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A STUDY OF DOT GAIN AND GAMUT FOR PRINTS MADE WITH HIGHLY PIGMENTED INKS

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Original scientific paper

Highly pigmented inks have the ability to cover screen elements with a thinner layer of ink applied whereby the intensity of their inking is higher compared to the classical inks. When using such inks, the printing reaches the point where the ink dot gain and the space of reproduction changes, which is closely related to the limits of the print quality. This is also directly related to the standardization of the print and the repeatability of the process. For this reason our research is focused on increasing the reproduction quality by using highly pigmented inks. The printing was carried out on two types of paper that were most commonly used in offset printing technology. In this paper, the reproduction quality was visually determined at changeable values of the inking densities, dot gain and gamut of colour. This paper also contains the new, recommended values of dot gain and gamut for printing processes using highly pigmented inks.

Keywords: *dot gain, gamut, highly pigmented inks*

Studija prirasta rastertonske vrijednosti i gamuta kod otisaka tiskanih s visokopigmentiranim bojama

Izvorni znanstveni članak

Visokopigmentirane boje imaju mogućnost s tanjim slojem boje prekriti rasterske elemente pri čemu je intezitet njihova obojenja veći u odnosu na klasične boje. Upotrebom takvih boja otisci dosegnu točku gdje se prirast rastertonske vrijednosti i prostor reprodukcije mijenja, a koja je usko povezana s granicama kvalitete otiska. Ovo je također izravno povezano sa standardizacijom tiska i ponovljivosti tiskarskog procesa. Upravo zbog toga naše istraživanje smo usmjerili na povećanje kvalitete reprodukcije upotrebom visokopigmetiranih boja. Otiskivanje je provedeno na dvije vrste papira koji se najčešće koriste u tehnici ofsetnog tiska. U ovome radu, kvaliteta reprodukcije vizualno je ispitivana s promjenjivim vrijednostima gustoće obojenja, prirastom rastertonskih vrijednosti i gamutu boja. Ovaj rad sadrži također i nove, preporučljive vrijednosti prirasta rastertonske vrijednosti i prostora reprodukcije boja kada se otiskivanje obavlja korištenjem visokopigmentiranih boja.

Ključne riječi: *gamut, prirast rastertonske vrijednosti, visokopigmentirane boje*

1 Introduction
Uvod

The technology of the used machines and tools in printing technology and in the offset printing has reached the stage when, technologically, it is very difficult to raise the printing quality with the up to now used production materials, which the world market demands more and more [1, 2]. Because of that the producers of the printing materials and inks invest great means in the development of materials which would enable increasing the printing quality [3, 4].

One of the main ways of increasing the printing quality today is the development of the new highly pigmented inks, which contrary to the inks used up to now, have the increased ability to cover the printing elements [5]. One of the main quality limitations of the printing made with classical inks was the impossibility of the ink to adhere qualitatively to paper i.e. to the printing substrate, when it is above the critical point of the ink layer thickness above 2 μm [3, 6]. The critical point of the ink layer thickness occurs in the moment when the ink cannot qualitatively adhere to the paper, i.e. when there is not enough absorption into paper or not enough drying of ink. In such situations the ink stays wet on the print and the undesired consequences occur. The mentioned consequences can be such that the ink offsets on the other side of the paper it is in contact with. The rubbing, i.e. removing of ink caused by the mechanical manipulations with prints can also occur.

The main advantage of the highly pigmented inks is in the fact that better inking is achieved with the standard thickness of the ink layer.

Because of that the research of the printing quality increase was performed with highly pigmented inks on two most often used papers in the sheet fed offset printing, so that the quality limitation is in the synthesis with the visual experience of the standard observer. In this paper the new values of the dot gain were analyzed and recommended as well as the values of the reproduction colour space increase in sheet fed offset printing with highly pigmented inks.

2 The transfer of tonal values
Prijenos tonskih vrijednosti

The aim of each reproduction is to optimize the reproduction chain so that the information about the colour in its transformation from the original to print is true to the original as much as possible. By transformation of such information from phase to phase, there is the possibility to lose tones and their irregular transformation [7].

The transfer of tonal values and the reproduction quality depend on the adherence of the ink to the printing form and the printing substrate. Theoretically defined, the screen element loses its theoretical value by screening the printing form whereby the increased, that is, the decreased ink adherence occurs [8]. Since the simple ink transfer onto the printing form also depends on the transfer time, the degree of pressure on the printing substrate, the rheological properties of the ink, the temperature of the ink [9] and the properties of the printing substrate, the quantity of the ink transferred can be calculated by the following equation [10]:

$$y=(1-\mathrm{e}^{-kx})\cdot\left[f\cdot x+b\cdot(1-f)\cdot(1-\mathrm{e}^{-\frac{x}{b}})\right], \quad (1)$$

in which y is the amount of the ink transferred onto the printing substrate per unit (g/m^2), k is smoothness of the printing substrate (m^2/g), x is the amount of ink on the printing form before impression (g/m^2), b is the immobilisation capacity of the substrate for the ink i.e. the amount of ink that can be immobilised before impression, f is the fraction of ink that is transferred to the paper during the film split ($0 \leq f \leq 1$).

Offset inks are composed of the components that give colour, of binding agents and different auxiliary means (fillers, siccatives, solvents, additives etc.). The means that give colour (pigments) in inks are contained in the quantity from 10 – 30 %. The greater the concentration of the pigments in ink the better the reproduction that is achieved regarding the limited possibilities of the ink layer thickness application on the printing material (about 2 μm).

Highly pigmented inks contain in their composition up to 100 % greater pigment concentration in comparison to the classical inks.

Pigment is the chemical substance which, mixed with the binding agent, gives the colour to the printing ink. The basic characteristic of the pigment is its insolubility in water and/or binding agents in which it disperses and which it has to soak well with.

2.1 Dot gain
Prirast rastertonske vrijednosti

However, the printing quality depends on the transfer quality of the screen elements. The surface under printing depends on screen elements that have not theoretical coverage identical with the real coverage. The increase of real coverage in regard to the theoretical one is called Dot Gain.

Dot gain consists of two parts: physical dot gain and optical dot gain. Physical dot gain occurs when the ink is transferred to the printing substrate and the ink is widely spread causing a growth in the size of dots, or when the surface energy of the printing substrate is higher than the surface tension of the ink itself [11].

Offset printing is the technology that gives the print in the way that the fountain solution adheres to some parts of the printing plate and ink to the other ones. The following Figure presents the oleophilic surface (the surface which accepts the ink) and oleophobic surface (the surface which repels the ink) on the printing plate on which it can be seen that the edge of the screen element has not the round shape.

The mentioned unevenness on the screen element causes the geometrical increase of the screen elements as well as the deformation in the shape of it. Geometrical deformation of the screen element is caused by other factors in printing as well, such as the dimensional change of paper, slurring, doubling etc. And the screen element that should have the round shape looks like the one in Fig. 1.

Figure 1 *Real screen element*
Slika 1. *Realan oblik rasterskog elementa*

Contrary to the physical dot gain, the optical dot gain is actually an optical illusion in which the size of dots appears bigger than their actual size. The reason for the occurrence of the optical dot gain is a light scattering within the surface of printing substrate [12, 13] which occurs because of the light reflectance and the light passing through the inner inhomogeneous parts of the paper.

All light, except the light that reflects from the inner paper layers, passing through the paper, because the majority of the paper is partly transparent as it can be seen in the Fig. 2 and Fig. 3.

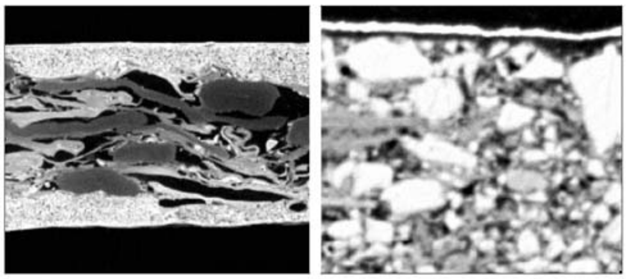

Figure 2 *Paper cross-section with magnification of 250×* [14]
Slika 2. *Presjek papira s povećanjem od 250×* [14]]

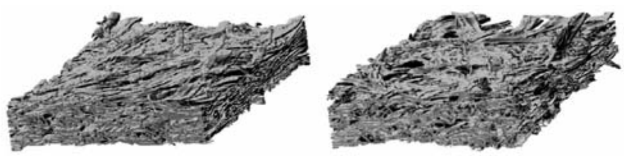

Figure 3 *Two different examples of three-dimensional paper structure obtained by X-rays 65 tomography* [15]
Slika 3. *Prikaz trodimenzionalne strukture papira od dva različita uzorka dobivena pomoću X-zraka 65 tomografije* [15]

Theoretically, the incoming light is reflected or absorbed from paper or ink, in which the reflected part is noticed by the observer. But paper is not the ideal substrate for printing because of its optical and physical imperfections. Each of them, such as e.g. colour variation, surface topography, optical density etc. degrades the print in its own way. Because of the mentioned reasons the incident light (photon) on the paper surface reflects in various ways as it is presented in Fig. 4.

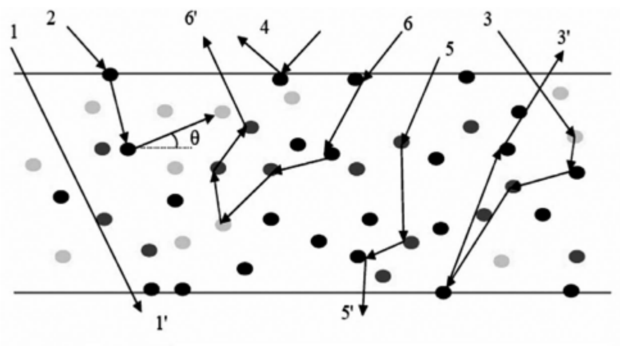

Figure 4 *Possible scenario of photon transfer in 2D paper presentation; 1 - direct transmission; 2 - absorption; 3-3' intern surface reflectance; 4 - surface reflectance; 5 - diffuse transmission and 6-6' intern multifold reflectance.*
Slika 4. *Mogući scenarij prolaska fotona u 2D prikazu papira; 1 – direktna transmisija; 2 - apsorpcija; 3-3' unutarnja površinska refleksija; 4 - površinska refleksija; 5 - difuzna transmisija i 6-6' unutarnja višestruka refleksija.*

The incident light is reflected from the material surface in the way presented in Fig. 4 and 5. Due to this interaction between the light and the printing substrate, dots obtain a shadow along their edge whereby we experience them as bigger and therefore the print becomes darker. Optical dot gain is always present when the prints are observed (measured and viewed) under a reflected light [17].

Numerous researches have been performed in order to define as precisely as possible the optical dot gain, as Yule and Nielsen had presented in their study from 1951 [18], but also Clapper and Yule [19], Huntsman [20], Arney, Engeldrum and Zeng [21, 22] etc.

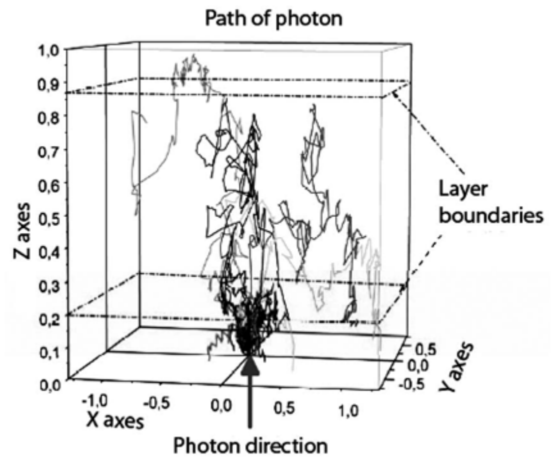

***Figure 5** Calculated ways of particular photons in a medium by means of the stimulating model* [16]. *The incoming of photons is on the lower boundary perpendicular to the surface.*
***Slika 5.** Izračunate putanje pojedinih fotona u mediju pomoću stimulirajućeg modela* [16]. *Ulazak fotona je na nižem graničnom sloju okomito na površinu.*

The combined physical and optical dot gain may be calculated using the print density measurements. The percentage of dot area (F_D) is determined by way of using Murray-Davies equation [23]:

$$F_D(\%) = \frac{1-10^{-(D_R - D_0)}}{1-10^{-(D_V - D_0)}} \cdot 100. \tag{2}$$

where D_R is the density of inking on halftone print, and D_V is density of inking on solid area (full-tone) and D_0 is the density on printing substrate (paper). The value of the dot gain (DG) is a difference between the nominal percentage dot area (F_F) and the calculated percentage of dot area (F_D) [3].

$$DG(\%) = F_D - F_F. \tag{3}$$

Murray-Davies equation connects the print coverage, i.e. the size of the printed screen elements and thickness of the ink film with optical density.

2.2 Colour density
Gustoća obojenja

Optical density (D) is related to reflectance as follows:

$$D = \lg\left(\frac{R_0}{R_1}\right), \tag{4}$$

in which R_1 is reflectance of printed solid or half tone value and R_0 is reflectance of unprinted substrate. The perceived strength of colour is related to logarithmic relationship of the reflectances.

The measuring instrument for optical density is densitometer, which is designed to select light of wavelength mostly absorbed by the used colour [17]. The densitometer is calibrated on the unprinted printing substrate and the value of D_0 gets the densitometric value "0". Densitometer works so that it measures the printing inks with the same light source through the defined colour filters. Filters correspond to the process inks C, M, Y, K for four-colour printing. The colour filter should have the maximum transmission in the minimum reflectance of the colour to be measured, that is, it should possess the colour complementary to the colour intended for measurement [3].

2.3 The colour space
Prostor boja

The distribution of the visual information can be dependent on different media that are limited by the information quantity that can be presented and that in greater part refers to the information about the transformation of the three-stimulus values of the defined colour. Scanners, computers image-setters, CtP devices, machines etc. are the media, which the final output information phase in graphic reproduction is dependent on. The limited quantity of information that is possessed by the independent devices, i.e. that refers to the given medium is called gamut [24].

The base for gamut calculation presents Neugebauer's model that can be presented as:

$$\begin{aligned} c(\alpha_1,\alpha_2,\alpha_3) &= (1-\alpha_1)\cdot(1-\alpha_2)\cdot(1-\alpha_3)\cdot g_{\mathrm{p}} + \\ &+ (\alpha_1)\cdot(1-\alpha_2)\cdot(1-\alpha_3)\cdot g_{\mathrm{p1}} + \\ &+ (1-\alpha_1)\cdot(\alpha_2)\cdot(1-\alpha_3)\cdot g_{\mathrm{p2}} + \\ &+ (\alpha_1)\cdot(\alpha_2)\cdot(1-\alpha_3)\cdot g_{\mathrm{p12}} + \\ &+ (1-\alpha_1)\cdot(1-\alpha_2)\cdot(\alpha_3)\cdot g_{\mathrm{p3}} + \\ &+ (\alpha_1)\cdot(1-\alpha_2)\cdot(\alpha_3)\cdot g_{\mathrm{p13}} + \\ &+ (1-\alpha_1)\cdot(\alpha_2)\cdot(\alpha_3)\cdot g_{\mathrm{p23}} + \\ &+ (\alpha_1)\cdot(\alpha_2)\cdot(\alpha_3)\cdot g_{\mathrm{p123}} \end{aligned}, \tag{5}$$

where the surface c has been printed with three inks as the function of three surface coverage values α_1, α_2 and α_3. g_p represents the colour of the paper, g_{p1} is the first ink printed on the paper, g_{p12} is the first and the second ink printed on the paper, etc.

For n number of colours there are $2n$ print primaries. If a part of the printing surface is marked with α_i, and if the integral values of inking are marked as $\alpha = (\alpha_1,\ldots,\alpha_n)$, then the Neugebauer's model for n number of colours can be calculated as the sum of all printing values q:

$$c(\alpha) = \sum_{q=1}^{2^n}\left[\prod_{i=1}^{n} f(q, i, \alpha_i)\right]\cdot g_q, \tag{6}$$

where $f(q, i, \alpha_i) = \alpha$ if q includes colour i, and $1-\alpha$ otherwise.

If the model is correlated with Ω_{CIE}, the scope of numerical values in a particular selected area of CIE colour space, and if Ω_{print} is the numerical scope of the control colour values of the medium, then the set [25, 26]

$$G = \{ t \in \mathbf{\Omega}_{CIE} \exists c \in \mathbf{\Omega}_{print} \text{ for } F_{device}(c) = t \}, \quad (7)$$

determines the gamut of the specified device (medium). This is also similar in case of complementary set:

$$G^c = \{ t \in \mathbf{\Omega}_{CIE} / \exists c \in \mathbf{\Omega}_{print} \text{ for } F_{device}(c) = t \}, \quad (8)$$

where the colours outside the gamut G^c of the specified device (medium) are defined.

The variable Fdevice represents the function that transforms the dependent colour space of the device/medium into the CIE colour space. The variable t represents the information on the ink in CIE space, and the variable c is its transferred value in a dependent colour space of the device, that is, the medium.

3 Experimental part
Eksperimentalni dio

In order to determine the colour space values in a qualitative and standardized way i.e. the values of gamut and dot gain of prints that were printed with highly pigmented inks, the prints printed with classical inks were produced as well for the comparison. The prints made with standard inks were produced according to international recommendation, which means that the values of the dot gain and gamut are strictly defined [27].

The research in this paper was done on the test form which had full tone patches which enabled the determination of the inking density DV, then the patches for determining the dot gain DG as well as 210 patches for gamut construction. On the prints, the multicolour images were printed which determined the subjective evaluation of the reproduction quality on the sample of 120 persons [28, 29, 30].

Table 1 *Characteristics of the glossy fine art paper*
Tablica 1. *Karakteristike papira za umjetnički tisak*

Parameter	Standard	Unit	Tolerances
Standard Quality Values			± 2 Sigma
Basis Weight	ISO 536	g/m^2	115 ± 4 %
Brightness (D65/100)	ISO 2470	%	88 ± 2 %
Gloss Tappi 750(MD)	Tappi T 480	%	69 ± 6 %
Opacity	ISO 2471	%	96,5 - 1,5 %
Rel. Humidity (230C)	Tappi 502	%	52 ± 7 %
pH Value	ISO 6588	%	>7 -
Spec. Volume	ISO 534	cm^3/g	0,79 ± 10 %

Table 2 *Characteristics of the offset paper*
Tablica 2. *Karakteristike ofsetnog papira*

Parameter	Standard	Unit	Tolerances
Standard Quality Values			± 2 Sigma
Basis Weight	ISO 536	g/m^2	115 ± 4 %
Brightness (D_{65}/10^0)	ISO 2470	%	90 ± 2 %
Smoothness Bekk	ISO 5627	s	180 – 50 %
Opacity	ISO 2471	%	90 - 1,5 %
Rel. Humidity (230C)	Tappi 502	%	50 ± 7 %
pH Value	ISO 6588	%	>7 -
Spec. Volume	ISO 534	cm^3/g	0,97 ± 10 %

The research in the paper was performed on two most often used materials in sheet fed offset printing, on the glossy fine art paper and on the offset paper (Tab. 1 and Tab. 2).

Multicolour images were also printed on prints by which the subjective quality evaluation of the reproduction was determined on a sample of 120 persons. The investigated prints were firstly printed with classical inks and after that with the highly pigmented inks [31].

The prints produced with classical inks were printed with the inking density of D_V according to the international recommendations (Tab. 3).

Table 3 *Values of inking density of prints printed with classical inks*
Tablica 3. *Vrijednosti gustoće obojenja otisaka dobivenih klasičnim bojama*

Inking Density		D_v
Glossy art paper	C	1,88
	M	1,83
	Y	1,77
	K	1,92
Offset paper	C	1,41
	M	1,38
	Y	1,30
	K	1,43

After printing with classical inks the prints with highly pigmented inks were also made so that the prints were printed with different inking densities. The inking density of all the prints did not pass over the smaller value than the one presented in Tab. 3. Other values of the inking density were increased during the testing time thus the prints with five different inking densities were obtained. They were marked starting from the smallest value to the biggest one with D_1(g) ... D_5(g), (g = glossy) and D_1(o) ... D_5(o), (o = offset).

Values of inking density of prints printed with highly pigmented inks are defined in Tab. 4.

The inking densities were the same for all the colours (CMYK).

Table 4 *Values of inking density of prints printed with highly pigmented inks*
Tablica 4. *Vrijednosti gustoće obojenja otisaka dobivenih s visokopigmentiranim bojama*

Inking Density (CMYK)	D_1	D_2	D_3	D_4	D_5
Glossy art paper	1,90	2,00	2,10	2,20	2,30
Offset paper	1,40	1,50	1,60	1,70	1,80

4 Results and discussion
Rezultati i rasprava

The research in the paper comprised the research of dot gain value, gamut size and the visual evaluation of the printing quality. The results of the mentioned research were put into correlation and synthesized in order to get the objective recommendations of dot gain values, gamut size for the prints printed with highly pigmented inks.

4.1
Dot gain curves
Krivulje rastertonske vrijednosti

The research of the dot gain was performed on fields of the control stripes in the range from 10 to 90 % screen value while the control of the inking density was done on the full field of 100 % screen value (DV). As the prints were made with five different inking densities, the differences in inking densities were the same for all the colours in printing as it is presented in Tab. 4.

By calculation of dot gain for the mentioned prints the curves for five different inking densities were constructed as the average value of all CMYK colours. The obtained results are given in Fig. 6 and Fig. 7.

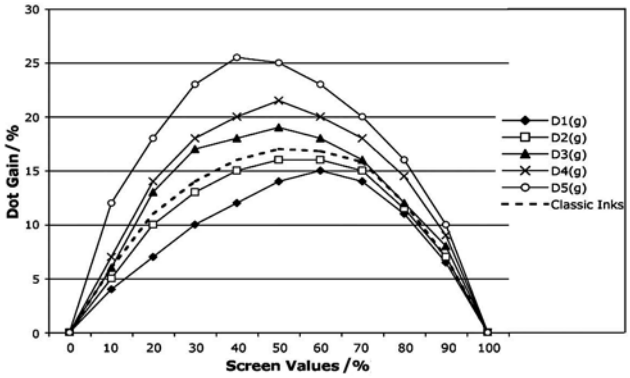

Figure 6 Dot gain of prints printed with highly pigmented inks on fine art glossy paper
Slika 6. Prirast rastertonske vrijednosti otisaka dobivenih s visokopigmentiranim bojama na papiru za umjetnički tisak

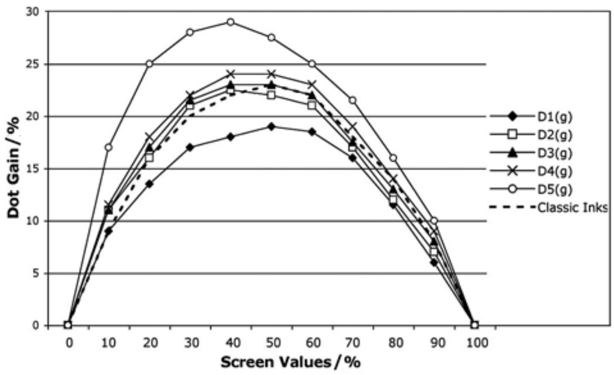

Figure 7 Dot gain of prints printed with highly pigmented inks on offset paper
Slika 7. Prirast rastertonske vrijednosti otisaka dobivenih s visokopigmentiranim bojama na ofsetnom papiru

By the research results analysis of dot gain it can be seen that the dot gain is dependent on the inking density. If the values of the dot gain of prints made with highly pigmented inks which were printed with the lowest inking densities were compared with the dot gain of prints of the classical inks, it could be concluded that the total dot gain was smaller with highly pigmented inks which is visible from the curves D_1(g) and D_1(o). The other prints were printed with higher inking densities and the dot gain on such prints was greater. The mentioned correlation was confirmed on both paper kinds. It is visible from the dot gain curves that the dot gain is different on the prints printed on fine art glossy paper than on the prints printed on offset paper. Generally speaking, the dot gain is greater on prints made on the offset paper regarding the fact that the smoothness of the offset paper is smaller which causes smaller deformations on the edge of the screen element and the light reflectance from the paper surface results in different optical dot gain [32].

The dot gain curves on both paper kinds show that by the increase of the dot gain values of the greatest dot gain the screen values become smaller. Generally speaking, at smaller dot gain the greater screen values have greater deformations which show greater dot gain on the value of 60 % on prints made on fine art glossy paper that is in correlation with the recommended international standards ISO 12647 – 2:2008.

However, by the dot gain analysis it is not possible to determine the acceptability of the quality by standard observer who is the last consumer of the graphic product, because the different dot gain has as consequence the different quality experience. This specially concerns the experience of the quality of the middle part of the tones [33].

4.2
Visual evaluation
Vizualno ispitivanje

As the human experience of quality is connected with the space of the reproduced colours, i.e. of gamut, the research of the print quality experience was performed on all the prints. The research was done so that 120 observers (50 % men and 50 % women) of different age and education level classified the prints quality by the method of binocular subjective matching on both kinds of paper. The research was performed five times so that the samples were completely mixed each time. After five researches the average value was calculated as well as the standard deviation as it is presented in Tab. 5 and Fig. 8.

Table 5 Average value and the standard deviation of the visual evaluation
Tablica 5. Prosječna vrijednost i standardna devijacija vizualnog ispitivanja

	Glossy fine art paper		Offset paper	
	Average value	Standard deviation	Average value	Standard deviation
D_1	6	1	4	2
D_2	12	2	10	2
D_3	41	2	28	1
D_4	33	2	42	2
D_5	26	2	34	2

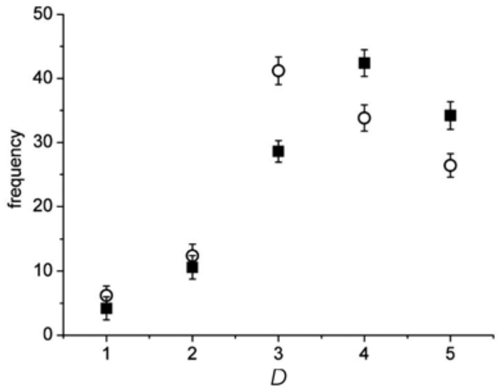

Figure 8 Visual evaluation of the printing quality with the standard deviation
Slika 8. Vizualno ispitivanje kvalitete tiska s uključenom standardnom devijacijom

From the calculated average value and the standard deviation presented in Fig. 8, it is visible that there is no overlapping of the value of the standard deviation boundary at different inking densities.

It is visible from the research results that there is a correlation between the quality experience and the increase of dot gain value, i.e. of the inking density. Namely, the quality experience of standard observer grows with the increase of the dot gain value only to a certain limit. When the dot gain becomes too big, the loss of the quality experience occurs.

However, it is not possible to determine how great the tone reproduction possibilities are by the dot gain research and the quality experience; so on the mentioned prints the three-stimulus colorimetric X, Y, Z values of the patches were measured for the construction of the colour space, i.e. gamut. The measuring of X, Y, Z was done on print with device X-Rite SpectroEye with the light source D50. The conversion of the measuring values into CIE $L^*a^*b^*$ values was done with the relative colorimetric rendering because the relative colorimetric rendering is useful when the relation among colours should be kept. The white colour was not defined because the research object, the printing and the deformation were in the screen elements. The relative colorimetric rendering was used for the prints made with highly pigmented inks as well as the prints printed with classical inks in order that all other research parameters stayed constant except the research performed in this paper. By the change of rendering kind the conclusion cannot be made which parameters cause the change of the printing quality.

4.3 Gamut of colour
Gamut boja

After the mentioned transformation the program Monaco Gamut Works was used to calculate the gamut.

The gamut construction was done after the measurements of 210 patches of the defined screen values in the controlled printing conditions and dot gain and after the calculation of the gamut volume that is expressed in the value of CCU (Cubic Colour Units) [34].

By the CCU calculation the gamut volumes were obtained as it is presented in Tab. 6.

Table 6 *Gamut volumes of prints printed with classical and highly pigmented inks CIE L*a*b* CCU*
Tablica 6. *Volumeni gamuta klasičnih i visokopigmentiranih boja CIE L*a*b* CCU*

Sample	Printing substrate	Classic inks	Highly pigm. inks
D_1(g)	Glossy fine art paper	670117	879115
D_2(g)	Glossy fine art paper	670117	885019
D_3(g)	Glossy fine art paper	670117	895276
D_4(g)	Glossy fine art paper	670117	906044
D_5(g)	Glossy fine art paper	670117	923423
D_1(o)	Offset paper	526992	561229
D_2(o)	Offset paper	526992	647116
D_3(o)	Offset paper	526992	682455
D_4(o)	Offset paper	526992	715004
D_5(o)	Offset paper	526992	717332

Because the colour space, i.e. gamut is one of the key elements for defining the printing quality and the repeatability of the processes in the graphic reproduction, it is necessary to know for each reproduction, which part of the spectrum is possible to be reproduced theoretically with regard to the input database. Because of that the values of the input database are also presented in the research results as the group of dots within and outside the colour space.

The mentioned theoretical gamut which was obtained by computer calculation from the input database, presents the gamut boundaries in theoretical conditions when the roughness of paper is minimal and when the adherence of ink on paper and the absorbency into the substrate is optimal. In such conditions the deformation of the screen element is also minimal. The mentioned dots refer to the prints made with classical inks. It is immediately visible that the gamut on these prints is smaller than the final theoretical dots. By printing with the highly pigmented inks the gamut is increased on both paper kinds and the final theoretical dots are mainly possible to be reproduced. It was determined in this way that the prints with the highly pigmented inks gave more realistic reproduction.

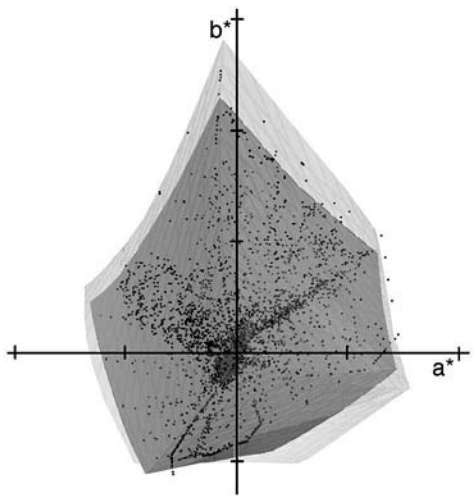

Figure 9a *CIE a*b* diagram of prints printed with highly pigmented and classical inks on glossy fine art paper and the dots of the input database*
Slika 9a. *CIE a*b* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na papiru za umjetnički tisak s točkama ulaznih definiranih vrijednosti*

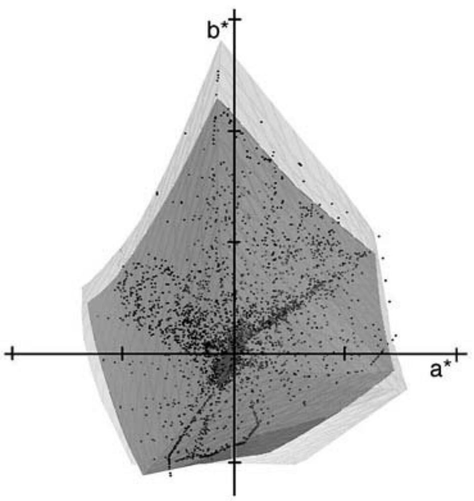

Figure 9b *CIE b*L* diagram of prints printed with highly pigmented and classical inks on glossy fine art paper and the dots of the input database*
Slika 9b. *CIE b*L* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na papiru za umjetnički tisak s točkama ulaznih definiranih vrijednosti*

Because of easier understanding of the three-dimensional CIE $L^*a^*b^*$ colour space, the constructed gamut is presented as CIE a^*b^*, CIE L^*a^* and CIE L^*b^* diagram. In all the presentations together with the gamut of prints made with highly pigmented inks (light gray) the gamut of prints made with classical inks is also presented (dark gray). The presented gamuts refer to the prints that were evaluated as the most qualitative ones in visual evaluation of the quality reproduction (Fig.-s 9 and 10).

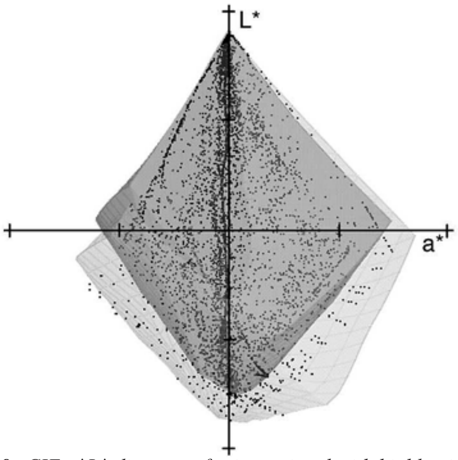

Figure 9c *CIE a*L* diagram of prints printed with highly pigmented and classical inks on glossy fine art paper and the dots of the input database*
Slika 9c. *CIE a*L* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na papiru za umjetnički tisak s točkama ulaznih definiranih vrijednosti*

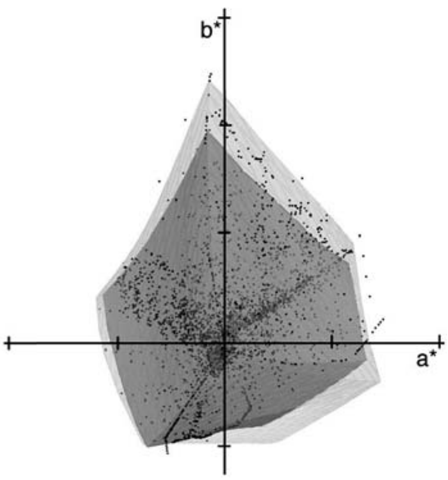

Figure 10a *CIE a*b* diagram of prints printed with highly pigmented and classical inks on offset paper and the dots of the input database*
Slika 10a. *CIE a*b* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na ofsetnom papiru s točkama ulaznih definiranih vrijednosti*

By comparison of the gamut size of prints printed with highly pigmented inks and with the classical inks it is visible that the gamut size of the prints with highly pigmented inks is greater on average. However, it is visible from the gamut construction that there is an area in which the gamut is smaller on prints with highly pigmented inks.

The smaller gamut on prints with highly pigmented inks occurs in the blue-green area because the value L^* on prints with highly pigmented inks is smaller, which shifts the reflectance of cyan into the darker area of the CIE $L^*a^*b^*$ system. With connecting the dots in gamut, the gamut of prints printed with highly pigmented inks occurs smaller than the gamut of prints printed with classical inks

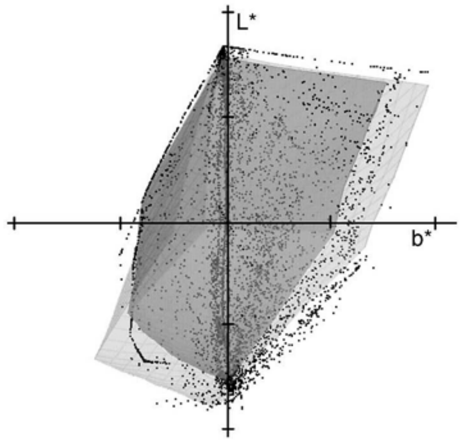

Figure 10b *CIE b*L* diagram of prints printed with highly pigmented and classical inks on offset paper and the dots of the input database*
Slika 10b. *CIE b*L* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na ofsetnom papiru s točkama ulaznih definiranih vrijednosti*

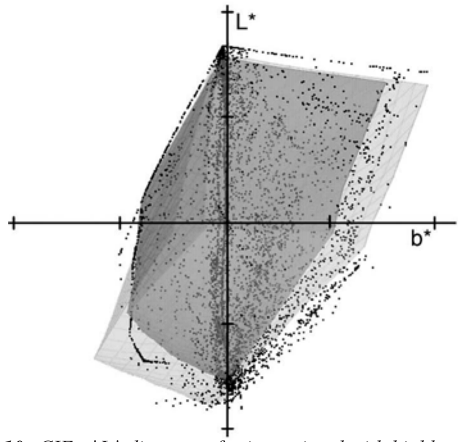

Figure 10c *CIE a*L* diagram of prints printed with highly pigmented and classical inks on offset paper and the dots of the input database*
Slika 10c. *CIE a*L* dijagram otisaka dobivenih s visokopigmentiranim bojama i klasičnim bojama na ofsetnom papiru s točkama ulaznih definiranih vrijednosti*

in the lighter values of CIE $L^*a^*b^*$ system.

5 Conclusion
Zaključak

The task of the offset printing technology is enabling the printing of high qualitative reproduction in which it is necessary to reproduce the colour space as big as possible so that the reproduction is true to original as much as possible. To obtain the qualitative reproduction depends on a series of parameters among which the most important ones are the standardized and defined dot gain, known colour space reproduction as well as the visual acceptance of the printing quality.

Realization of such quality depends on the synthesis of the mentioned parameters that can satisfy the end consumer of the graphic product. The research in this paper established the correlation of the mentioned parameters so that it was proved that the experience of the quality reproduction is dependent on the relation of dot gain and the reproduction gamut.

The research in this paper confirmed that the human experience of the printing quality on prints shows that the print is more qualitative when the reproduction of greater gamut is possible. However, too big gamut can cause the decrease of experience of the reproduction quality primarily because of too big dot gain that causes the changes of quality experience in medium tones.

It is also confirmed in the research that the difference in the gamut size is caused by various values of dot gain in printing.

On the basis of the obtained results and analysis, with the aim of increasing the quality of the printing product, the new values of the dot gain are recommended during the printing process with the highly pigmented inks (Fig. 11 and Tab. 7).

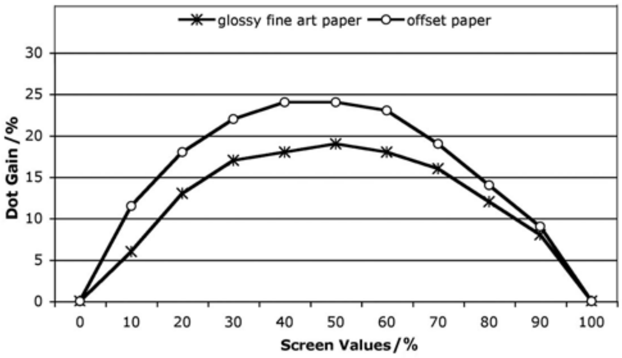

Figure 11 *New recommended values of the dot gain in printing with highly pigmented inks on glossy fine art paper and on offset paper*
Slika 11. *Nove preporučljive vrijednosti prirasta rastertonske vrijednosti prilikom tiska s visokopigmentiranim bojama na papiru za umjetnički tisak i na ofsetnom papiru*

Table 7 *Numerical new recommended values of the dot gain in printing with highly pigmented inks on glossy fine art paper and on offset paper*
Tablica 7. *Brojčani prikaz preporučljivih vrijednosti prirasta rastertonske vrijednosti prilikom tiska s visokopigmentiranim bojama na papiru za umjetnički tisak i na ofsetnom papiru*

Screen value / %	Dot gain on glossy fine art paper / %	Dot gain on offset paper / %
25	14	19
40	18	24
50	19	24
70	16	19
75	14	17
80	12	14

By calculating the relations of gamut sizes of the mentioned samples printed with highly pigmented inks and the samples printed with classical inks, it was found out that the prints with highly pigmented inks had the gamut volumes greater than the gamut of prints printed with classical inks, for the following values:

- 33,6 % - fine art glossy paper
- 29,5 % - offset paper.

From all the mentioned, it can be concluded that with the printing with highly pigmented inks it is possible to achieve greater reproduction quality. However, by using the highly pigmented inks it is necessary to pay attention to colour management because the usage of such inks enables the reproduction of more saturated inks that results in greater dot gain. The recommended dot gain values should be taken into consideration during the database creation, i.e. proof file creation, which enables a satisfactory reproduction of all the tones especially of the tones of the medium part of the spectrum in which the dot gain has the greatest influence on final product.

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