of corporate colors, was offered. The procedure uses a standard approach to printing machine profiling with a given paper, the calculation of the nearest gamut points coordinates using projection and interpolation according to a profile using a method based on neuro-fuzzy network. The method reduces chromatic aberrations that for gamut colors do not exceed the normative values. The obtained results can be used in the production of promotional products to be printed by means of electrophotography.

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ВИКОРИСТАННЯ НЕЙРО-ФАЗЗИ СИСТЕМИ ДЛЯ ІНТЕРПОЛЯЦІЇ ДАНИХ ПІД ЧАС ВІДТВОРЕННЯ МЕТАМІРНИХ КОЛЬОРІВ

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Стаття присвячена проблемі підвищення точності відтворення фірмових кольорів під час друку. Запропонований підхід заснований на використанні явища метамерії — подібності візуального враження при відмінності спектральної природи кольорів. Для друку продукції зображення піддаються перетворенням з використанням системи управління кольором, дані для перетворень містяться в спеціальному файлі — профілі пристрою виводу. Для скорочення обсягів пам'яті при зберіганні колірні дані формуються для невеликої кількості кольорів, решта ж обчислюються за допомогою інтерполяції. У ході колірних перетворень для друку відбувається зміна розмірності просторів даних, і результуючий простір утворюється за допомогою нерегулярної сітки з вузлових точок. У статті пропонується використовувати нейро-фаззи систему для виконання інтерполюючих розрахунків в нерегулярній сітці з метою точного відтворення кольору, що всередині охоплення. Для кольорів, що не потрапляють в колірне охоплення пристрою, пропонується попереднє проектування на найближчу обмежувальну охоплення площину з подальшою нерегулярною інтерполяцією.

Ключові слова: *нейро-фаззи система, нерегулярна інтерполяція, метамірні кольори, точність кольоровідтворення, колірне охоплення.*

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