Study of the Dependence of Colour Gamut Volume Determined with Different Methods on Reflection Densities of the Process Inks Solids in Printing

Tomasz Dąbrowa, Dariusz Dziewulski

The volume of a colour gamut of a print sample, expressed in units of any colorimetric space is rarely determined, and at best is only considered to be supplemental information. This parameter can be, however, very useful in the process of selection of the optimum intensities of process inks within the scope of given print technology and specified substrate. Observation of changes of volume of the colour solid allows for optimisation of reflection densities of fully overprinted areas of process inks so that the largest possible colour range may be printed, without the unnecessary thickening of ink film and subsequent consequences related to increased film thickness. In the study, five different methods of colour gamut volume calculation were analysed and compared. This was achieved by study of the dependence of colour gamut volumes calculated by various methods on the reflection densities of fully overprinted areas of process inks.

Introduction

The colour gamut in the printing industry (specifically its' "shape" and volume), constitutes an extremely important source of information regarding the potential capabilities of a print technique or technology in question. A wider range of available colours improves the colouring of the print sample, thus making it more attractive. When the colouring of the original does not surpass the colour gamut of the copy, perfect colorimetric reproduction is possible. Otherwise, the larger colour gamut of the copy, the lesser consequences of the inevitable colour compression of the original will be. The aforementioned compression is performed according to a selected algorithm of colour rendering intent – perceptual, saturation, absolute, or relative colorimetric.
Many technological aspects determine the colour gamut of the print sample in any printing method, but the main parameters influencing the shape and volume of the solid of reproduced colours are the colours of the fully overprinted areas of primary and secondary colours as well as colour with all process colours (CMYK – black point) overprinted according to the assumed TIL (Total Ink Limit) as well as the colour of the print substrate (white point). Other parameters of a copy such as printing curve (dot gain) do not influence the shape or the size of the colour gamut in a significant way. They do determine, however, the profile of an output device; that is, the method of conversion from four-dimensional space to three-dimensional one and vice versa – CMYK2CIELAB and CIELAB2CMYK, respectively.
The volume of the colour gamut of a printed sample, expressed for example in CIELAB units, in the light of CIELAB colour space disproportion may yield some additional, although usually only supplemental information. By simply comparing colour gamuts of two different printing techniques, one cannot ascertain whether the larger gamut fully encompasses the smaller colour solid. Most often, outside the common volume, each gamut has a specific colour range which does not overlap with the other colour solid. The colour gamut volume may be, however, a very useful parameter for selection of the best process inks intensities in a specific printing method on a specific substrate, expressed as colours or reflection densities of fully overprinted (solid) areas of process inks. By determining and analysing the volume changes of a colour gamut it is possible to optimize process inks' intensities in a way that allows us to receive a "higher number" of reproduced colours without unnecessarily increasing the ink film thickness and without intensifying the negative effects of such increase.

Aim of the research

The main goal of this research was the analysis and comparison of different methods of colour gamut volume calculation. This was achieved by study of the dependence of colour gamut volumes calculated by various methods on the reflection densities of fully overprinted (solid) areas of process inks.

Scope of the research

Five different methods of colour gamut volume calculations were compared during the research:

- The dodecahedron method
- The icositetrahedron method
- The Gamutvision (Imatest) software method
- The ColorThink Pro 3.0 (Chromix) software method
- The Adobe Photoshop (G. Hoffmann) software method.

Preparation of the samples for study

The volume of the colour gamut was determined for samples printed on the Epson Proofing Paper Semimate coated paper. The printer, Epson Stylus Pro 4800, employing the Inkjet (DOD) technique, was controlled by the O.R.I.S. ColorTuner 5.2.1 (CGS) software. This allowed for changes of the process inks' intensities in a wide range of values. Linearization of the printer was performed each time with the value of the Yule-Nielsen factor assumed to be n = 2.0 and a characterization test chart ECI 2002 (visual) with additional halftone patches for primary and secondary colours were printed. After the printed images' colours stabilized (circa about 24 hours after print) spectrophotometric measurements were performed using the Spectrolino or Spectrolino-Spectroscan (GretagMacbeth) spectrophotometer at the following settings: illumination D_{50}, normal colorimetric viewer 2°, "no filter", DIN 16536 WB. The colour gamut volumes were calculated basing on the coordinates of colours measured for appropriate areas or based on ICC profiles of each sample generated beforehand with the ProfileMaker (GretagMacbeth) software. In total, 9 samples were prepared for the study, characterized by different maximum reflection densities of the primary colours: C, M, Y (Tab.1). Sample #3 fulfilled the ISO 12647-2 norms for coated papers in regard to fully overprinted areas of process inks [5]. Sample #9 was characterised by maximum, under given conditions (substrate – printer), reflection densities of such areas.

Methodology of colour gamut volume determination and results of the study

The dodecahedron method [1,2,3,4]

In this method, the colour solid is assumed to be a dodecahedron. Eight of its vertexes are the points of primary colours - C, M, Y, secondary colours – R (M+Y), G (C+Y), B (C+M), white point W (substrate colour), and the black point CMY. The volume of the dodecahedron can be calculated as the sum of the volumes of twelve trianglebased pyramids that share a single common vertex located inside the solid on the *L** axis. This O-point has the coordinates: $L^*=50$; $a^*=0$; $b^*=0$. Thus, the twelve pyramids constituting the colour solid have the following vertices:

1. W, C, B, O
2. W, B, M, O
3. W, M, R, O
4. W, R, Y, O
5. W, Y, G, O
6. W, G, C, O
7. CMY, C, B, O
8. CMY, B, M, O
9. CMY, M, R, O
10. CMY, R, Y, O
11. CMY, Y, G, O
12. CMY, G, C, O

Tab. 1. Reflection densities of primary colours (C, M, Y) of the studied samples (DIN 16536 WB)

	sample 1	sample 2	sample 3 (ISO)	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9 (max)
D_C	0,99	1,32	1,66	1,79	1,91	2,00	2,10	2,14	2,25
D_M	0,76	1,09	1,37	1,47	1,58	1,68	1,78	1,83	1,87
D_Y	0,76	1,01	1,25	1,35	1,45	1,54	1,63	1,68	1,72

The volume of each of the twelve pyramids has been calculated as 1/6 of the volume of a parallelepiped spanning three vectors with a common initial point (Fig.1), which is equal to the absolute value of the triple product of said vectors. For example, the volume of the W, C, B, O pyramid can be obtained from the following expression:

$$V = \frac{1}{6}\left|\vec{u}\cdot(\vec{v}\times\vec{w})\right| = \frac{1}{6}\left|a_1b_2c_3 + a_2b_3c_1 + a_3b_1c_2 - a_3b_2c_1 - a_2b_1c_3 - a_1b_3c_2\right|$$

where:

$$\vec{u} = [L_C^* - L_O^*; a_C^* - a_O^*; b_C^* - b_O^*]; \quad \vec{u} = [a_1, a_2, a_3];$$
$$\vec{v} = [L_C^* - L_B^*; a_C^* - a_B^*; b_C^* - b_B^*]; \quad \vec{v} = [b_1, b_2, b_3];$$
$$\vec{w} = [L_C^* - L_{CMY}^*; a_C^* - a_{CMY}^*; b_C^* - b_{CMY}^*]; \quad \vec{w} = [c_1, c_2, c_3];$$

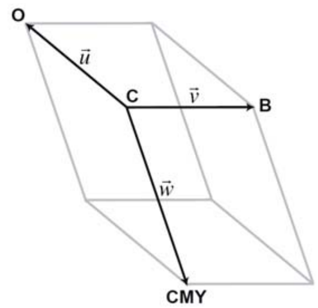


Fig. 1
Parallelepiped defined by three vectors with a common initial point

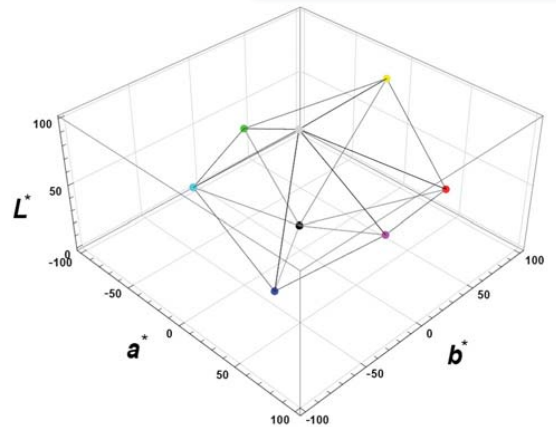


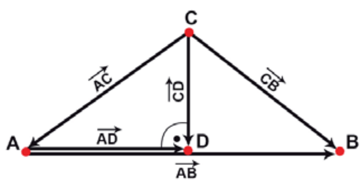
Fig. 2
The dodecahedron colour solid of sample #3

Figure 2 presents the dodecahedron colour solid for sample #3 and Figure 9 – the calculated volume of the colour gamut as a function of reflection densities of fully overprinted areas of process inks. As can be seen on the diagram (fig.9), the volume of the colour gamut increases with the increase in reflection densities of process inks, starting with $V_{CIELAB} \approx 242 \cdot 10^3$ for sample #1. The maximum ($V_{CIELAB} \approx 420 \cdot 10^3$) is reached for sample #7 and the volume subsequently decreases until $V_{CIELAB} \approx 410 \cdot 10^3$ in sample #9.

The icositetrahedron method

This method for volume calculation of colour solids, just as the previous method, was used in earlier studies carried out in the Institute of Printing of Warsaw University of Technology. It should be expected that the icositetrahedron method is more accurate than the dodecahedron method due to the use of additional data. Six additional vertices allow for more precise determination of the solid's volume in CIELAB colour space. Coordinates of the additional points are determined by primary and secondary colours with specified dot areas (S) most distant from the segments connecting the primary and secondary colours' points with the white point (printing substrate). The length of these segments for halftones in the range of 0%<S<100% of the C. M, Y. R, G and B colours was determined for each printed sample separately in the way described below for segment CD (Fig.3).

Fig. 3 The method of determining the distance (CD) of a point from a line in space



$$|\overrightarrow{CD}| = \sqrt{|\overrightarrow{AC}|^2 - \left(\frac{|\overrightarrow{AC}|^2 + |\overrightarrow{AB}|^2 - |\overrightarrow{CB}|^2}{2|\overrightarrow{AB}|}\right)^2}$$

where:

$$|\overrightarrow{AC}| = \sqrt{(L_A^* - L_C^*)^2 + (a_A^* - a_C^*)^2 + (b_A^* - b_C^*)^2}$$
$$|\overrightarrow{AB}| = \sqrt{(L_A^* - L_B^*)^2 + (a_A^* - a_B^*)^2 + (b_A^* - b_B^*)^2}$$
$$|\overrightarrow{CB}| = \sqrt{(L_C^* - L_B^*)^2 + (a_C^* - a_B^*)^2 + (b_C^* - b_B^*)^2}$$

Figure 4 presents the graphs of dependencies of the different halftone primary and secondary colour points' distance from segments connecting the primary and secondary colour points with the white point of the print substrate for sample #3. The additional vertices obtained in this fashion are clearly visible. 14 vertices are thus obtained and the colour solid becomes an icositetrahedron (Fig.5). Its volume can be calculated in a similar way as the volume of the dodecahedron. The solid is divided not into twelve, but into twenty four triangle-based pyramids and a common apex located inside the solid – the O-point with the coordinates: *L**=50; *a**=0; *b**=0.

Figure 5 presents the icositetrahedron colour solid for sample #3, while Figure 9 – the dependence of the volume of thus calculated colour gamut on the reflection densities of fully overprinted areas of process inks. As can be easily seen from the graph, in this case the volume of the colour solid increases with the increase of reflection densities or process inks but does not reach a maximum, as was the case in the dodecahedron method. The volume of the colour gamut changed in the range from $V_{CIELAB} \approx 244 \cdot 10^3$ for sample #1 to $V_{CIELAB} \approx 492 \cdot 10^3$ for sample #9 and for each of the samples was higher than the volume calculated with the dodecahedron method.

Fig. 4
Dependence of the distance of the different halftones primary and secondary colours' points from the segments connecting points of primary and secondary colour's with the white point for sample #3 with marked areas that will contribute six additional vertices to the solid

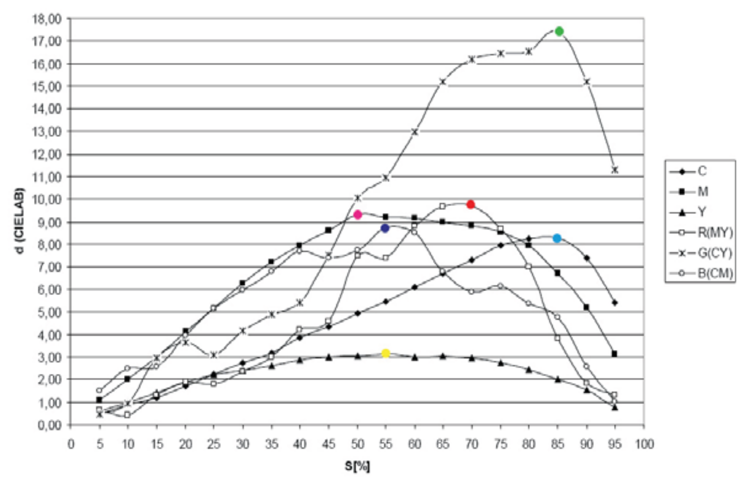
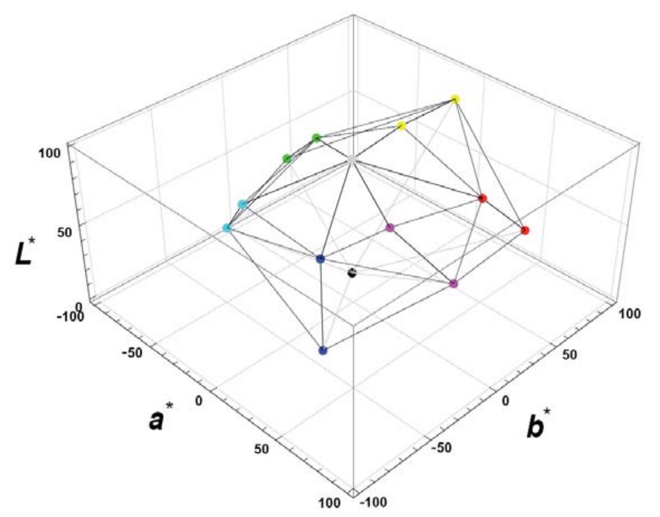


Fig. 5
The icositetrahedron colour solid for sample #3



The ColorThink Pro software method [6]

ColorThink Pro 3.0 (Chromix) is a program for diagnostics and management of ICC profiles. It has the option to visualize the colour gamut. The Profile Inspector module, among other information regarding the profile, provides also the volume of the colour gamut. The calculations involve a "slice-by-slice" algorithm, which samples the solid in the plane perpendicular to the L^* axis with $\Delta L^*=1$. The area of all cross-sections is summed and the result gives the volume in cubic units of the CIELAB colour space.

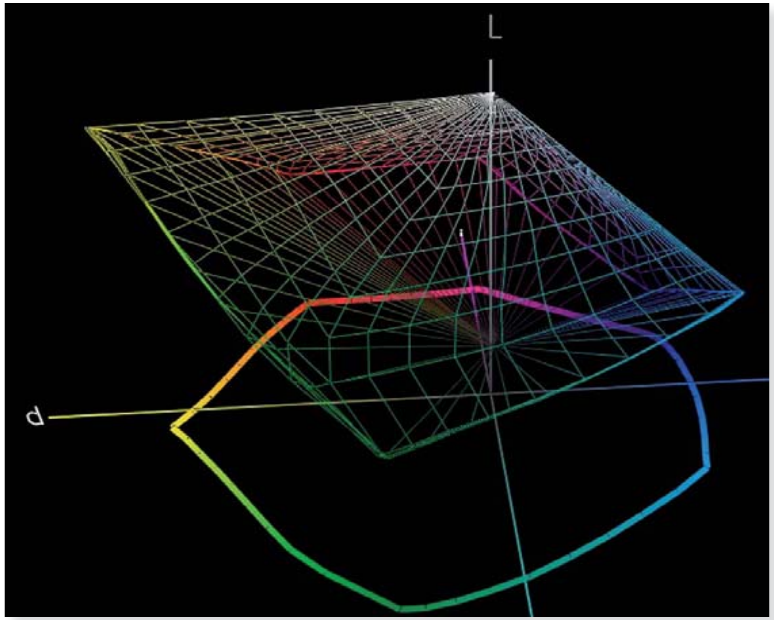


Fig. 6
Colour solid of sample #3 – visualization in the ColorThink Pro 3.0 (Chromix) software

Figure 6 presents the visualisation of the colour solid in the ColorThink software for sample #3. Figure 9 presents the graph of the dependency of the volume determined in this way on the reflection densities of fully overprinted areas of process inks. As can be seen from the graph (Fig.9), the volume of the colour gamut increases with the increase in reflection densities of process inks in the whole studied range, just as was the case in the icositetrahedron method.
The volume of the colour solid changed from $V_{CIELAB} \approx 242 \cdot 10^3$ for sample #1 to $V_{CIELAB} \approx 527 \cdot 10^3$ for sample #9. Volume of the colour solid for sample #1 calculated by ColorThink software was very similar to the value obtained in the convex icositetrahedron method. The divergence between results obtained in those two methods increased with the increase of reflection densities of process inks' and reached c.a. 7% for sample #9.

The Gamutvision software method [7]

The Gamutvision (Imatest) software has a visualisation option for the colour gamut and its various transformations dependent on the selected method of conversion. The program can also calculate the volume of the colour solid.

The Gamutvision algorithm calculates the gamut volume from an image containing all the values of HSL Hue H and Lightness L for a fixed value of Saturation S (usually the maximum value, S=1). The algorithm is as follows:

- First, the RGB image values are mapped into the L*a*b* space.
- "Centre of mass" of the solid is determined. Usually it is located near the $L^* = 55$, $a^* = b^* = 0$ point.
- The data is converted in the cylindrical set of coordinates (R, Θ, Φ) with origin at the centre of mass of the solid
- A "binning" array representing uniformly spaced longitudinal and latitudinal angles (Θ and Φ, spaced $\delta\Theta$ and $\delta\Phi$) is created
- The average radius (R) corresponding to each image point in the appropriate binning array element is placed
- Interpolation to fill the missing points is realized
- The volumes for each array entry is summed to find the total volume $V = \Sigma\delta V$, where:
  $\delta V = R^2\ \delta h\ \delta\Theta / 3$;
  $\delta h = R \cos(\Phi)\ \delta\Phi$;
  $\delta V = R^3 \cos(\Phi)\ \delta\Theta\ \delta\Phi / 3$

Fig. 7
Colour solid for sample #3 – visualization in the Gamutvision (Imatest) software

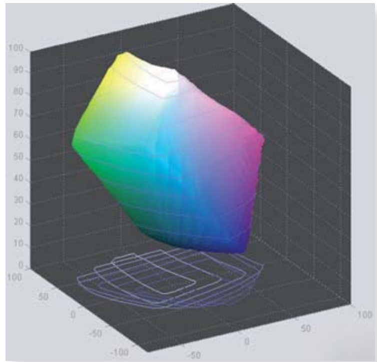


Figure 7 presents the visualisation of the colour solid in the Gamutvision software for sample #3. Figure 9 presents the graph of the dependency of the volume determined in this way on the reflection densities of fully overprinted areas of process inks. As can be seen, the volume of the colour gamut increases with the increase in reflection densities of process inks, starting with $V_{CIELAB} \approx 306{,}5 \cdot 10^3$ for sample #1, reaches a maximum ($V_{CIELAB} \approx 541{,}5 \cdot 10^3$) for sample #8, and slightly decreases to $V_{CIELAB} \approx 534{,}5 \cdot 10^3$ for sample #9. This dependence is similar to the one observed for changed in volume calculated with the convex dodecahedron method, although the volumes themselves are larger by, on average, 25-30%.

The Adobe Photoshop (G. Hoffmann) software method [8]

This method was proposed in 2005 by prof. G. Hoffmann. It bases on the interpretation of a test image prepared in PostScript by Adobe Photoshop 7.0 software. The test image is composed of 100 elements of 72x72 pixels, one for each brightness level from the range of $1 \le L^* \le 100$, with colours declared in the chromaticity range of $-100 \le a^* \le 100$ and $-100 \le b^* \le 100$. The method employs two tools of the Photoshop software – "Proof Setup" and the "Gamut Warning" Basing on the data stored in the ICC profile of the output device, the program signals that certain colours cannot be printed and labels them as "Out of Gamut". Those colours may be substituted with freely chosen other colours. After saving the test image as a RGB TIFF, one can use the "Histogram" function to find out how many pixels represent the non-reproducible colours. This value is subtracted from the total amount of pixels of the test image, which is equal to 720x720= $5184 \cdot 10^2$. The result, multiplied by 7.72 gives the volume of the colour solid in the CIELAB space units. Figure 8 presents a test image for the G. Hoffman's test representing the chromaticity of colours for sample #3 at 100 subsequent levels of brightness, just as they are scanned by Photoshop's "Gamut Warning" tool. Figure 9 presents the graph of the dependency of the volume determined with the G. Hoffman's method on the reflection densities of fully overprinted areas of process inks. As can be seen on the graph, the volume of the colour solid increases with the increase in reflection densities of process inks, starting at $V_{CIELAB} \approx 362 \cdot 10^3$ which is larger than the values obtained for sample #1 with the use of previous methods. The dependence stabilises for moderate reflection densities of process inks and increases sharply for high reflection densities of process inks, reaching the value of c.a. 1112·10^3 for sample #9. This value is more than two times higher than the ones obtained with the use of the other methods.

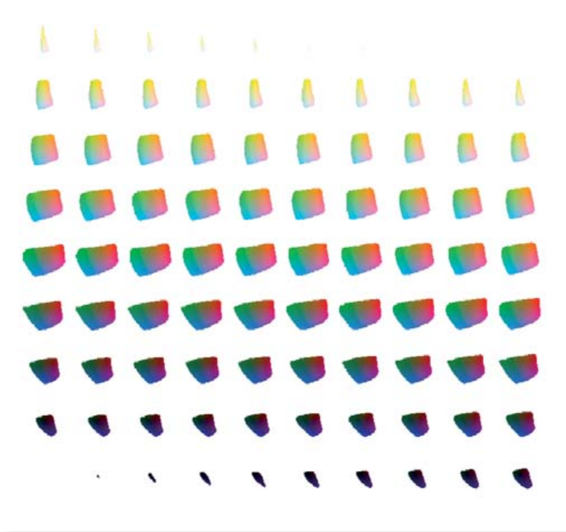


Fig. 8
G. Hoffman's test image – colour gamut of sample #3

Conclusions

As follows from the graphs presented in Figure 9:

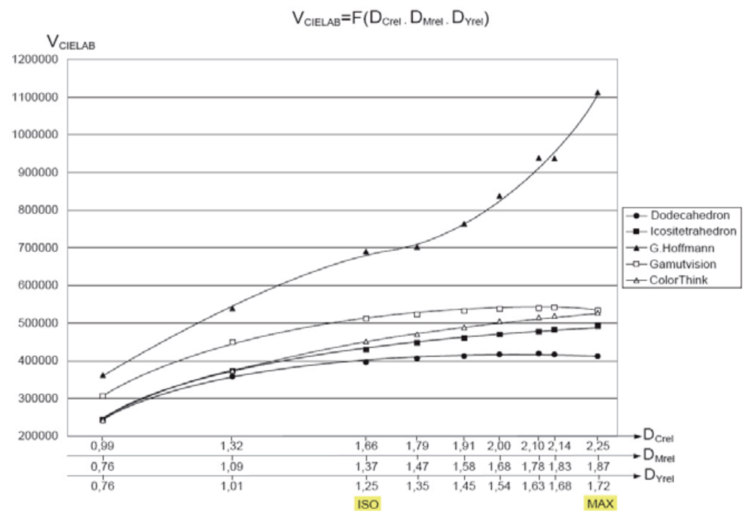
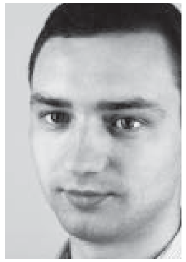


Fig. 9
Dependencies of colour gamut volumes on reflection densities of fully overprinted (solid) areas of process inks for all compared methods (samples 1-9)

Tomasz Dąbrowa, PhD

Warsaw University of Technology, Faculty of Production Engineering, Institute of Mechanics and Printing

t.dabrowa@ippw.internetdsl.pl



Dariusz Dziewulski, M.Sc.

Warsaw University of Technology, Faculty of Production Engineering, Institute of Mechanics and Printing

ddx@wp.pl

- Some of the colour gamut volumes determined with the tested methods significantly differ from one another – in extreme cases by about 50% for low and medium and by about 150% for high reflection densities of process ink colours.
- The curves characterising the dependence of the print samples' colour solid volumes obtained with different calculation methods on the reflection density of process inks colours do not intersect anywhere in the entire studied range of process inks' reflection densities. This allows for a tentative assumption that some of the methods uniformly overestimate, while others underestimate, the volumes of the colour gamut in the entire studied range.
- The lowest values of colour solid's volumes were obtained with the dodecahedron method. It is reasonable, since this method underestimates the volume of the solid by not taking into the account several of the print samples colour solid's convexities.
- The highest values of colour solid's volumes were obtained with the use of the Photoshop software method. Of particular concern is the dramatic increase of calculated volume in the range of highest process inks intensities. The results obtained raise doubts as to the precision of the method. The lack of it might result from relying on inaccurate "Gamut warning" Photoshop tool.
- The colour gamut volumes increase with the increase of reflection densities of fully overprinted areas of process colours in a whole range of their values or stabilize for medium and even fall a little for maximum densities of process inks, depending on the method used. In case of two from the studied methods, i.e. the dodecahedron method and the Gamutvision software method, a slight decrease in the volume of colour gamut was observed in the range of highest reflection density of process colours inks. This decrease is rather difficult to explain. One would rather expect an asymptotic stabilisation of volume above certain high reflection densities of process colour inks. Neither the icositetrahedron nor the ColorThink software method rules that out, although the stabilisation most likely occurs at higher reflection densities than the range obtained in the samples used for study.
- It appears that the ColorThink software method is both simple and trustworthy in respect to calculation of print samples colour gamut volume. It requires, however, an ICC profile or the possibility of its determination on the basis of colorimetric measurements of a print process characterization test chart. If that condition is not met, the icositetrahedron method may be used, provided, of course, that the halftone scales of primary and secondary colours as well as the black point are projected on the print sample. This method is a complicated one, but the volumes of colour solids obtained are very close to those obtained by applying the ColorThink software method, especially in the range of low and medium reflection densities of process ink colours. For the purpose of study of the dependence of thickness of offset inks on the volume of the colour gamut with the use of an IGT apparatus, the dodecahedron method may be applied.

(first received 30.01.09)

References

1. McBride T.O.: Analysis of Digital Printer System Color Gamut, IS&T's NIP12: International Conference on Digital Printing Technologies 1996, pp. 117-119.
2. Lindberg A.: Characterization of color gamut, M-real Report 2003.
3. Dąbrowa T., Gajdhur M.: Color gamut of a press print and dependence of the basic attributes of overprint colours on the process ink film thickness, Surface Coatings International Part B: Coating Transactions, Volume 89 Number 4 (2006), pp. 305-314.
4. Braun G., Spaulding K.: Method for evaluation the Color Gamut and Quantization Characteristics of Output-Referred Extended-Gamut Color Encodings, New York, IS&T/SID Tenth Color Imagining Conference.
5. ISO 12647-2:2004(E), Graphic technology – Process control for the manufacture of half–tone colour separations, proof and production prints - Part 2: Offset lithographic processes, 2004.
6. http://www2.chromix.com/colorthink/pro/.
7. http://www.gamutvision.com/docs/.
8. http://www.fho-emden.de/~hoffmann/hungams17042004.pdf.