Journal of Imaging Science and Technology® 54(1): 010502–010502-9, 2010.

Image Reproduction for Near Infrared Spectrum and the Infraredesign Theory

Klaudio Pap and Ivana Žiljak
Department of Computer Graphics, Faculty of Graphic Arts, University of Zagreb, Getaldićeva 2, 10000 Zagreb, Croatia
E-mail: klaudio.pap@zg.t-com.hr

Jana Žiljak Vujić
Polytechnic of Informatics and Design, Vrbik 8, 10000 Zagreb, Croatia

Abstract. *This article presents results of a study of color separation for the near infrared wavelength area in case of a double image reproduction. One image is observed in the visible spectrum and another one is detected under near infrared (NIR) light. For the purpose of NIR separation (CMYKIR), discussion is extended to CMYK working space as a device dependent on comparing several printing technologies. CMYK process inks characteristics enable visualization of the same color tone in default color settings with the goal to create two independent images in the same print; two independent pieces of information recognizable under two different types of lighting. The new approach to image reproduction is based on the idea of controlling and processing several images incorporated into one reproduction. This article unites five principles which are set for processing near infrared image reproduction: the range of CMY into CMYK transformation, CMY invisibility in near infrared light, carbon black in NIR, gray and CMY gray, and device dependency of CMYK inks. The reproduction is observed selectively in wavelengths ranging from 400 to 1000 nm. Independent graphics may be graphics generated by algorithms, conventional images or texts. Information about its visible area is joined to each graphic. Detecting graphic work incorporated differently in a print with the help of the corresponding instruments is becoming a new chapter in security graphics, design, and informatics. © 2010 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.2010.54.1.010502]

INTRODUCTION

In security documents the IR effect usually appears in one color.[1] It is either dark gray, dark brown, or in most cases the green color. The graphic is usually separated into two elements. It may be also left integrated for the purpose of IR detection. Such a color is printed as a dedicated spot color by the overprinting or underprinting method. There are steganographics techniques that do not use special spot colors based on the cryptographic methods[2] or the pixel values differencing method.[3] Security printing in digital printing technologies requires development of methods allowing the brand owner to select the best printing technology for the security printing deterrents[4] or, alternatively, standard xerographic material for infrared encoding of security elements is used, according to the defined tone and a set of process xerographic colors, i.e., infrared marks.[5] This article depicts a steganographic method using infrared detection for unlimited number of colors and various printing techniques with process CMYK colors. The goal is to merge a multicolored image with the assigned infrared image along the entire possible color range. This article presents a further development of our CMYKIR separation.[6,7] It puts forward the method of mixing process CMYK inks in order to achieve that the same color tone both responds and does not respond under NIR light.

The authors introduce terms, ideas and their meanings. Observing "near infrared (NIR) graphics" or "infrared material" means to see them with the help of instruments that detect inks in wavelengths higher than 700 nm. "Near infrared information" is a part of the graphic observed as isolated in the NIR area. "Hidden information" is a graphic that cannot be detected in the visible spectrum (VS) but may be detected under NIR light. CMYKIR separation is separation with the goal to provoke recognition of planned images separately in the VS and NIR areas.

The input data for our CMYKIR separation are two graphics. The first graphic is joined with information that will be observed in the VS; VS image. The second graphic is meant to be observed under NIR only, and it has the role of a "mask;" NIR image. The print is a single four color reproduction. Two graphics are detected at the output as two images that are observed under two different sets of conditions. The original protected graphic visible under wavelengths observed by the human eye is separated from the second image on basis of information from the second graphic, referred to as the mask that determines the intensity of the response in the near infrared area. Both graphics may be a picture, drawing, abstract graphic, algorithm-determined mixing of inks, or an abstract graphic on basis of information from numerical, textual, or image data. A programmed graphic enables print individualization with infrared protection. Each sample may have its serial number, an individualized portrait or and individual graphic element layout.

Received May 7, 2009; accepted for publication Sep. 16, 2009; published online Jan. 12, 2010.
1062-3701/2010/54(1)/010502/9/$20.00.

RESEARCH OF NIR INK PROPERTIES FOR SETTING THE INFRAREDESIGN METHOD

The initial point for CMYKIR ink designing research is pigment characteristics that behave in such a way as to respond differently under near infrared radiation. This difference enables dosing of the NIR effect and algorithm modeling in the targeted design of creating a double image. The area of NIR effect research spreads to all sorts of inks. The Projectina Docubox 500 detection system was used in the experimental testing phase. The effectiveness of the proposed Infraredesign method was verified also by the Projectina system. This system is based on the video camera with a spectral range of 350–1000 nm and a 250 W tungsten halogen lamp as a visible incident high intensity spot light source of electromagnetic radiation with barrier filters of 570, 610, 630, 645, 665, 695, 715, 780, 830, and 1000 nm for experimental filtering.[6] Barrier filters from 600 to 1000 nm were used in experimental scanning for experimental colors with several different responding states.

On basis of linear regression, equations have been determined for an extensive color range but also for a concrete printing job and printing technique. Gradient coefficients are derived from linear regression on basis of numerous print measurements. The detected value in the Projectina system depends on the manner of the registration of the IR effect (barrier filter), the way the reproduction material is processed (printing technology), and scanner characteristics (charge coupled device matrix 768×576).

The initial point for defining color NIR graphic is based on five printing ink properties. The first property is the possibility of replacing CMY printing inks with carbon black printing ink K while maintaining the same color tone in the visual area V. The second property is that some CMY printing inks do not respond under NIR light. The third property is that carbon black ink K is detected under IR light.[8] The fourth property is that two gray tones of the same color differ, one is derived from CMY with similar portions, and the second is pure black K printing ink. The fifth property of ink is based on the statement that CMYK printing inks are device dependent, and this means that a corresponding color setting must be made for each concrete application, ink type, and printing type.[9]

Replacing CMY Printing Inks with Carbon Black

The first property of inks, the replacing of CMY with K, has made way for great freedom in mixing printing inks in acquiring the same color tone. This great freedom is used in printing practice. In this sense there were various separation methods imposed historically having different goals, and thus, e.g., the gray-component replacement (GCR), under-color removal (UCR), and under-color addition (UCA) methods had been created. Certain discussions were led in respect to saving values linked with the total quantities of ink layering on paper, and improving image quality.[10] It is characteristic for all the mentioned methods that only one CMY for K replacement value is set. The same RGB values in all pixels of the overall image will carry out the transformation into CMYK in the same manner.

Contrary to this, the CMYKIR separation method implies the joining of K depending on the exterior information that may be brought from a special image individualized for each pixel. Therefore, this article covers and observes the whole area of possible RGB/CMY/CMYK replacements from $X=0$ to $X_{\max}$, i.e., from $K=0$ to maximum K for which the same values are maintained in the visual system V. The visual system V is defined through a set of parameters:

$$V = \begin{bmatrix} \mathrm{R} & \mathrm{H} & \mathrm{L} \\ \mathrm{G} & \mathrm{S} & \mathrm{a} \\ \mathrm{B} & \mathrm{B} & \mathrm{b} \end{bmatrix}, \qquad (1)$$

and the vectors

$$X_0 = \begin{bmatrix} C_0 \\ M_0 \\ Y_0 \\ K_0 = 0 \end{bmatrix}, \quad X_{\max} = \begin{bmatrix} C \\ M \\ Y \\ K_{\max} \end{bmatrix}, \qquad (2)$$

describing separation states in certain points depending on K. Assertions have been made for the same color tone X_0; $X_{\max}$: color tone X_0 does not respond in NIR, while $X_{\max}$ in case of the same color tone has a maximum response in the NIR area. The next chapter describes X_0 as the second property.

In case of for $K=$maximum at least one of the CMY values equals zero. For a K value higher than $K_{\max}$ the color tone changes. This is not the subject of discussion in this article. The NIR separation requires an analog relation of the overall area in order to maintain the same color tone. Graph (Figure 1) and relations in the form of square equations are given for the olive green and dark green color derived from linear regression on basis of print measurements printed on Xeikon digital printing machine (135 g, matt paper).

The V matrix and X_0 and $X_{\max}$ vectors for the olive green color are

$$V = \begin{bmatrix} 127 & 63^\circ & 53 \\ 130 & 47\% & -9 \\ 69 & 51\% & 36 \end{bmatrix}, \quad X_0 = \begin{bmatrix} 55 \\ 36 \\ 69 \\ 0 \end{bmatrix}, \quad X_{\max} = \begin{bmatrix} 24 \\ 0 \\ 60 \\ 57 \end{bmatrix}. \qquad (3)$$

Olive green goes up to 57% of K intensity at which point the value for magenta drops to zero. CMYKIR equations based on regression analysis of measuring colors after printing are

$$C_1 = -0.003\,03K^2 - 0.334\,35K + 54.179,$$

$$M_1 = -0.003\,54K^2 - 0.4203K + 35.856,$$

$$Y_1 = -0.000\,18K^2 - 0.1416K + 68.79. \qquad (4)$$

The V matrix and X_0 and $X_{\max}$ vectors for the dark green color are

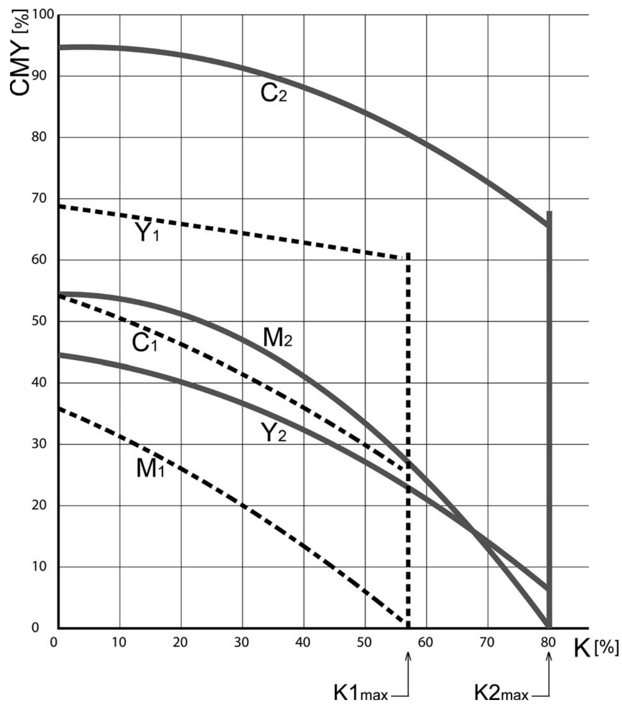


Figure 1. Dependency of CMY on K under the condition of maintaining the same values of both colors, the olive green ($C_1M_1Y_1$) and dark green ($C_2M_2Y_2$), in the visible part of the spectrum for mixing of the different respective values of the process colors in the Xeikon digital print.

$$V=\begin{bmatrix}49 & 198^\circ & 30\\ 78 & 46\% & -15\\ 90 & 35\% & -13\end{bmatrix},\quad X_0=\begin{bmatrix}95\\55\\45\\0\end{bmatrix},\quad X_{\max}=\begin{bmatrix}66\\0\\6\\80\end{bmatrix}. \tag{5}$$

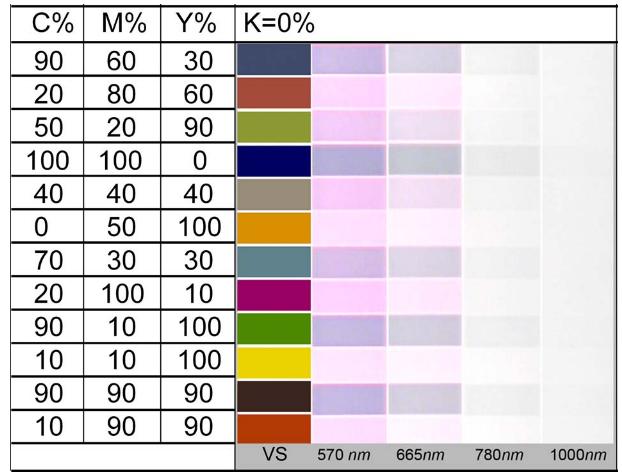
Dark green goes up to 80% of K intensity. This point was determined by magenta. It is characteristic for the majority of colors (not a general rule) that the ink having the lowest value at the beginning ($K=0$) is also the ink that drops to zero and that ink determines the maximum replacement of CMY with K. In case of the dark green color there is an exception. Magenta drops more quickly than yellow so there is a point of progress transition. The maximum value for CMY replacement with K was determined by magenta. Analog relations for the CMYKIR dark green color are as follows:

$$C_2=-0.005\,05K^2+0.039\,32K+94.66,$$

$$M_2=-0.0086K^2+0.009\,978K+54.436,$$

$$Y_2=-0.004\,34K^2-0.131\,15K+44.527. \tag{6}$$

The wide range of possible replacements of CMY with K is used in this article for introducing CMYKIR separation methods or shorter NIR separations. The goal is to enforce the appearance of independent graphics in the near infrared spectrum fully controlled and in coordination with our



C%	M%	Y%	K=0%
90	60	30	
20	80	60	
50	20	90	
100	100	0	
40	40	40	
0	50	100	
70	30	30	
20	100	10	
90	10	100	
10	10	100	
90	90	90	
10	90	90	
			VS 570 *nm* 665*nm* 780*nm* 1000*nm*

Figure 2. 12 colors not having a K component printed on the Xeikon digital printing machine and scanned at 570, 665, 780, and 1000 nm wavelengths in the Projectina system.

wishes: whether we wish to have or not to have the image recall in the NIR area.

CMY Printing Inks Not Responding Under NIR Light

The second property refers to CMY printing inks not responding under NIR light with a value under 1000 nm. Images of twelve randomly chosen colors not having the K component scanned under 570, 665, 780, and 100 nm wavelengths show that they do not have any characteristic for recognition and differentiation in wavelengths above 800 nm (Figure 2).

The ink response disappears in different ways because each component responds differently under NIR light. The colors that have a higher cyan intensity shift their instrumental value as far as up to 800 nm. This characteristic may be used differently in a design requiring a strong proof of a graphic's authenticity designed with the target NIR effect.

Carbon Black Ink is Detected Under NIR Light

The third Infraredesign characteristic is about carbon black ink K, detected under NIR light. The ink K has a unique characteristic of absorbing NIR light, and this is different if compared to other printing inks. That is why the authors state conditionally in this article that "our eyes recognize the ink K and see it under NIR light." Although this is done with the help of an instrument, the effect is used to divide the image into two parts. One part of the print can be detected and the other part of the print cannot be seen under NIR light. This characteristic is the most frequent problem when checking infrared separation. Many printing inks do not contain in their composition the characteristic necessary for recognizing the K component under NIR light. This especially applies to inkjet digital printing. In Xeikon digital print sample, the K component responds differently in comparison to expectations (Figure 3). The 10% intensity in the VS rises up to 40% under NIR light. Opposite to this, the intensity of 100% in the VS gains a maximum 70% under NIR light. A similar anomaly also applies a 1000 nm light that lets out lighter tones than the 700 nm light.

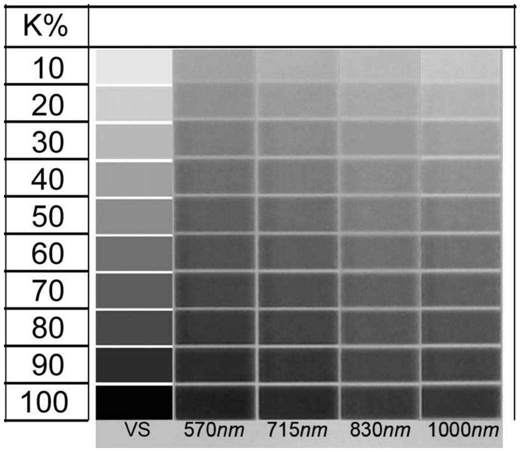


Figure 3. Gray levels printed on the Xeikon digital printing machine scanned with the Projectina IR camera with 570, 715, 830, and 1000 nm barrier filters.

Table I. CMYK values for six colors printed on Xeikon digital printing machine in three states: X_0; for K=0; $X_{50}$for K=50% of X_{max}, and values X_{max} for K_{max}.

	A1: RGB:115, 96, 33			A2: RGB:80, 113, 27		
	X_0%	$X_{50\%K}$%	X_{MAX}%	X_0%	$X_{50\%K}$%	X_{MAX}%
C	56	38	0	81	70	64
M	55	45	19	33	17	0
Y	92	87	76	96	95	95
K	0	37	74	0	25	49
	A3: RGB:168, 142, 6			A4: RGB:126, 22, 3		
	X_0%	$X_{50\%K}$%	X_{MAX}%	X_0%	$X_{50\%K}$%	X_{MAX}%
C	33	19	0	37	23	0
M	40	28	18	97	96	95
Y	96	96	95	92	91	88
K	0	23	45	0	24	47
	A5: RGB:54, 36, 92			A6: RGB:45, 100, 136		
	X_0%	$X_{50\%K}$%	X_{MAX}%	X_0%	$X_{50\%K}$%	X_{MAX}%
C	90	74	70	95	94	92
M	90	89	86	45	33	20
Y	25	12	0	20	12	0
K	0	18	35	0	21	42

The black ink component joined with CMY inks is observed with the transition from RGB to CMYK for six randomly chosen colors A1, A2, A3, A4, A5, and A6. Adobe RGB values are given in Table I. The transition to CMYK values depends on the color setting, due to the fact that CMYK inks are device dependent (discussion on the fifth property).

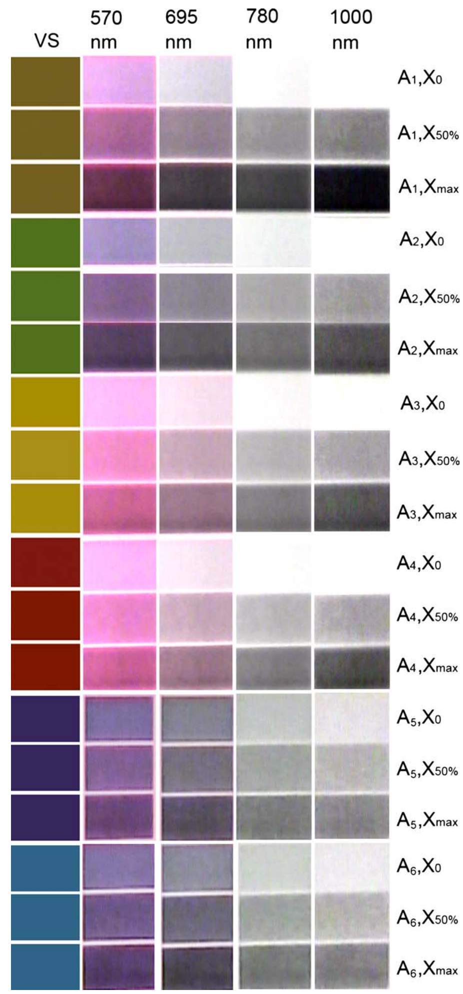


Figure 4. Near infrared scanning for 6 colors A1, A2, A3, A4, A5, and A6 depending on wavelength, printed on Xeikon digital printing machine.

In order to achieve NIR separation, a wide and continuous separation range is necessary. Table I shows CMYK values for six colors, each in three states: X_0, C_0, M_0, and Y_0 with $K=0$; values for $K=50\%$ of K_{max}, and values for CMYK at K_{max}.

Each color tone has been divided into three states and subjected to NIR light using wavelengths: 570, 695, 780, and 1000 nm (Figure 4). NIR scanning shows that the yellow component disappears as early as under 570 nm. Magenta also disappears under the 695 nm wavelength but cyan remains. Cyan is not detected at 780 nm. The intensity of carbon K black ink is proportional to its portion in individual color tones. The last line, 1000 nm, shows that K is darkest with the first A1 color due to the fact that its values are 74%. Neither of the tones in the X_0 ($K=0$) position have a response at 780 nm or 1000 nm. Standard separation for Xeikon digital printing with the author's color setting Xeikon4 will give only one separation point (Table II) for colors A1, A2, A3, A4, A5, and A6.

Infraredesign Gray Tone Characteristic

It is customary to say that a gray tone may be acquired with similar values of CMY components. Real three gray tones are

Table II. CMYK values for standard separation for Xeikon digital printing with one separation point for colors A1, A2, A3, A4, A5, and A6.

	A1	A2	A3	A4	A5	A6
C%	19	70	19	23	86	94
M%	31	16	28	96	89	33
Y%	79	95	96	91	18	11
K%	59	26	22	24	12	21

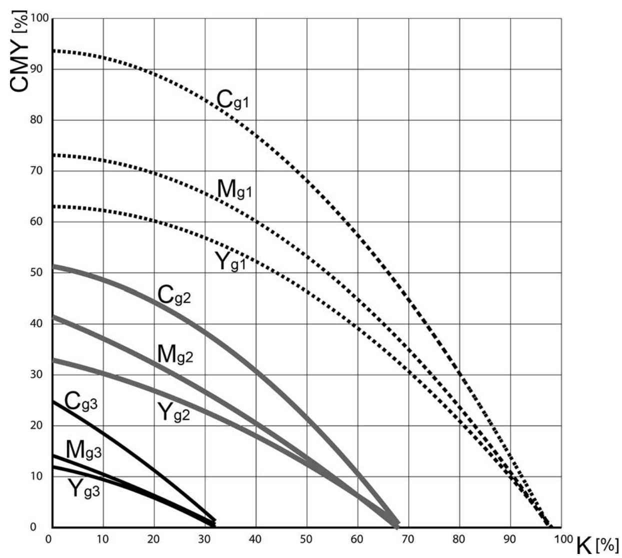


Figure 5. Three gray tones for color setting Xeikon 4 with decreased CMY inks and introduction of the *K* component.

shown (Figure 5) for color setting Xeikon4. There is a characteristic distribution of cyan, magenta, and yellow ink. Cyan is in all gray tones at higher intensity. The differences are enormous so there is no place for gray as an "equal value" of intensity. The difference of the cyan intensity in comparison to yellow is around 30%.

Theoretical expectations, as well as real inks have a common point in position $X_{\max}$. In that point the gray color results from the black ink *K* component only. NIR appearance is in correlation with *K* components. For some other wavelengths there would be a "cyan effect" observed up to 780 nm. Such characteristics may be used for determining a print's and reproduction's authenticity.[6]

Analytical relations are entered into the NIR separation program covering the area from $X=0$ to $X_{\max}$ for each gray tone. Relations have been determined on basis of regression analysis of print measurements and the dependency of CMY on *K* for three gray tones.

Relations for gray tone g1 are

$$C_{g1} = -0.009\,38K^2 - 0.0419K + 93.63,$$

$$M_{g1} = -0.007\,34K^2 - 0.0317K + 73.13,$$

$$Y_{g1} = -0.006\,41K^2 - 0.0134K + 63.03, \tag{7}$$

on basis of parameters:

$$V_1 = \begin{bmatrix} 60 & h & 24 \\ 60 & 0 & 0 \\ 60 & 24 & 0 \end{bmatrix}, \quad K_{1\max} = 97\%. \tag{8}$$

Relations for gray tone g2 are

$$C_{g2} = -0.008\,22K^2 - 0.1854K + 51.28,$$

$$M_{g2} = -0.003\,12K^2 - 0.3992K + 41.42,$$

$$Y_{g2} = -0.003\,57K^2 - 0.2308K + 32.93, \tag{9}$$

on basis of parameters:

$$V_2 = \begin{bmatrix} 131 & h & 55 \\ 131 & 0 & 0 \\ 131 & 51 & 0 \end{bmatrix}, \quad K_{1\max} = 68\%. \tag{10}$$

Relations for gray tone g3 are

$$C_{g3} = -0.004\,73K^2 - 0.5825K + 24.77,$$

$$M_{g3} = -0.002\,37K^2 - 0.3465K + 14.16,$$

$$Y_{g3} = -0.005\,36K^2 - 0.1985K + 11.94, \tag{11}$$

on basis of parameters:

$$V_3 = \begin{bmatrix} 200 & h & 81 \\ 200 & 0 & 0 \\ 200 & 79 & 0 \end{bmatrix}, \quad K_{3\max} = 32\%. \tag{12}$$

Device-dependent CMYK Inks and Generalized CMYKIR Separation

Image reproduction in the Infraredesign method respects its own characteristic of printing inks due to the fact that all real process inks are device dependent. In NIR separation this is very important especially when two neighboring pixels of the same color are separated with extremely different black component settings. If this issue is not approached with a precise algorithm adjusted for a concrete printing ink, in the VS our eyes will observe the difference of the color tone for two neighboring pixels.

Hiding an image within another image, and achieving the final goal of double separation is possible only if color setting parameters are calculated for a concrete printing technique. The enormous difference between the separation settings shows how important it is to understand the reality of the respective printing ink characteristics in real-life application. The public as well as the private color setting determine one point for the set color tone for which separation is to be carried out according to the GCR method and its parameters. This takes place for each tone separately, in each

Table III. Device dependent values for the brownish violet color (Adobe RGB: 146, 110, 83; Lab: 51, 17, 25; HSB: 26, 43, 57) for eight technology standards.

Adobe RGB=146, 110, 83; HSB=24, 43, 59; Lab=51, 18, 24	Device	Japan 2001 uncoated	Japan 2001 coated	Japan 2002 newspaper JNP	Fogra27 coated	Fogra39 coated, FoC	Xeikon X4	Fogra29 uncoated	U.S. seetfed uncoated
X0(K=0)	C0	33	45	40	45	45	38	28	37
	M0	50	62	68	61	61	55	60	57
	Y0	85	71	94	70	73	55	74	72
GCR, device dependent, gray gama2.2, dot gain 20%	C	28	44	29	36	29	22	30	23
	M	51	62	56	56	53	48	55	51
	Y	79	70	81	66	64	48	68	63
	K	8	1	11	14	24	31	12	16
Maksimum K	Cmax	0	0	0	0	0	0	0	0
	Mmax	35	41	34	43	42	41	41	43
	Ymax	53	49	48	54	54	40	54	49
	Kmax	40	48	36	45	46	52	39	38

color management setting. NIR separation does not use GCR of one separation point for the observed color but joins a whole range for K values to each color tone: from $K=0$ to K_{max}.

Discussion of CMYK device-dependent inks is aimed only toward the goal of the successful NIR separation. The discussion on the quality, faithful reproduction and image adequacy is important in order to obtain identical images in extreme (X_0 and X_{max}) NIR separation. Most of all it depends on the truthfulness of color setting measurement in the printing technology. The success in applying NIR separation depends essentially on respecting the device-dependent determination of CMYK ink mixing. NIR separation is also called “extreme separation” because it uses X_0 and X_{max} in the same document and all the values between them. NIR separation may lead towards the research of proving the adequate CMYK translation because it depends significantly on the printing device.

The name CMYKIR separation was given because its goal is to create two images and at the same time to take care on the device-dependent characteristic. The authors have tested the degree of the hidden image. The respective ink characteristics are very different within the same color tone in the V space. The great dependency on the device is shown (Table III) for eight different technology standards for the same color tone Adobe RGB: 146, 110, 83; Laboratory: 51, 17, 25; HSB: 26, 43, 57.

The values in rows named “device dependent” are the output values in the separation in the relation RGB/CMYK in conventional programs for certain device color settings. Those values are only one point in the NIR separation using the overall range of $K=0$ to $K=\mathrm{max}$ while maintaining the same color tone.

Figure 6 shows dependency of CMY on K for the device and the belonging color settings: FoC “Fogra39 coated” and JAP “Japan 2002 NewsPaper” for brownish violet color (Adobe RGB: 146, 110, 83; Lab: 51, 17, 25; HSB: 26, 43, 57).

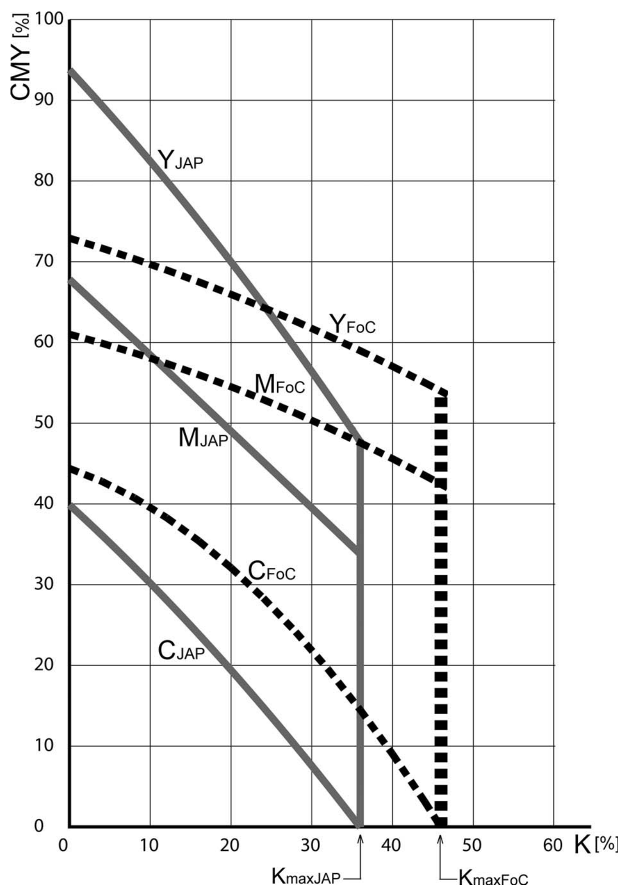


Figure 6. Dependency of CMY on K for printing and color settings FoC “Fogra39 coated” and JAP “Japan 2002 NewsPaper” for the brownish violet color (Adobe RGB: 146, 110, 83; Lab: 51, 17, 25 ; HSB: 26, 43, 57).

Associated analytical equations for brownish violet color are

$$C_{\mathrm{FoC}} = -0.01341K^2 - 0.3449K + 44.39,$$

$$M_{\mathrm{FoC}} = -0.003\,02K^2 - 0.2645K + 61.00,$$

$$Y_{\mathrm{FoC}} = -0.002\,46K^2 - 0.2986K + 72.91, \tag{13}$$

and

$$C_{\mathrm{JAP}} = -0.0053K^2 - 0.915\,12K + 39.88,$$

$$M_{\mathrm{JAP}} = -0.000\,33K^2 - 0.9335K + 67.81,$$

$$Y_{\mathrm{JAP}} = -0.005\,68K^2 - 1.0751K + 93.76. \tag{14}$$

In the experimental work the authors used generalized equations for CMYKIR separation applied in Xeikon digital printing with v2 standard toner on 135 g matte paper (color setting Xeikon4) with coefficients determined on basis of linear regression with 112 measuring points. This experimental relation applies only to the experimental framework of the narrow coloring area. It has been explained in the next chapter.

The equations are

$$K_1 = K_{\min}S, \tag{15}$$

where $K_{\min}$ is the minimum value of C_0, M_0, and Y_0 as starting values, and S is the gray intensity of the required stego image, and

$$K_2 = K_1 - 0.3K_1^2,$$

$$C = C_0 - K_2(-0.003\,32C_0 + 0.003\,404M_0 + 0.002\,106Y_0 + 0.486\,812), \tag{16}$$

$$M = M_0 - K_2(0.003\,524C_0 - 0.005\,09M_0 + 0.0014Y_0 + 0.420\,66),$$

$$Y = Y_0 - K_2(0.002\,168C_0 + 0.004\,019M_0 + 0.0014Y_0 - 0.00408),$$

$$K = K_2, \tag{17}$$

where C, M, Y, and K are final values of CMYKIR separation.

DISCUSSION ON LIMITATIONS OF THE QUALITY OF THE INFRAREDESIGN METHOD

Let us define the X_0 image without a K component that cannot be seen in the NIR area and the original steganographic image S_0 initiating the CMYKIR separation. The X image is a final reproduction image with a K component originating from intensity of the S_0 image. The steganographic S image has been built into the X picture as the K channel. It may be detected in the NIR area. It differs from the S_0 image since it depends on the carrier image X_0. Images S and S_0 are grayscale images. Images X_0 and X are equal for all pixels in the V area and that is the priority in separation. The graph (Figure 7) is used for discussion on limitations of the S image quality. Values C_0, M_0, and Y_0 have the position of $K=0$ so there is no response in the NIR area. Values $C_{\max}$, $M_{\max}$, and $Y_{\max}$ have the position with a maximal value of the carbon black ink. This value ($K=\max$) has the highest response in the NIR area for the V tone of each pixel. At least one of the values $C_{\max}$, $M_{\max}$, or $Y_{\max}$ equals zero.

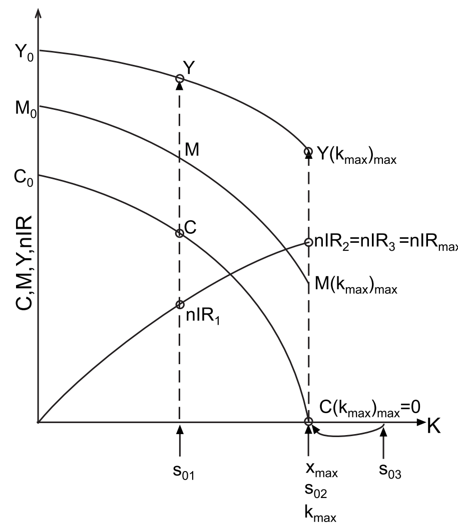


Figure 7. Graph of the limitation of the stego image in the Infraredesign method with qualitative correlation between the NIR intensity and carbon black process component K.

There are three possible states for each position of the i pixel in x_i and s_i in the X and S images. Three different pixels with the same V tone have been monitored in reference to three different correlations between the carrier image and the steganographic one. Values s_{01}, s_{02}, and s_{03} represent coverage values of three different pixels in the S_0 image. Values s_1, s_2, and s_3 are values of the K channel of the X image. Three possible states are

(a) $s_{01} < k_{\max}$; $s_1 = k$; all C, M, Y values exceed zero;
(b) $s_{02} = k_{\max}$; $s_2 = k_{\max}$; at least one C, M, Y value equals zero;
(c) $s_{03} > k_{\max}$; $s_3 = k_{\max}$; there is no complete change in the NIR picture.

In case of a and b, separation of utilization of the K component value has the maximum value possible. In case of c, the quality of the s_3 pixel must be given up. The intensity is smaller that the one assigned in s_{03}. The s_3 value should not be raised up to since it would result in the X image being different from the X_0 image in the V area. The tone color in the final reproduction would have been changed.

The worst scenario corresponds to cases when the intensity of one of the c_{oi}, m_{oi}, or y_{oi} component equals zero.

In this case s_{oi} equals zero as well. If abstract security graphic is foreseen, the recommendation is to choose the X_0 color tones with the minimal value of C_0, M_0, or Y_0 at least higher than 20%.

The graph shows NIR intensity depending on the carbon black process component as qualitative correlation. Each instrument interprets infrared light in its own numeric values (video camera, IR Projectina scanners). This led to developing procedures for coloring gray signals of IR pictures as pseudocolors. This article does not expand the discussion on these methods.

EXPERIMENTAL RESULTS

The effectiveness of the proposed Infraredesign method was verified by the Projectina system. Its central part is an infrared video camera operating in the 350–1000 nm range. A 250 W Wolphram halogen lamp was used as the source of electromagnetic radiation. Barrier filters of 570, 610, 630, 645, 665, 695, 715, 780, 830, and 1000 nm were used for experimental filtering during scanning procedure.

Besides the generally known color settings that are supplied with programs for separation, our color setting Xeikon 4 is used here and measured for the Xeikon digital printing most often used by the authors in experimenting with NIR double images. For the needs of NIR separation, color settings were set separately for Xeikon and digital ink jet HP5000 for printing on various types of paper and textiles. We have named these color settings as ⟨⟨private color settings⟩⟩. Due to the fact that NIR separations use the space from X_0 to $X_{\max}$ it is not possible to apply conventional procedures of transition from one color setting to another.

Double Information

Joining two images in extreme conditions is carried out after measurements of individual ink tones and for color setting space to be carried out by printing. Two pieces of information are the text and the image in the form of an abstract graphic (Figure 8). The first information is observed in the VS and the other one is detected under infrared light. Three colors A2, A3, and A4 from Fig. 4 have been used. The green color background A2 is given with the K printing ink maximum. The text “technology” is given as $K=0$. This is why the background green A2 is dark and the text is light. The same sequence is also given for the red A4 color. The background is given as $K=0$ for the brown A3 color in the middle row, and the text “DOUBLE IMAGE” is designed with a maximum carbon black ink. The difference between the background and the text is not observable in the VS. The information is completely hidden. Two graphics are separated with the help of filtering of selected wavelengths. The planned text and the background with extreme separation values are separated as two different images, two pieces of information in the same printed area.

The letters in A2 have a certain response in 665 nm in the cyan component. In this wavelength the background is visible in the A4 part of the color due to the greater share of magenta. Gradual raising of the wavelength length results in the total contrast of information as early as at 850 nm.

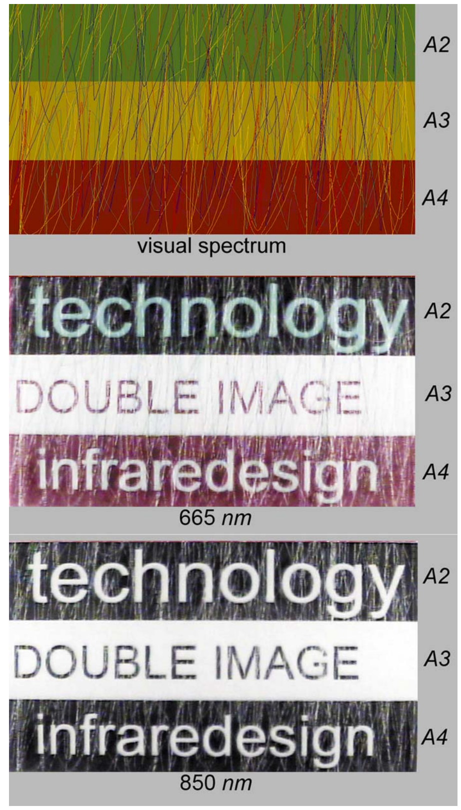


Figure 8. Abstract graphic with the text implemented in the background of the same tone with different infrared intensity values.

Double Images

A special program for NIR separation loaded with two images has been developed by the authors. The first color image uses all RGB tones. The second image is grayscale. The first image is the one to be seen as a reproduction in the VS even after NIR separation; the authors refer to it as the NIR image. The second image carries the information on carbon black ink K representation in the first image during the first image’s separation. The goal is to have a double characteristic for the NIR image. In the VS it is seen as the first image and under NIR light as the second image.

All device NIR interpretations have a certain amount of “artificial color” impression. In this respect tools have been developed for “pseudocolor” enabling special effects in studying NIR images. Only grayscale device interpretation is used in this work. The test is shown for joining images named as MachuPicchu and Stonehenge (MP and SH) (Figure 9). The double separation procedure for two independent images has two phases. The first phase is the transition of the first MP image from RGB into CMYK, referred to as “the zero separation state” X_0. The second step is the transition of $C_0M_0Y_0$ into CMYK with the goal of creating a CMYKIR record, referred to as “the X state.” The K component is dosed according to information from the second SH image; the mask describing the NIR graphic. The result is the double MP-IR/SH image shown in Fig. 9 as “visual spectrum.” With gradual filtering another image appears—the Stonehenge image. At 630 nm the yellow component is completely gone from the first image. At 715 nm magenta is

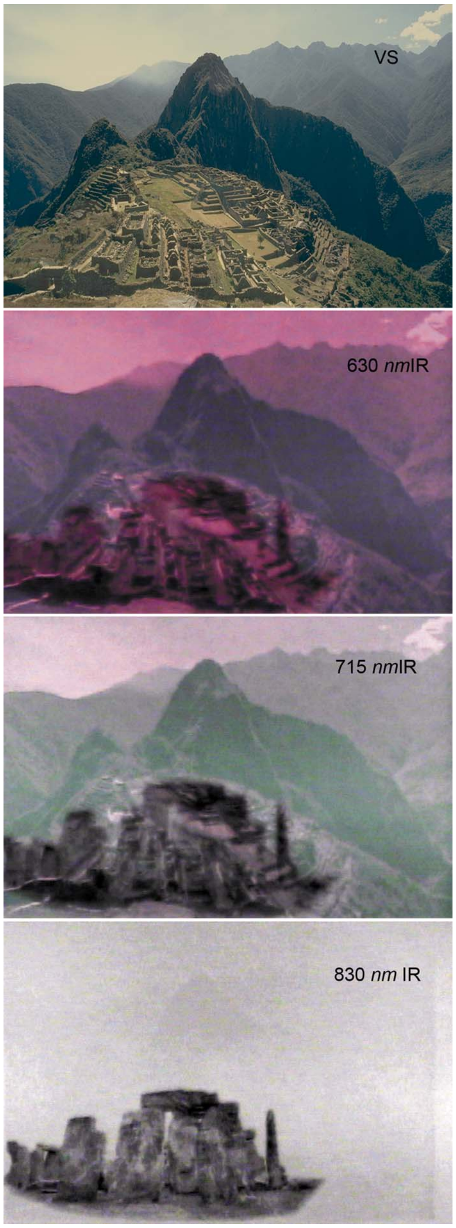


Figure 9. Result of double image separation of the original (Machu-Picchu) with the mask (Stonehenge) scanned at 630, 715, and 830 nm.

gone from the NIR image. The first MP image gradually disappears and at 1000 nm there is no information on it.

Double information is seen in the VS in the MP-IR image. The MP-IR image is not totally equivalent to the original MP image. The pixels in the MP image that had a lighter shade than the identically positioned pixels in the SH image have been carried out in the MP-IR image with a different intensity of the black color. This is manifested as white (light) borders in the NIR image (wall tops) that had not been present in the SH image. This may be considered as additional protection against "taking out" the double image from the MP-IR image SH image even in the case of a top quality scanner.

CONCLUSION

When responding under 400–1000 nm wavelength range, ink properties enable generating new technologies of imaging with double states. This goal required the introduction of new separation algorithms referred to as CMYKIR. Two images are integrated by the method of infrared separation and prepared for printing with the goal to be detected separately in different observation conditions. One image is seen in the visual spectrum and the other under near infrared light. This enables the presence of double information in the print, an image hidden within an image, and a new type of technology in image material security. CMYKIR separation is based on five ink properties including the response domains of individual printing inks and the device-dependent CMYK working space. The proposed double image technology may be applied and verified on various materials: paper, textiles, ceramics, and plastics. There is no limitation in the printout dimension, resolution or type of digital format. The original images may be pixel or vector graphics and graphics derived from algorithms with the source of information coming from databases. Such reproductions will present a progress in document and securities printing and provide a new type of designer expression. The security printing area becomes widely applicable. The overall new security imaging technology may be carried out completely only by using printing inks that are not marked as secret or banned. This article shows examples of application with the goal of opening new areas in imaging technology.

REFERENCES

[1] M. Yousaf and M. Lazzouni, "Formulation of a invisible infrared printing ink", Dyes Pigm. **27**, 297–303 (1995).
[2] Y. H. Yu, C. C. Chang, and I. C. Lin, "A new steganographic method for color and grayscale image hiding", Comput. Vis. Image Underst. **107**, 183–194 (2007).
[3] H. C. Lu, Y. P. Chu, and M. S. Hwang, "New steganographic method of pixel value differencing", J. Imaging Sci. Technol. **50**, 424–426 (2006).
[4] S. J. Simske, J. S. Aronoff, M. M. Sturgill, and G. Golodetz, "Security printing deterrents: A comparison of thermal ink jet, dry electrophotographic, and liquid electrophotographic printing: Art. No. 050201", J. Imaging Sci. Technol. **52**, 50201 (2008).
[5] R. Bala, R. Eschbach, and M. S. Maltz, "Infrared encoding of security elements using standard xerographic materials", US Patent 20,080,302,263 (2007).
[6] V. Žiljak, K. Pap, and I. Žiljak, "CMYKIR security graphics separation in the infrared area", Infrared Phys. Technol. **52**, 62–69 (2009).
[7] I. Žiljak, J. Ž. Vujić, and K. Pap, "Color control with dual separation for daylight and daylight/infrared light", *Advances in Printing and Media Technology* (Media and Graphic Arts Industries, 2008), Vol. XXXV, pp. 273–278.
[8] A. Vila, N. Ferrer, and J. F. Garcia, "Chemical composition of contemporary black printing inks based on infrared spectroscopy: Basic information for the characterization and discrimination of artistic prints", Anal. Chim. Acta **591**, 97–105 (2007).
[9] J. J. Mccann, "Color theory and color imaging systems: Past, present, and future", J. Imaging Sci. Technol. **42**, 70–78 (1998).
[10] Y. D. Chen, R. S. Berns, L. A. Taplin, and F. H. Imai, "Multi-ink color-separation algorithm improving image quality", J. Imaging Sci. Technol. **52**, 71 (2008).