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Security offset printing with twin colors by means of CMYF separation

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Abstract

A new method of security printing is introduced in this work, thus creating highly protected documents by ink management in three spectrally separated ranges. A numerical experimental color setting has been developed, considering ink properties in three wave ranges: 200–400 nm, 400–700 nm and 700–1 000 nm. Separation is carried out with process and spot inks, aiming at concealing the graphic in visible spectrum. Such a graphic can be recognized instrumentally in the ultraviolet (F) and infrared (Z) spectra. Extending the Infraredesign method, the ultraviolet spectrum is included through the properties of the dark brown UV ink, thus giving fluorescent green in UV spectrum, while the absorption value is 38 % for parameter Z in the NIR spectrum. A separate, third image is visible by the naked eye. By algorithmic mixing of F-ink, having absorption properties in UV and IR ranges, a unique solution for the security printing of documents and valuables is accomplished. CMYF method differs from the CMYKIR method, since the K ink does not have the same properties, while their Z factor is completely different under the same printing conditions. With this new method – CMYF separation – formulations and standards are set for determining the differences between the original and the forgery.

Keywords: security design, fluorescent ink, document protection, hidden graphics, spectrophotometry

1. Introduction

With the development of the printing technology, printing inks are varying depending on the application: offset printing (Kipphan, 2001), screen printing, digital printing. Current investigations of inks are oriented towards the graphics in the visible portion of the spectrum, which are described with three values: RGB, HSB or CIELAB). With the programming of the structure of graphic elements characteristics of the inks are utilized, thus creating new graphic protections (Schell, 2007). Suggested separation of images on the same print is a new approach of marking and recognizing of visual information by the means of printing technology.

IRD theory (Pap, Žiljak and Žiljak-Vujić, 2010) is based on the characteristic of process inks from the scale: cyan, magenta, yellow and black. C, M and Y inks do not absorb light over 740 nm, while carbon black ink (Pekarovicova and Pekarovic, 2009), besides visible light, absorbs also NIR emission, which is in the range over 740 nm.

In this investigation black process ink is replaced with the visible dark brown UV fluorescent ink (F ink), which has response in three different spectral portions: ultraviolet (UV), visible (Vis) and near infrared (NIR). The novelty is in the investigation of offset printing inks, by which multiple images could be obtained, with the response in the UV, Vis and NIR spectral ranges. After experimental determination of color setting for spot UV and IR inks (Yousaf and Lazzouni, 1995), an ink is developed, which will serve as a hidden protection in two spectra outside the visible area. Such an ink enables indefinite number of methods for the protection of documents (Nickell, 2005). Each following print run of the protected document can have another authorized security design. By the CMYF separation, through the properties of the F ink, the separation is extended to UV, Vis and NIR range.

The objective of this research is production of highly protected document in offset printing, by managing inks in three spectrally separate ranges. With algorithmic mixing of UV and IR inks, an unique graphic solution is obtained for security printing of the protected documents. Within this, a graphic is planned with three different information, deliberately created in one image for the three different spectral ranges. The CMYF method was carried out with offset printing inks with the aim of planning, concealing and detecting of information in the areas outside the visible spectrum.

2. Materials and equipment used

The following materials, equipment and instruments were used in carrying out the experiments and measurements:

- Offset process inks: Huber Rapid Cyan, Magenta, Yellow and Black; Petrel – Black fluo green offset ink 05011
- Offset printing press: Heidelberg Speedmaster 74
- Platesetter: Agfa Excalibur 45
- Plates: Agfa Thermostar P970 positive thermal plates
- Papers: protected Mould 95 g/m^2 chemically reactivated, with watermark and fluorescent fibers, and art paper 115 g/m^2.
- Devices: Scanner for barrier scanning Projectina Docubox Forensic System PIA 6000/Multispectral Imaging Module; Spectrophotometer X-Rite SpectroEye; densitometer; register of colors, grey step wedge.

3. Experimental

In offset security printing, protective inks that are used the most are invisible fluorescent UV inks, which do not have the property of infrared adsorption, and their Z value (Žiljak, Pap and Žiljak Stanimirović, 2012) is zero (Z = 0). Here, process cyan, magenta and yellow inks are related to the ink F, which has the value of Z = 87 %. A controlled separation is carried out in UV an NIR spectra, by means of which the CMYKIR method (Žiljak, Pap and Žiljak, 2010) is extended to the CMYF method. All experiments and testings are performed under the conditions of real printing; therefore, the results of barrier scanning can be applied in different products (for example official forms, valuables, ID documents).

Concealment of the elements is obtained by CMYF separation, based on the continuous space of substitution of CMY and F. A series of 11 experiments were carried out in order to obtain correct formulations of color values. As a result, instead of an image visible in NIR spectrum only, a concealed image is attained, visible in UV as well as in NIR range. For accomplishing the described steganography, it was necessary to find an appropriate offset ink, having the response both in UV and NIR spectra. Concealed images will be better visible in UV and in NIR spectra if they contain greater share of F ink and lower share of CMY components and vice versa; if there is no F component present, the image will not be visible neither in UV nor in NIR spectra. All colors in the visible range are described with the following standards: CIELAB; RGB (Red, Green, Blue); HSB (Hue, Saturation, Brightness).

F/Z graphic, containing CMYF offset inks, is concealed in the color tone created from CMY inks. A new ink scale for offset printing is determined by multiple testings. CIELAB color space is used for the analysis of the measured results, adapting and mixing of inks for offset printing. Graphics concealed in UV and IR spectra are detected by instrumental barrier scanning. Separation solutions for three different spectral ranges are made with an indefinite number of color tones. Process inks are ensuring the basis for setting of the algorithm for the concealment of the graphic in UV and NIR spectra. NIR spectral ranges in highly protected printed document. For the determination of the value of offset ink F, the full tone of 100 % was printed on different printing substrates: protected Mould 95 g/m^2 and art paper 115 g/m^2. The obtained values of prints were measured by X-Rite SpectroEye spectrophotometer. For the applied spectrophotometer, the requirements of colorimetric calculations were examined by using illuminant D50, with 2° standard observer.

A visible dark brown UV ink is used in the experiments, which – exposed to the UV radiation – gives fluorescence in green color. With this fluorescent offset UV ink (F), a CMYF separation with IR properties was obtained. The aim is getting an image which will be visible in UV and an image visible in IR range, respectively. Both images are given by F ink with Z value. These two images are geometrically equal, but UV image is fluorescent green and reveals under UV emission, while IR image is grey and revealed under IR emission.

4. Results and conclusions

4.1 The F ink

New fluorescent color is different than the one that can be seen by the naked eye. F ink printed on the paper is dark brown in the visible spectral range, but exposed to wavelength of 365 nm it is fluorescenting in green.

This ink has also the property of infrared absorption with the value Z = 0.87. Prints with F ink have different values in CIELAB color space, depending on the type of paper they are printed on (Table 1).

4.2 ΔE^*_{ab} and iterations

All measurable properties of colors are accommodated to the CIELAB color space, with the aim of concealing the image in ultraviolet and near infrared range. Offset test prints were made with 32 different colors (Figure 1).

Table 1: Values of the F ink full tone prints (100 %) on different printing substrates

Offset Ink	Printing substrates	CIELAB			Z original [%]	Color Settings
		Min.	Max.	Avg.		
The F ink	Mould protected 95 g/m^2	42,62 0,10 8,39	46,05 0,48 9,84	44,83 0,30 9,08	87	RGB: 109, 106, 92
	Sihl protected 95 g/m^2	41,69 −0,37 7,51	43,97 0,1 8,59	42,92 −0,26 8,12	87	RGB: 106, 101, 88
	Art paper 115 g/m^2	36,24 0,39 12,24	38,21 0,60 12,91	36,98 0,44 12,50	85	RGB: 93, 87, 66
	Offset white 100 g/m^2	36,64 −0,48 5,56	38,96 −0,23 6,07	37,86 −0,34 5,82	87	RGB: 93, 89, 80

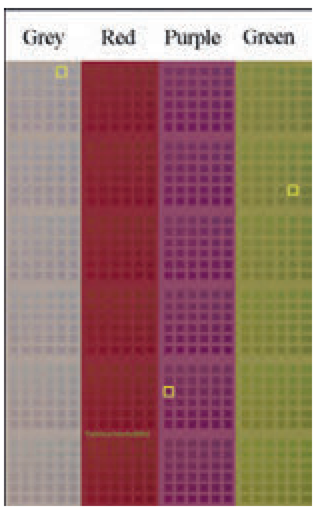


Figure 1: Four CMY colors with 216 combinations of CMYF color tones each (Iteration 3)

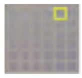
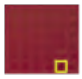
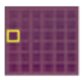
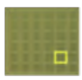
The experiments have had three iterations with a shift in the value of each particular color of 4 %, 3 %, 2 % and 1 % in the steps of the closest six positions. Each color tone in every iteration has six groups of 36 samples (squares, fields), thus obtaining 216 near-by tones (6 × 6 = 36; 36 × 6 = 216). Only one of these tones with the lowest ΔE^*_{ab} entered the following phase of the experiment, as placed in the centre of 216 fields. Each field of color tone (hereinafter referred as to sample) has different CMYF value, so that the change of 1 % in one of the three process colors marks the shift to the first next sample. For the first tests ΔE^*_{ab} was measured between 32 basic colors which were printed on the substrate (CMY, F = 0) and 216 deduced combinations of the tone of this basic color (CMYF, F = 40). For further experiments, samples of color tones were taken, which had the lowest values of color difference, ΔE^*_{ab}. From these samples of color tones a new setting for printing was created. Each of the chosen samples with the lowest ΔE^*_{ab} was placed in the centre of the group to which it belongs and from there other samples were derived with the lowest alteration of CMYF values. The experiment was over when ΔE^*_{ab} was established as lower than 2. It was shown that the ideal tone is different for prints on art paper, offset and protected papers, so that the same ink had different CIELAB values when changing the printing substrate (Table 1). CIELAB values, with which the printing has started, were only the source, while the differences occurred due to the behavior of the ink on different papers. Each of the material elements – ink and paper – brings additional variations in definitions.

4.3 Twin colors

Twin colors were defined by experimental methods, while the formulations were determined by the type of paper, type of ink and the printing technology. From the calculated and measured colorimetric values of process inks, cyan, magenta and yellow – which do not contain F ink – a color tone of F = 0 ink was created, while twin ink F = 40 has in its composition a pre-defined value of the F ink. In the visual range of the spectrum twin inks are completely covering one another, while the determined color difference ΔE^*_{ab} is bellow 2.

Table 2 shows dot areas of colors which are matching the conditions for “twin colors”, with $\Delta E^*_{ab} < 2$. It was printed in offset technique on the protected paper Mould with CMYF inks. Copies are first visually observed, so that the congruence between the color tones was determined by the bare eye. After visual identification of the twin colors on the printed copy, five series of measurements were carried out with the spectrophotometer in order to determine the average value of ΔE^*_{ab}. Column with red figures does not show visual congruence of color tones. The lowest determined value in congruence of red color is 7.95.

Table 2: Compositions with determined color differences ΔE^*_{ab} < 2 for grey, red, purple and green

Color	Color samples	F = 0; CMY	F = 40; CMYF	ΔE^*_{ab}
Grey		33, 33, 33	6, 6, 0, 40	0.25
Red		43, 95, 90	15, 92, 70, 40	7.95
Purple		44, 81, 42	22, 81, 12, 40	1.95
Green		41, 39, 86	25, 17, 78, 40	0.62

Graphic images with twin colors are produced, hiding within an image which is revealed by barrier scanning. In ultraviolet range at the wavelength of 365 nm an image is revealed, glowing in green, while in the near infrared range at the wavelength of 1 000 nm, BW image is exposed in all tones of the grayscale. These two images are presenting the same concealed object, which is revealed under different emissions of radiation.

New standards are developed in the protection of documents, which are manifested through the new methods of mixing CMYF inks, with the response in UV, Vis and NIR spectra. The application of CMYF is aimed at security printing, which is thus entering a new area, expanding graphic security systems within enhanced graphic technology. Management of the offset inks is extended with two opposite invisible spectral ranges, aiming at the creation of a new technology of security printing. Forgeries can be recognized by barrier scanning. New color scales are created, as well as new color settings for offset process inks, for the F ink and for the protected paper.

4.4 CMYF separation

With the replacement of carbon black from the CMYK scale with the dark brown UV fluorescent green (F ink), during the first tests the obtained results have shown significant alteration in color differences (ΔE^*_{ab}) between CMY (F = 0) and CMYF (F = 40) color tones. Great differences have been established between CMYKIR (Žiljak, Pap and Žiljak, 2009) and CMYF separations. Due to high preciseness required for the concealing of images, a high number of tests were carried out. Tests were performed by offset printing on a Heidelberg Speedmaster 74. The third iteration was printed on the protected paper Mould 95 g/m^2, where the value of the F ink is CIELAB = 45, 0, 9. Samples were selected from CMYF with the lowest color difference ΔE^*_{ab} in comparison to the stable CMY printed on the substrate. From these selected color tone samples with F/Z graphics have been created by mathematical simulation. In this way, two identical color tones were created, which are identical in the visual system, having previously determined UV and IR values. All CMYF color samples contain exactly 40 % of the F ink, so that colorimetric value can be precisely determined. The fixed value of 40 % was set because all the following experiments were carried out with other UV inks, having the IR effect. It was shown that such two inks could be mixed in an indefinite number of combinations with cyan, magenta and yellow, thus giving new color tones.

4.5 State F_{40} and F_0

The aim is obtaining the same color tone from the CMY and CMYF inks. For 216 combinations of CMYF color samples (hereinafter referred to as State F_{40}), which are placed in the square fields on the substrate of the basic CMY color (hereinafter referred to as State F_0), visual compliance is looked for. This way, 19 corresponding color samples were obtained, i.e. 19 twin colors. The CMY system is used as a base for creating the formulation, because the determined values of cyan, magenta and yellow "control" color are constant, while each field has different composition of CMYF. CIELAB values are determined on prints by a spectrophotometer. State F_{40} and State F_0 are experimentally equalized. Color setting for the papers and inks used in this research does not exist, but visual equalization of State F = 40 (F_{40}) with State F = 0 (F_0) was determined with a sequence of multiple tests.

State F_0 is invisible under the influence of the near infrared spectrum of wavelength of 1 000 nm and there is no reflection or response in the ultraviolet part of 365 nm (Table 3). State F_{40} has a specific response in both, UV and NIR spectra. Under the ultraviolet emission it transits into green, while aroused with IR radiation it converts into grey.

Table 3: State F_{40} and F_0 for selected samples of grey, purple and green color tone

Color	State of ink	Color value	Max. Z values [%]	λ = 1000 nm	λ = 365 nm
Grey	State F_{40}	$C_6M_6Y_0F_{40}$	38 %	Grey	Fluorescents green
	State F_0	$C_{33}M_{33}Y_{33}$	0 %	Invisible	No effect of fluorescence
Purple	State F_{40}	$C_{22}M_{81}Y_{12}F_{40}$	38 %	Grey	Fluorescents green
	State F_0	$C_{44}M_{81}Y_{42}$	0 %	Invisible	No effect of fluorescence
Green	State F_{40}	$C_{25}M_{17}Y_{78}F_{40}$	38 %	Grey	Fluorescents green
	State F_0	$C_{41}M_{39}Y_{86}$	0 %	Invisible	No effect of fluorescence

Figure 2.1: Pine color

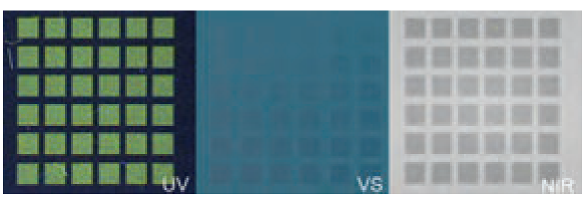


Figure 2.2: Turquoise color

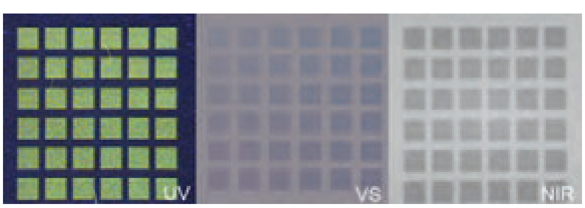


Figure 2.3: Light Grey color

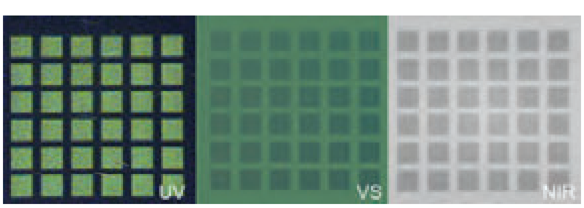


Figure 2.4: Green color

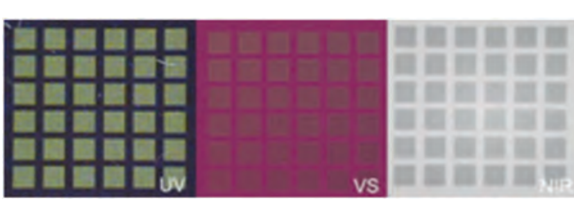


Figure 2.5: Chestnut color

By means of the barrier scanner, selected color samples (fields), for which the lowest ΔE^*_{ab} was determined, were scanned with the wavelengths of 365 and 1 000 nm. For all color tones of the sample F_{40}, the color value is 40 %. Fluorescent green tones (after being exposed to UV radiation), are different for all colors. As the differences in colors are higher, that higher is the difference in the fluorescent green tones of the selected samples. Differences in tone samples of the fluorescent green, scanned with the wavelength of 365 nm, are clearly eye-visible (Figures 2.1 to 2.5). An example for this are the differences between the color Pine (Figure 2.1) and color Light Grey (Figure 2.3). Pine color (Figure 2.1), $F_{40} = C_{67}M_{59}Y_{65}F_{40}$, scanned with wavelength of 365 nm, gives CIELAB: 50, −16, 26, while Light Grey color (Figure 2.3), $F_{40} = C_{28}M_{16}Y_0F_{40}$, scanned with the same wavelength, has CIELAB: 66, −21, 35. The same samples, scanned with the wavelength of 1 000 nm, do not show difference in color tones. The Z factor is therefore the same for all samples and equals to 38 % (Table 4).

4.6 F/Z graphics

The aim is the concealment of the graphic when observed by the naked eye. F/Z graphic can be recognized instrumentally in the UV range with the wavelength of 365 nm (F state) and in NIR range with the wavelength of 1 000 nm (Z value of the color matter). Two different graphics are mutually linked and printed within the same form. The visibilities in UV and NIR portion are not equal, but depend on the wavelengths of the barrier settings of the respective scanner. The influence of CMY process inks is completely eradicated at 1 000 nm.

The color tone is understood as an experience of color in the visible spectrum, when observed by the naked eye. The environment of UV graphic is obtained with cyan, magenta and yellow, which do not have UV characteristics. In this way, the UV graphic is independently concealed in the visible spectrum. CMY inks can form an independent single color or multi-color graphic in the visible spectrum.

Table 4: Values of selected fields scanned with λ = 365 nm and λ = 1000 nm

Num.	Color	λ = 365 nm		λ = 1000 nm
		CIELAB	RGB	Z [%]
1.	Pine	50, −16, 26	111, 126, 79	38
2.	State Turquoise	56, −28, 30	113, 146, 84	38
3.	Light Grey	66, −21, 35	148, 169, 99	38
4.	Green	61, −30, 35	124, 160, 88	38
5.	Chestnut	52, −8, 21	122, 126, 89	38

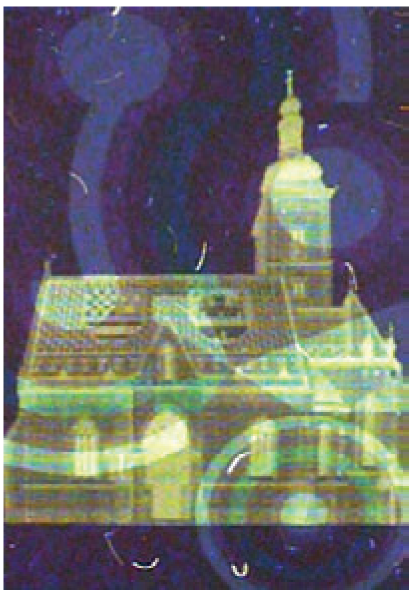


Figure 3.1: Target projected image of the church, hidden in the graphic and detected in the UV spectrum of 365 nm

Figure 3.2: Target projected image of the church, hidden in the graphic and detected in the NIR spectrum of 1000 nm

An effect was discovered on the influence of CMY components on the F ink. This breaking through of color tones from the image under the wavelength of 365 nm is caused by different layers of process inks (Figure 3.1). When observing the image at infrared range of 1 000 nm, this effect cannot be noticed (Figure 3.2), but at a wavelength of 780 nm cyan (Figure 4) has such an influence, which is at this wavelength visible together with IR color. Particular quantities of CMY are acting differently on the response of F ink at 365 nm, so certain parts of the image are darker or lighter, although the F factor is the same (38 %). Due to that, F/Z graphics are not of the same contrast in UV and IR range.

Figure 3.3: Scanned copy of an abstract graphic, which in itself contains a hidden image of a church with the content of coloransts in UV, Vis and NIR range, Vis scan from 400 to 700 nm

The abstract graphic (Figure 3.3) is typical in document protection. IR spectrum clearly describes the graphic (Figure 3.2), while in the UV spectrum it depends on the share of CMY inks (Figure 3.1).

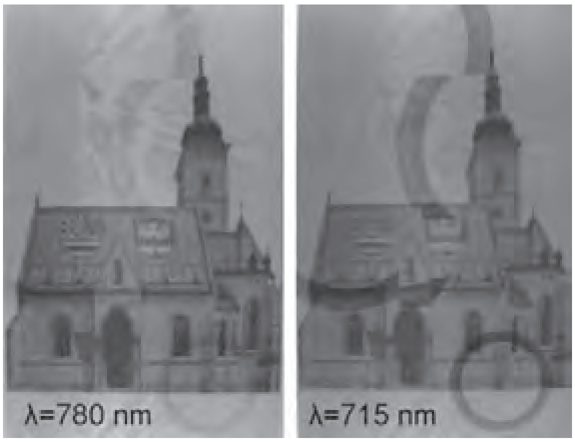


Figure 4: Influence of cyan, NIR 780 nm and 715 nm

Using computer graphic, two photos were processed and merged into one image (Figure 5). The graphics are mutually concealing each other. Related to the mixing of CMY process inks, the concealed image in UV space is modulated and on particular areas has lower or higher response, although the F component is always 40%.

Figure 5: Channels of cyan, magenta, yellow and F.

5. Conclusions

CMYF method enables concealment of the image and its recognition in UV and NIR range. The application of CMYF is referred to the security printing, which is entering a new area, expanding security systems within the graphic technology. New standards are developed in the protection of documents, which are manifested through new methods of mixing CMYF inks, with the response in UV, Vis and NIR spectra. Management of the offset inks is extended with two opposite invisible spectral ranges, aiming at the creation of a new technology of security printing. Forgeries can be recognized by barrier scanning. New color scales are created, as well as new color settings for offset process inks, for the F ink and for the protected paper. Although CMY inks are used, in the final industrial application it will be a mixture of these inks according to the specific formulation, which will be available as one single spot color. This color – with the built-in characteristics of process inks – is used when calculating the values within the known CMY system.

When creating an image in image, the designer should elaborate planning of the F/Z graphic with the Vis content, taking into consideration which technology is enabling the F/Z graphic. The education of designers is therefore necessary in application of such protection. If authorized types of screening are also included in the protected graphic, it would result with a highly protected document, which is impossible to reiterate. Technical standardization is clearly essential as a technical application or ready-made technical matrix. In designing the F/Z protection, the way and technology of the F ink application are strictly related to the color coordinates of the CIELAB color space.

Although the standardization of the criteria under which the application of the F/Z protection will be designed is important, equally essential is the standardization of the criteria by which something will give the status of necessary protection. In technical standardization of the F/Z methods of protection, it is therefore crucial to answer the following questions: how to apply, where to apply and what to apply. So, when adopting the standardization criteria and with every new design of a document, the following is established: formulations of colors and inks, concealed contents, visible contents, type of printing substrate and production technology.

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