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DETERMINATION OF EQUIVALENT-DENSITY DOMAIN IN BLACK COMPENSATION IMPLEMENTATION FOR THE SELECTED PROFILE

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Original scientific paper

In a standard graphic reproduction subtractive system of the process inks' coverage is observed. For achieving a wider reproduction range as well as higher density, additional black printer is added into a printing system. Today's graphic arts ISO specifications define overall coverage, including black compensation principles. Although in theory the substitution of chromatic part of process inks with a black one can be easily performed, practical results can render certain misalignments in neutral as well as other tertiary colours, not achieving predicted values. That maintains the demand of additional customization of reproduction for certain images to preserve reproduction quality. A test target proof and soft proof are considered for proposed profiles, including adequate equivalent densities or lightness.

Keywords: *black compensation, black printer, graphic reproduction, tertiary colours*

Određivanje područja odgovarajućih gustoća kod primjene kompenzacije crne za izabrani profil

Izvorni znanstveni članak

U standardnoj grafičkoj reprodukciji promatra se subtraktivni sustav procesnog miješanja boja i pokrivenost bojama. Kako bi se postignuo veći raspon reprodukcije tonova kao i veće zacrnjenje, dodatni crni izvadak se ugrađuje u reprodukcijski sustav. Današnje ISO specifikacije za grafičku reprodukciju preporučaju određenu ukupnu pokrivenost, uključujući principe kompenzacije crne boje. Iako zamjena kromatskog dijela procesnih boja sa crnom može biti vrlo velika, praktični rezultati mogu voditi određenom odstupanju kod neutralnih kao i tercijarnih boja. To upućuje na potrebu dodatne prilagodbe za određene slike kako bi se osigurala kvaliteta reprodukcije. Testna karta je reproducirana kao ekranska i otisnuta za izabrani profil, gdje su postignute odgovarajuće ujednačene gustoće.

Ključne riječi: *crni izvadak, grafička reprodukcija, kompenzacija crnom, tercijarne boje*

1 Introduction
Uvod

Input devices such as scanner or digital camera provide an RGB image. Such image is suitable for viewing on monitors, where additive colour mixing system produces millions of colours. If the input picture is analogue (photograph, painting or similar) it has to be digitalized for contemporary programming and informatics managed reproduction systems. Graphic arts reproduction basically uses subtractive reproducing system (mainly process CMY), where black printer (K) in most cases is added for distinct practical and technical reasons [1]. For various purposes spot colours can be used, defined as additional separates, or converted to the nearest CMYK separation. In any case, a suitable workflow has to be obtained, not only for text and image imposition, but for the whole reproduction process. It is important to get the best possible image in (all) the printing process, not only for the open systems' purposes. In various situations the image in two different systems (RGB and CMYK) has to be compared not only for web purposes but also as a soft proof in graphic arts, proof printers, (prepress) production and actual print production for the demand of high and equalized quality, both for print customers and final users. These distinct types of equipment and various applications used have their own and specific characteristics (using various algorithms) that can influence the product, such as colour and gray scale shift, reproduction range. All used equipment operates specifically so that they could render colours not in the same way, what is connected with the situation of device dependent colour systems. To achieve a print or reproduction result that will have predictable colours today, tomorrow and worldwide, great support is in colour management [2, 3, 4]. Related organizations define specifications not only for materials, measurements and procedures but also colour settings for defined purposes. It could be stated that colour management interprets colours between various input and output devices, respectively colour spaces attributes-profiles, using a device independent connection colour space (International Colour Consortium, ICC profile), connecting standard profile for each input or output devices. Across the ICC profile variety of colours (tones and hues) can be translated or rendered regardless of the reproduction system, device or application used. Practically ICC profile of a colour device is achieved from many measurements and provides simulation and optimization by the use of colour engines. The ICC format allows the colour space of the selected colour device to be connected to another with optimal colour reproduction facility, or in other words the colour gamut of a device maps to a device independent space, and then transcribes it to the colour gamut of another device (CMS module). Through the ICC-format, ICC-profile, various colours and hues can be interpreted in a similar fashion regardless of the platform and application (computer type, monitor model, system construction and pre-press programs). Basic profile functioning and information can be listed as follows [5, 6]:

- profiles for various platforms
- different colour gamuts
- RGB and CMYK gray balance
- gamut warning
- separation
- chroma shift
- total ink coverage.

Performer of that process, colour management system (CMS), simplified, is just a settled or accepted way of how to manage coloured images from the input to the output in accordance with an intermediate independent profile connection space (PCS), as shown in Fig. 1.

CMS enforces series of colour management applications, modules and tools with intent to commit colour device as colour-independent. CMS can be described by the following basic operations: consistency of the devices used, calibration that deals with the substrates and inks' characteristics, characterization that involves generating of the profiles, and conversion between RGB and CMYK colour device spaces [7].

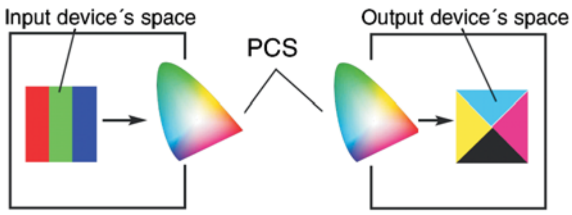

Figure 1 Position of independent PCS connecting two dependent spaces
***Slika 1.** Pozicija neovisnog PCS prostora kod povezivanja dva prostora boja ovisna o uređaju*

Device profile describes basic colorimetric (and some other) properties of a device. The profile is not only the routing to convert data among devices, it is suitable to coordinate each device via central scale. If the pixel RGB value is expressed, it is necessary to know to what colour it is related. The interpretation of the colour is needed, and the profile relates the device dependent, multi valued, colour valued to device independent (e.g. colorimetric CIELab) space. It means that the device's profile contains the needed data to convert the values from device to device. In one case, as for soft proof purpose, the profile describes the data for (calibrated) screen, and in another for output CMYK device.

Compensation of black [8] is a different approach to the usual achromatic approach in reproduction. That kind of reduction is a common procedure providing various benefits as stability of reproduction, stability of reproduced colours, fewer printing problems, better drying characteristic, etc. [9].

It is associated with graphic reproduction of tertiary colours, whereat it associates all applied principles such as UCR (Under colour removal for neutral) and CCR (complementary colour removal), and PCR (polychromatic colour removal), for possible reductions. The start point is in the fact that neutral scale (lightness) is generated by three primaries, in additive RGB where their equal amount represents greys, and subtractive primaries in CMY reproduction system. Basic CMY primaries build gray scale, but any other colour (tertiary colours) as well, consisting of all primaries has a neutral (gray) component that can be substituted. By converting from RGB to CMY(K) pure primary or secondary combinations are not so frequent, so reduction of common achromatic part is usual. As some practical limitations are frequent [10] reduction is seldom made to the maximum possible amount. On the other hand ICC specification limits the achromatic amount for the type of printing indirectly, in a way to determine the allowed CMYK coverage for the specified process [3]. The basic principle of the achromatic reduction is shown in Fig. 2.

As supposed in the example, a maximum reduction, 50 % of CMY coverage is possible (N denotes common CMY amount), that would be replaced with black. Total ink amount (TAC) for the supposed colour was 200 % coverage, and after reduction 100 % coverage. The neutral balance of colours, possible density loss, printing and similar problems are not taken into consideration in this example.

From the input RGB device pixel information has to

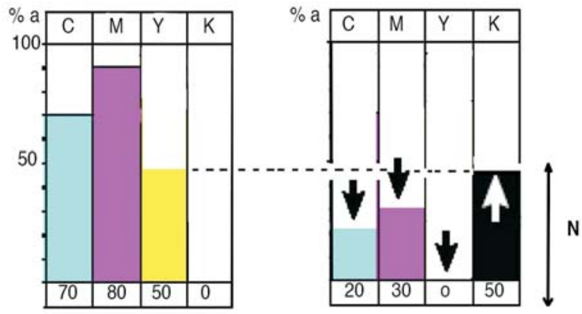

Figure 2 Principle of achromatic reduction: left starting combination, right maximum reduction
***Slika 2.** Princip akromatske redukcije: početna kombinacija (lijevo), maksimum redukcije (desno)*

be converted to the output CMYK reproduction system-device. Basic Postscript functions for CMY (1) and maximum K (2) are listed as follows:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

$$K = \min\,[C, M, Y]. \quad (2)$$

It must be denoted that such pure functions cannot be directly implemented, considering various specificities of the system. Different dedicated profiles cover numerous common situations, presented by ISO, but various data can be also found in other sources [11]. Sometimes some additional adjustment profiling is suitable and useful, although in such situations attention is needed so as not to override the proposed framework, and access the closed system.

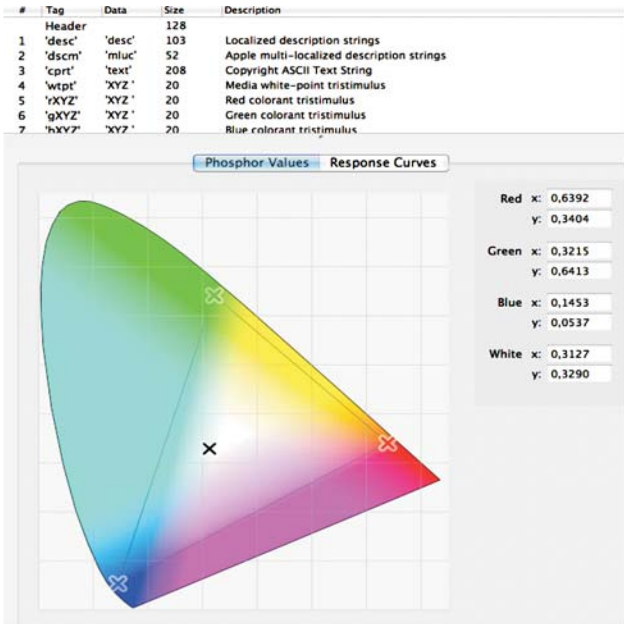

***Figure 3** Gamut of the calibrated screen*
***Slika 3.** Opseg boja kalibriranog zaslona*

In CMYK system only (pure) primary and secondary colours do not have the other components. Otherwise it is a combination of CMY and K. K renders the achromatic part of the colour as well as its reflection content (measured as density or lightness). Two parameters will be considered in the experiment, grey balance and achromatic reduction yield for finding acceptable area of combinations without density (or respectively lightness) loss.

Reproduction parameters can involve various settings needed. The profile can usually cover standard demands when applied to the picture, but in particular cases, such as some dedicated materials or equipment, designers' needs, or tuning the system, some additional setting or checking have to be performed. As supposed to get a gray balance as a soft proof and a print (proof) the screen and the print have to be adjusted. Neutrals on screen ensure equal RGB values on calibrated (profiled) screen according to the applied RGB and colour temperature (D 50, gamma 1,8, WP: 0,31, 0,32). Gamut of the screen and white point is shown in Fig. 3.

As opposed to screen, in reproduction there is a relation between CMY values that produce neutral greys. It can be a very sensitive job to achieve and to measure neutrals [12]. The term gray balance of the reproduction curves covers the relation (ratio) C:M:Y, where mostly C=1 (as integrated density D_i) and the others are described with lower values. Adobe applications render M and Y as the same amount. The relation should cover the whole tone reproduction curve, but sometimes deviations partially occur in a part of the reproduction curve, so some undesired tonal shifts can appear. Usually, the reproduction process is established with several control points (respectively low (A), middle (M) and high (B) densities, coverages, pixel values or similar). Those values are often indicated on various control elements (charts, wedges), which are also specified in profiles. Step wedge, shown in Fig. 4, is chosen for more reasons: neutral patches with defined step, suitable density range, ABM test points, possible CMY control.

Figure 4 *Control step wedge*
Slika 4. *Kontrolni stepenasti test element*

The classic photomechanical three point control is compiled to digital purposes [13] and can be found applied in various fields of reproduction [14, 15]. Various gray and colour reproduction test wedges and charts can be found for application (as targets and files [16, 17]) although they can be self defined, but special care has to be routed to their neutral density or neutral appearance according to the specified system. [18].

There is a combination of decreasing CMY coverages, adding up (increasing) K coverage, so various combinations of CMY and CMYK can be reached. Of course, in the meaning of achromatic reproduction combinations with decreasing coloured cast and increasing K coverage that should create unifying concerned densities (or lightness) can be determined.

2 Experiment
Eksperiment

In prior tests the gray balance was verified and balanced with the output equipment. As suggested and according to ISO the (90-80-80) rate was tuned at the output device. This

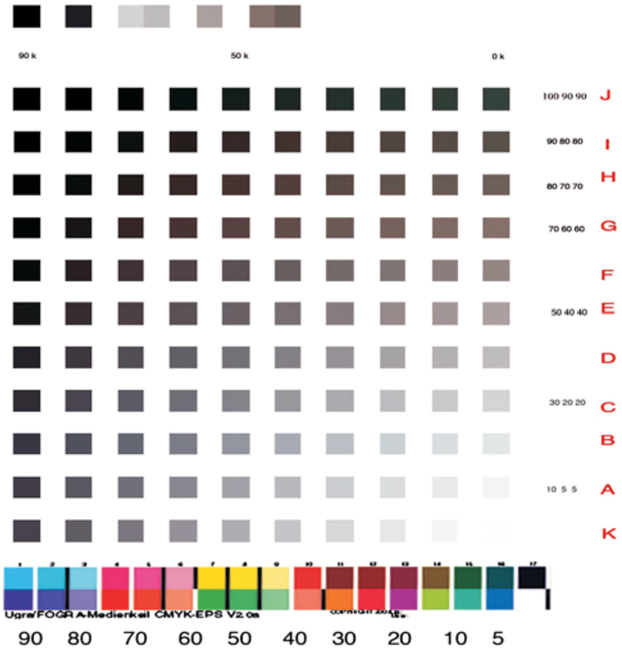

Figure 5 *Gray chart CMY and K combinations (A-J are CMY combinations, K indicates black increase, patches on the top and coloured scale are supplementary combinations for reproduction control)*
Slika 5. *Karta sivih tonova sa CMY i K kombinacijama (A-J su CMY kombinacije, K pokazuje crno povećanje, polja na vrhu ljestvice i kolorirana ljestvica su dodatne kombinacije za kontrolu reprodukcije)*

corresponds to the density values ratio C:M:Y and appears as 1: 0.8: 0.8. The basic profile was settled as Eurostandard coated, medium K. Standard test charts and targets are either common or universal [19], or dedicated for specified purpose, [16, 17], for achromatic reduction analysis a required custom card was developed (Fig. 5). In perpendicular combinations of CMY values are adjusted in a suitable step of 10 % (coverage) denoted as A to J, where only first step indicates CMY 10-5-5 coverage, and the horizontal axis presents black coverage settled in a suitable step of 10 % coverage. Only the first step (A) is a 5 % coverage step. Smaller step of coverages (or densities) is commonly used for specific area determinations. Although lower value is suggested, in basic application preferences the total ink coverage is allowed to 350 % just to check additional high coverage/density relation. The output profile colour gamut is shown in Fig. 6. For the soft proof

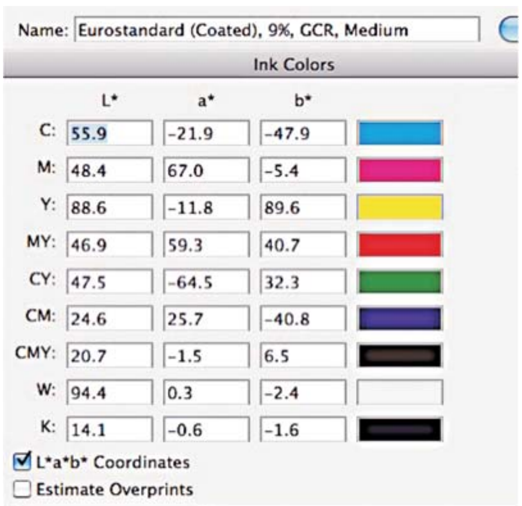

Figure 6 *Colorimetric characteristics of the supposed output gamut for Eurostandard*
Slika 6. *Kolorimetrijske značajke pretpostavljenog opsega boja*

step of CMY 90-80-80 coverage is commonly used as shadow value, and as one of possible points of reproduction curve limit (B point). It is denoted that I step begins without K, and the following "equivalent" values for the lightness can be found in table 1 as a soft proof, and in table 2 as a print proof. Two other values of 50 and 30 coverage are investigated as they can be applied as midtone and highlight adjusting in photographic part, and often they are used as control points at platemaking or printing processes. Some values are estimated, (as 80/90) cause the coverage step of 10. Colorimetric values were slightly rounded, as some are estimated due to coverage step.

Table 1 *Equivalent values for the I step (soft proof)*
Tablica 1. *Ekvivalentne vrijednosti za I korak*

Row	C	M	Y	K	L	a	b	Total supposed coverage
I	90	80	80	0	33	-4	6	250
H	80	70	70	20	34	-2	4	240
G	70	60	60	40	34	1	2	230
E	50	40	40	60	34	1	2	190
C	30	20	20	70	33	0	0	140
A	10	5	5	80/90	33	0	0	100

Table 2 *Equivalent values for the E step (soft proof)*
Tablica 2. *Ekvivalentne vrijednosti za E korak*

Row	C	M	Y	K	L	a	b	Total supposed coverage
E	50	40	40	0	61	0	2	130
D	40	30	30	20	60	0	2	120
C	30	20	20	30	63	-1	-1	100
B	20	10	10	40	63	-2	-2	80
A	10	5	5	50	61	-1	-1	70

Table 3 *Equivalent values for the C step (soft proof, 10/20 estimated value)*
Tablica 3. *Ekvivalentne vrijednosti za C korak (10/20 procijenjena vrijednost)*

Row	C	M	Y	K	L	a	b	Total supposed coverage
C	30	20	20	0	79	-2	0	70
B	20	10	10	10/20	75	-3	-2	40
A	10	5	5	20/30	70	-1	-2	20

In soft proof the lightness value was conclusive value (as density can not be determined on screen), so it was taken from the info data.

Table 4 *Equivalent values for the I step (hard proof, 80/90 is estimated value)*
Tablica 4. *Ekvivalentne vrijednosti za I korak (otisak, 80/90 procijenjena vrijednost)*

Row	C	M	Y	K	L	a	b	D_n neutral density
I	90	80	80	0	32	-4	0	1,14
H	80	70	70	30	32	-4	4	1,15
G	70	60	60	50	31	-3	3	1,17
E	50	40	40	70	31	-3	1	1,17
C	30	20	20	80	33	-3	0	1,13
A	10	5	5	80/90	35	-4	0	1,08

Table 5 *Equivalent values for the E step*
Tablica 5. *Ekvivalentne vrijednosti za E korak*

Row	C	M	Y	K	L	a	b	D_n neutral density
E	50	40	40	0	61	-5	1	0,54
D	40	30	30	20	60	-6	-3	0,53
C	30	20	20	30	63	-6	-3	0,55
B	20	10	10	40	63	-4	-3	0,51
A	10	5	5	50/60	61	-4	-2	0,52

Table 6 *Equivalent values for the C step*
Tablica 6. *Ekvivalentne vrijednosti za C korak*

Row	C	M	Y	K	L	a	b	D_n neutral density
C	30	20	20	0	78	-5	3	0,28
B	20	10	10	10	76	-7	5	0,31
A	10	5	5	20	75	-5	-4	0,32

As criteria of efficacy besides comparing values of lightness or density, colorimetric difference (ΔE 76) was calculated for the combination of high coverage (Tab. 7). If observing the substituting rate process CMY coverages with K coverage for the same reflection presented in Fig. 7, only the first part of the curve is conditionally linear.

Table 7 *Calculated ΔE for I step on soft and hard proof*
Tablica 7. *Izmjerene vrijednosti ΔE za I korak na probnom i realiziranom otisku*

	IH	IG	IE	IC	IA
Soft proof	3	3,7	3,6	4,1	4,1
Hard proof	4	3,6	1,7	2	3

In respect to this work, Apple studio display was used as a soft proof device, Application support: Adobe CS, Epson Stylus Studio Pro 3800 with ultrachrome K3 inks, Mediaware pearl gloss super 200 g substrate, as a hard proof output device, profile: Eurostandard coated, where measurements were made with the x-rite i-one spectrophotometer (45/0 geometry, D50, 2° observer) including x-rite Colorshop program application support.

3 Discussion and conclusions
Rasprava i zaključci

As colour printing is common in graphic reproduction, basic primaries are not only responsible for variety of hues, they also modulate lightness of tones and colours. While converting the image to printing system, corresponding CMY values that build tertiary (including both gray and neutral) tones, can be substituted with black. Coverages and tone value increase (dot gain) as a present variable, [20] on colour separations were not determined, predicted ones from soft proof were considered. As shown in tables 1 and 4 the soft proof preferred values do not differ much from the hard proof ones, and soft proof can serve for verifying the hard proof in the case of adjusted profiles used.

If observed the reduction rate (Tab. 1 and 4 row), applied black content is more than 50 % K coverage, what exceed 50 % reduction of possible calculated rate. When total coverage decreases under 200, lightness as well density are beginning to change. Similar decrease is for combination CMY 50-40-40 (Tab. 2 and Tab. 5), that happens at 30 % K coverage, and for CMY 30-20-20 coverage combination (Tab. 3 and Tab. 6) after 10 % K coverage. Within this range and for the supposed profile these reductions are acceptable, that can be seen from ΔE differences, could be treated as satisfying, (some authors are sometimes suggesting modification of standard colorimetric difference figures, [21] (Tab. 7). According to the obtained data (for the supposed profile) it can be determined that for more than 50 % reduction, or more than approximately 25 % total coverage decrease, differences occur. The substitution of the achromatic part with black (Fig. 7) is only conditionally linear by lower amount, what interprets density and/or lightness changes by higher reductions.

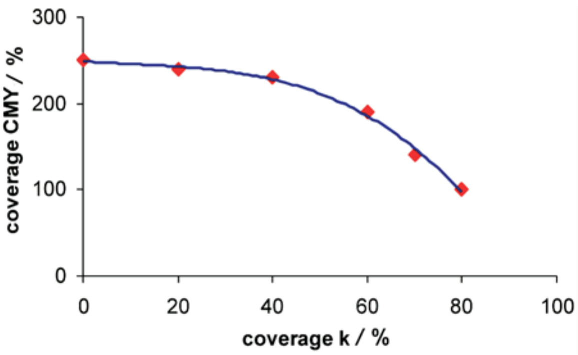

***Figure** 7 Dependence of CMY coverage to K coverage by reduction*
***Slika** 7. Ovisnost pokrivenosti CMY i K pokrivenosti kod redukcije*

Also, a proximate shape of the K tone curve could be suggested (from 3 observed points of attuned A-B-M system) for the B point as 70 to 80 coverage (depending on tone increase), mid point of 30-40 coverage, foot value 20 coverage, starting between A and B point, what depends on the decision of the skeleton black foot range.

It should be stated that achromatic way of reproduction has many benefits, but has to be controlled and adjusted for the specified system or device profile. Achromatic reduction can be applied for all tertiary colours, although, if manifested high reduction values (Tab. 4, rows E, C, A and Tab. 5 rows B and A), the influence of black can be perceived on chromaticity loss. This will be observed in additional studies of reproduction of various tertiary colour hues. Consideration of colour gamut [22, 23] and gamut volume is suggested in management and estimating of achromatic reproductions [24].

For most standard images basic profiles can be used, but for special aims and custom purposes additional tests and tunings have to be performed intending to get better, adjusted or specialized reproduction result.

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