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INFRARED STEGANOGRAPHY WITH INDIVIDUAL SCREENING SHAPES APPLIED TO POSTAGE STAMPS WITH SECURITY FEATURES

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Original scientific paper
Designing a postage stamp requires positioning of graphic security elements in a limited small format, so the design is made for two states: for the visible spectrum and the infrared spectrum. Individual screening elements are introduced as security elements in the steganography of invisible pictures in the 700 to 1000 nm spectrum. The CMYKIR theory of hiding the infrared message in the picture is extended by mixing process inks with the control of spot twins of the same colour tone in the X_0 and X_{40} states. Two pictures are integrated in the security print; a multicolour picture visible to the naked eye, and another hidden picture visible when illuminated with an IR detecting instrument. The CMYKIR method is joined with the new element's algorithm used for dispersing of the hidden picture's ("Z picture's") fringes. This kind of steganography is applied in the design of postage stamps and it is a new way of securing them.

Keywords: *CMYKIR separation; individual screen element; infrared design; postage stamps with security features; steganography*

Steganografija na poštanskoj marci s infracrvenim individualiziranim rasterskim oblicima

Izvorni znanstveni članak
Dizajn poštanske marke zahtijeva smještanje grafičkih i zaštitnih elemenata u ograničen mali format pri čemu ni jedan od elemenata ne smije biti zapostavljen. Uvode se individualni rasterski oblici kao element zaštite u steganografiji dvostrukih slika u proširenom vizualnom i infracrvenom spektru od 700 do 1000 nm. Proširuje se CMYKIR teorija skrivanja infracrvene poruke u slici miješanjem procesnih bojila uz kontrolu spot blizanaca tonova u stanju X_0 te X_{40}. U sigurnosnom otisku su integrirane dvije slike, višebojna slika vidljiva golim okom, te druga skrivena slika vidljiva aparaturom za infracrveni spektar. CMYKIR metodi pridružuje se algoritam novog rasterskog elementa, koji služi za raspršivanje rubova skrivene slike nazvane "Z slika". Ovaj način steganografije primijenjen je u dizajnu i tisku poštanskih maraka u svrhu njihove zaštite na nov način.

Ključne riječi: *CMYKIR separacija; individualni rasterski element; infracrveni dizajn; poštanske marke sa sigurnosnim svojstvima; steganografija*

1 Introduction

As a security document, the postage stamp goes through specific phases of design, adapted to its functionality. It is a work of art [1] in the same way that it is a secured document [2]. It must contain a rich graphic design and corresponding security features [1]. The stamp's double function is also present in its design. The design has a high quality graphic, but in general, there is not the same level of attention paid to security as is the case when banknotes are in question [3]. Today the security features on postage stamps are standardized, known to the public [4]. In the spirit of developing novelties and new discoveries in technology and the graphic industry, the postage stamp is the ideal candidate for applying the CMYKIR technology [5] efficient in the extended wavelength spectrum, creating a double picture – in the visible and in the near infrared area (NIR) that extends and protects the area of efficiency [6, 7].

CMYKIR colour separation is based on the premise that the black (K) component has an infrared response in the CMY system and that it can be controlled in every colour tone [8]. In accordance with new discoveries, the desired colour effect in the infrared area is taken into account when separating the channels for printing. Thus a single tone can have a continuous response in the NIR spectrum. Parameter Z is joined with the standard (CIELab, RGB, HSB) parameters of such a tone describing its infrared response [9].

A single tone has continuous response between Z_{min} and Z_{max}. Z_{min} describes the minimum infrared response of a certain colour, whereas Z_{max} shows its maximum response, i.e. the black component quantity that a certain tone can accept but not change visually. The experimental range Z_0 and Z_{40} are introduced meaning that each colour tone will have a colorant without the carbon black component as a minimum response in the infrared spectrum. A colour "twin" has been joined with all the Z_0 colorants, having a 40 % carbon black component along with process C, M, Y colorants decrease. Twins have the same values in the RGB system.

Mixing of physical colorants varies for different printing techniques, and the CMYK channel separation coefficients must be adapted for each different printing technique. Extensive measuring has been carried out in different conditions and for various types of printing, and infrared hiding of pictures has already found its application in our research work and studies followed by real-life digital printing [10], flexoprint [11], screen printing. Printing has been carried out on various types of paper, cardboard [12], foil [13], textile [13] and leather.

This paper is based on colorant mixing measurements for offset printing in standard colour profiles Eurostandard Coated and U. S. Web coated (SWOP).

A separate part of this paper is on mathematical determining of an individualized screen shape that contributes to resolving the task of hiding the infrared picture, and at the same time this represents a new security component. Research work in the area of screens of special shape [14 ÷ 18] is extended with the definition of a new screening element named "IV4n" that resembles a cobweb, the parameters, positions, screen lines and angle of which are fully algorithm controlled. Examples have been elaborated where the same screen is shown in regular structure with clearly visible pointed structure, and there are examples where full deformation of the original shape is achieved with stochastic methods of setting the positions, screen lines and angle [19, 20].

In the experimental part, the design and graphic preparation were carried out for postage stamps that contain a double picture in the visible and the infrared spectrum with the application of a new screen shape. Dispersion of the infrared fringe information is achieved by entering into the picture's micro-structure, as well as better fitting of the infrared picture into the other, visible graphic. With the introduction of individualized screening elements the existing printing technology using amplitude and frequency modulated screening points that cannot participate in document securing is criticized. Double image created with this technology is detected with the apparatus for infrared area [21].

2 Modelling the individualized screening element

The screening element is designed with mathematical modelling and program controlling of form, positions, liniature and angle. It is created in the space called "the screening cell". It is a unit of space needed by the Postscript interpreter in order to design a screening shape. Mathematical relations that determine the screen shape are set in three-dimensional space with the help of the Mathematica programming support. Fig. 1 shows the "IV4n" screen element model in two-dimensional and three-dimensional space. The corresponding mathematical formula of this screen model is defined as $Z = f(x,y)$ where screening cell space is defined in the range of X: −1 ÷ 1; Y: −1 ÷ 1; and Z: 0 ÷ 1.

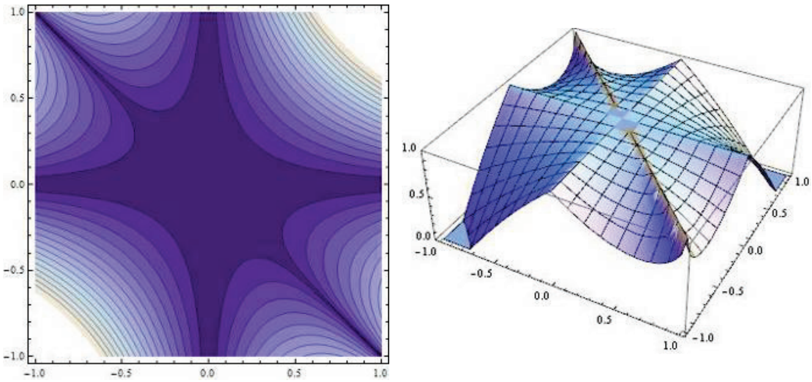


Figure 1 Two-dimensional and three-dimensional display of the screening element peak mathematical formulation (1)

Function Z is the mathematical interpretation of the screen element growth in respect to pixel ink coverage. The algorithm is given that decomposes the image into pixels joined by the screening element.

$$Z = 1 - \sqrt{\left| x^3 \cdot y^2 + x^2 \cdot y^3 \right|}. \qquad (1)$$

This screening element is completely different in comparison to the circular dot used in conventional screening. The screening element with very developed fringes, pointed and line mutating makes it even more important to hide the NIR picture from our eyes in the visual spectrum.

When translating the formula in Postscript interpretation it is necessary to respect the set X, Y and Z coordinate ranges. For each screening element point Postscript sets X and Y coordinates on the memory top and determines $Z=f(x,y)$. Elements with a greater Z value are shown in the lighter area and vice versa. The smaller the Z coefficient, the greater is the screening cell ink coverage. The screening element graphic display in two-dimensional and three-dimensional space is shown in Fig. 1. The ink coverage area that determines the crystal structure screening element shape is visible.

The Postscript interpretation of the screening element formula is defined as:

```
/IV4n {dup dup mul 2 index dup mul mul dup 3
2 roll mul 3 1 roll mul add abs sqrt 1 exch
sub}def
```
(2)

The screen appearance is shown in Fig. 2. The lower left square contains the screening element with a maximum of ink coverage 95 %, and each following one is decreased by 5 % to the minimum ink coverage of 0 %. The screen line is set at 5 lpi whereas the screening angle equals 0° in all the squares. The screening element structure is very well observed here where the visual effect is different in each ink coverage segment; basically it is designed as a pointed structure resembling a cobweb, and the transformations range from visually crystal structures to ellipsoidal structures resembling bugs and butterflies.

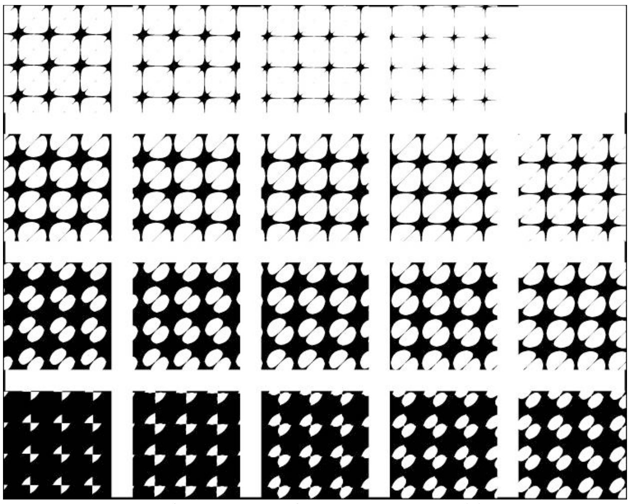


Figure 2 Surface coverage from 0 % to 95 % with 5 % steps

An 8-bit image is used in Postscript interpretation (3) that has 256 levels of grey. Data on the pixel surface coverage is given in the hexadecimal system with two digits. The test grayscale consists of 16 pixel columns that gain values of 95 % to 5 % surface coverage. The code record of pixel ink coverage is recorded in the hexadecimal system in the range from F2 (95 %) to 0C (5 %).

```
/grayValue <F2E5...hex code
grayscale...190C> def
/L 5 def /K 0 def
L K {IV4n} bind setscreen
…
1 1 8 [ pixW  0 0  pixH  0 0]
{grayValue j 1 getinterval}
image
…
```
(3)

In the original definition screen "IV4n" creates a regular micro-structure and this applies to all the amplitude screens. It is possible to incorporate stochastic variables into the screen element parameter definition that will dissipate regular shapes created by the same position, angle and screen line. Fig. 4 shows the grayscale gradation solution where a stochastic change of rotation between 0° and 90° has been achieved. This results in an irregular screening structure. By combining regular structure and screening element stochastic rotation it is possible to determine boundaries with certain surface coverage and to determine their structure separately, as shown in Fig. 5.

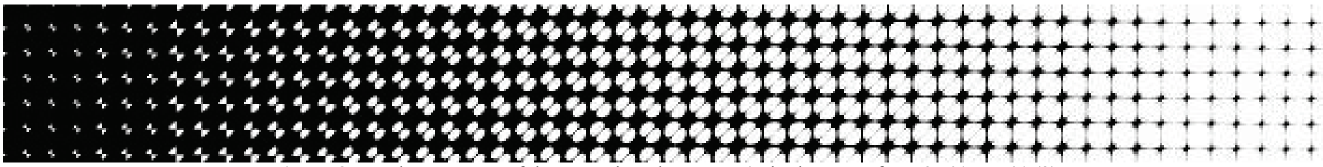
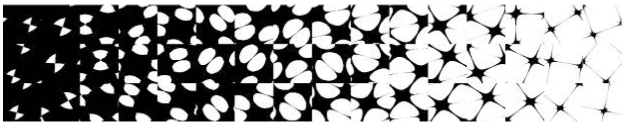
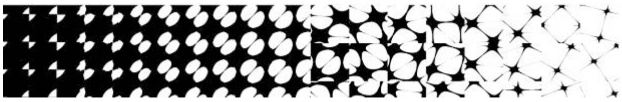


Figure 3 Regular structure of the screening element IV4n in the range from 95 % to 5 % (3)



```
246135 srand /m { 2 31 exp 1 sub } def /rn {rand
m div} def
/K rn 90 mul def
L K {IV4n} bind setscreen
```

Figure 4 Stochastic angle choice in screen IV4n with Postscript interpretation



```
/K rn 90 mul def
grayValue j get 128 lt {/K 0 def} if
L K {IV4n} bind setscreen
```

Figure 5 Controlled stochastic dispersing of the screen for tones lower than 50 % surface coverage with Postscript interpretation

```
/L 3 def /K rn 90 mul def
L K {IV4n} bind setscreen
/deform 0.03 rn mul def

1 1 8 [pixW deform dup pixH deform dup]
{grayValue j 1 getinterval}
image
```

Figure 6 Stochastic angle choice with pixel deformation

The stochastic effect is added in the program part for carrying out the screening and not in the initial mathematical definition (1). In this way the initial Postscript interpretation (2) is always the same and the stochastic effect is redefined for each pixel separately.

In the above examples (Fig. 4 and 5) the border is noticed that is created by the edge of original pixel inside of which the screening form is situated. In order to prevent such regular cuts of screening element that prevent randomized structure, Postscript offers the possibility to have pixel deformation inside of which deformation is achieved along the *X* and *Y* axis (Fig. 6).

The screening element tested in the grayscale picture is applied in digital pixel graphic screening practice in the chapters that follow.

2 CMYKIR picture separation

The double picture created by CMYKIR separation goes through specific preparation phases. In the initial phase two pictures are chosen having motifs that will be used for the visible and the invisible spectrum parts. Motifs for postage stamps are chosen in accordance with certain events, and this has also been done for the two experimental stamps that are presented in this paper. The first example is of a stamp designed on the occasion of Sir Isaac Newton's birthday and the 345th anniversary of his inventing the reflex telescope.

The postage stamp designed in this manner complies with artistic and functional requirements and at the same time it has top security features as prevention against counterfeiting. Two graphics are contained in the 3 × 3,5 cm postage stamp format and typographic elements that have a satisfactory legibility level. The two graphics supplement each other in their meaning and together they represent an extended piece of information. Together they are a unique designer concept. By having a hidden picture in the infrared area the stamp is adequately secured because the process of preparing such a picture goes through special CMYK channel separation algorithms with the goal to create a double picture in the extended spectrum – extended reality.

A part of the picture is visible to the naked eye, whereas the other part of the graphic is observed with the help of an instrument, only in the near infrared area (NIR) 1000 nm with a set value *Z* (NIR-Z picture). In such a manner double space is gained for designing the graphic and new phases are introduced in the design of the graphics and their preparation for printing.

The graphic that will be visible to the naked eye is prepared as the input image in the RGB colour system. The picture for the infrared spectrum part is prepared in the grayscale mode with maximum ink coverage of 40 %. It will be used as a mask when calculating the ratio of colorant for each pixel in order to achieve the infrared effect. The instruments for detecting electromagnetic radiation infrared absorption produce a picture with certain ink coverage in the grayscale from 0 to 100 %.

The maximum absorption is defined as "IR black" and reflection is projected as "IR white". Parameter Z is introduced describing the colour in the IR spectrum at 1000 nm. For one colour tone it is possible to achieve gradation in the IR spectrum from Z_{min} to Z_{max}, determined depending on the CMYK component quantity. In order to gain the "IR white" effect for the colorant mixed in the CMYK system it is necessary to reduce the K component to the minimum with adequate increasing of the other components. And vice versa; in order to achieve Z_{max} it is necessary to raise the K level with the adequate decreasing of the CMY channel. The maximum ink coverage that a colour tone can accept is determined as the lowest CMY value of the components:

$$K_{max} = \min (C_0, M_0, Y_0). \quad (4)$$

Conventional separation methods can carry out subtraction of the C, M and Y components in respect to the K component more or less accurately in assigned colour settings. Each setting of paper and physical colorants at disposal has its own colour setting according to which colours with infrared response must be planned. Colour separation in CMYKIR steganography is based on coefficient separation development, studying colorant behaviour in the near infrared area and the fact that CMYKIR process inks depend on the printing technology and material type maintaining the coloured surface quantity level, and thereby the reproduction quality.

a) b)

Figure 7 Preparation of the two pictures for the visible (a) and the infrared spectrum (b)

Tab. 1 shows CMYK component mixing for ten "twin" colours. In this paper the colour settings are Eurostandard Coated and U. S. SWOP coated for printing postage stamps. Colour settings are set with a minimum and maximum *Z* parameter in the K component. The necessary subtractions and additions of CMY components are estimated accordingly in order to obtain a visually uniform colour tone. In this case the minimum Z parameter is 0 %, and the maximum one is set to 40 %. The difference is obvious between the two standards where the same initial colour tone with Z_{min} gains different values in the RGB system, depending on the colour setting.

Table 1 Eurostandard and U. S. Web SWOP Coated Color Values

Spot colour CMYK (K = 0)	Euro-standard RGB	Euro-standard CMYK (K = 40 %)	SWOP RGB	SWOP CMYK (K = 40 %)
38,30, 34	185,181,173	0, 6,10	167, 164, 156	0, 2, 8
41,39,86	171,163,76	8,13,79	152, 145, 61	7, 10, 71
86,82,85	75,71,51	74,67,77	57, 51, 51	67, 63, 59
74,80,95	97,82,23	56,66,91	79, 59, 37	50, 62, 71
99,43,40	45,111,143	94,4,22	38, 106, 132	85, 4, 17
45,55,99	154,137,0	15,34,97	137, 116, 26	11, 31, 82
43,99,99	134, 34, 0	4,96,99	125, 0, 11	2, 88, 68
44,92,38	145, 65,105	3,87,3	130, 0, 82	0, 85, 0
70,56,36	122,122, 142	48,35,12	99, 101, 126	45, 31, 6
45,40,30	171, 162, 168	9,20,4	150, 143, 151	10, 14, 1

Set colours in CMYK (K = 0) with corresponding RGB and calculated CMYK (K = 40) for colour setting Eurostandard and SWOP coated.

3 Applying CMYKIR separation and individual screen in postage stamp design

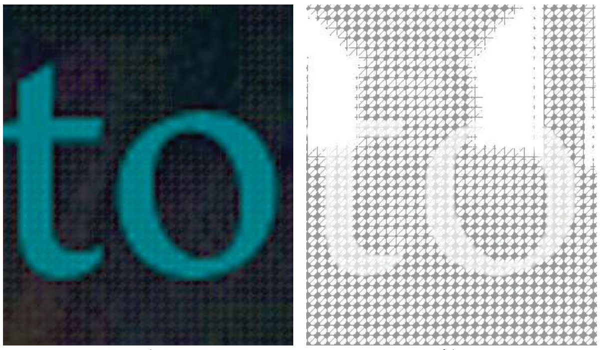
The picture preparation stage includes processing of the visible picture in the RGB system and processing of the IR picture in grayscale mode with maximum ink coverage of 40 % in order to achieve optimal hiding results. Two design examples are shown using the technology of screened hidden pictures. In the first example a regular screening element structure is used for the experimental stamp, incorporated into the K channel of the picture holding the infrared picture (Fig. 7). CMYK channels created after CMYKIR separation are displayed (Fig. 8). CMY colour channels carry information on the visible picture where colours are mixed on the basis of estimated values for the set colour setting.

Channel K contains the picture that can be detected in the print with the help of an infrared absorption detector; an infrared camera, a ZRGB camera, infrared spectacles. The screen structure can be seen in the detail of the picture (Fig. 9) that in the final stage disperses the black channel gradation and provides better fitting in of the hidden picture into the visible picture. Screening is carried out in regular structure with program set parameters having the same screen line and angle. Picture fringes in the black channel are dispersed (Fig. 9b) and in the visible part they are fully merged with the CMY channels (Fig. 9a).

Motif choices in Fig. 10 as well as the first example (Fig. 7) are based on the intertwining of the anniversary theme motifs in the sense of connecting Guttenberg's revolutionary discovery of shifting types and book reproduction for contemporary civilization based on knowledge and information, and the first books printed in Croatia only 15 years after his tragic death. A graphic is planned in the visible part representing a detail coming from the first Croatian book printed in the Glagolitic script. The text in the lower part of the stamp contains the year of printing, book name and explanation linked with the graphic. The typographic elements are planned with a sufficient legibility level for the small postage stamp format. The designed hidden picture contains the portrait of Johannes Gutenberg, the printer, and the textual part with the year of his death, name of the printer and motif description.

a) CYAN b) MAGENTA c) YELLOW d) KARBON BLACK

Figure 8 Individual CMYKIR separation channels



a) b)

Figure 9 Enlarged stamp detail with screen a) spectrum visible part and b) spectrum infrared part

a) b)

Figure 10 Second motif with planned visible and infrared picture before the CMYKIR separation and screening process

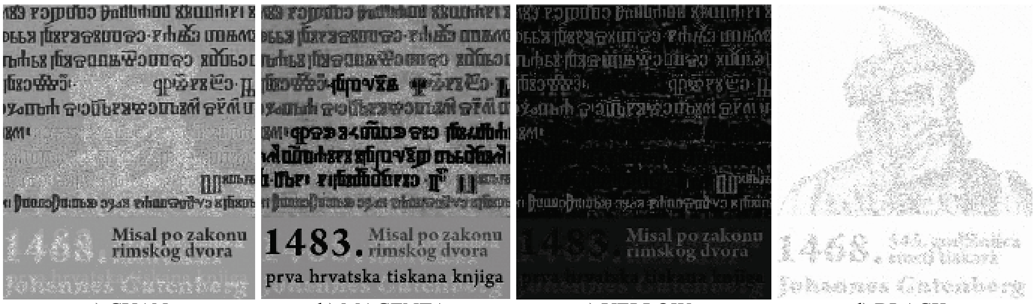
Fig. 11 shows a detail in all four channels after CMYKIR procedure. Channel K is carried out in the form of a bitmap with a new screening element, followed by being produced together with the other CMY channels in CMYKIR separation. The trace of the screening element from the black channel is visible in the other channels and this is proof that with algorithm modification new CMY channel estimates were obtained from the original colours. The altered appearance of the screening element is visible in the K channel (Fig. 11) where the dispersion was at its maximum.

Stochastics are introduced because of the low screen line that would cause the moiré effect. Low line is favourable for the IRD method so that the replacement of CMY with K would be at end points X_0 and X_{40}. Twin colorants of the same colour tone were estimated for this purpose. The proposal is to avoid intermediate stage X except in special cases where the VS and Z graphics' correlation does not allow such replacement. Such cases take place on the VS graphics white parts. The light letter parts in Fig. 9b illustrate such situations. The VS picture is always the imperative in respect to which the Z picture is subordinated.

The channel K detail in Fig. 12 shows the graphic that is carried out on the basis of stochastic dispersing of the screening element. The stochastic parameters applied in screening of this example are incorporated into definition of the position, screen line and screen angle. Also, the deformation of the original pixel deformation has been carried out, resulting in complete loss of the initial screen shape. The stochastic screen line range in this example has been reduced on purpose, so as to better accentuate the screening element, but a range with larger screen lines is set for offset printing needs so as to maintain the details.

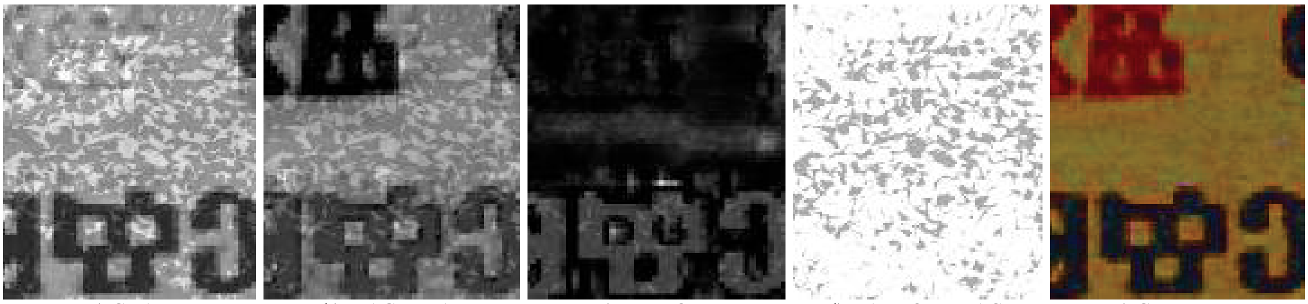
Any possibility in modifying the screening element between the two described extremes is possible. All parameters influencing the screening element are available in the program code, and it is possible to modify them in order to achieve the maximum effect in hiding the picture and in individualization.

A double state in the postage stamp is achieved by merging CMYKIR channels. The initial planned picture will remain in the visible spectrum, while the picture in the infrared channel will be equal to channel K. 40 % ink coverage in channel K is sufficient for the Z picture to be seen well with cameras for the NIR area (observing cameras, video-cameras in "night-shot" mode, special cameras). CMYKIR separation has very precisely carried out subtraction of the CMY channels and thereby the hiding of the double picture.



a) CYAN b) MAGENTA c) YELLOW d) BLACK

Figure 11 Subtraction the K_{40} value from the CMY channel



a) CYAN b) MAGENTA c) YELLOW d) KARBON BLACK e) CMYKIR

Figure 12 Detail of the second motif in the CMYK channels following CMYKIR separation

5 Conclusion

CMYKIR technology of hiding the second image is introduced into stamp multi-colour security graphics. Postage stamps have a visual image that is the visual message carrier and a no less important hidden infrared picture that is seen when viewing with the help of an adequate instrument. Together they are part of a unique designer and security concept. Printing is carried out with process dyes in such a way that the two images protect each other. There are no extra procedures or expenses. After CMYKIR separation it is not possible to have even the slightest corrections of the CMYK channel before printing.

If anything was done in this respect, there would be a disturbance, and the hidden Z picture would appear in the visible spectrum. In order to achieve the maximum effect of hiding, a "pointed" screening element is introduced that mutates starting from the shape of a line and through the shape of a cobweb and two-egg structures all the way to total shutting off of pixel coverage. The quality of hiding the Z picture is amplified by introducing stochastic deformations at two levels: firstly – pixel deformation, and secondly - the screening element deformation. These algorithms are part of the enclosed program design that creates a high resolution bitmap. The fourth K channel that is responsible for the image in the infrared spectre has an independent screen line and advance angle.

Screening allows individualization of each postage stamp series providing thus great improvement in respect to further authentication. Screen design is not only a top security feature, but it is also an artistic component because it is possible to conceive a special element for each postage stamp that carries a visual message. Individualized screening allows easier realization of complex tasks – hiding of the second image in the infrared area, and those are, for example, fringe areas of hiding signs in the set light colour tones for the visible area. Screening is also a novelty in the so-called artificial adding of high resolution that is especially interesting in designer samples that have been taken over from archives or old newspapers.

This has eliminated any appearance of moiré effect. It also contributes to the effect of mutual hiding of two graphics. It is not possible to recognize such postage stamp visual/infrared printing by scanning it, or if there is the possibility of decoding it, restoring it or producing false copies.

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