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DEVELOPMENT OF A PROTOTYPE FOR ZRGB INFRAREDESIGN DEVICE

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Original scientific paper

Infraredesign theory has developed a method of implementing graphics that carry two pieces of information, where the first one is seen in the visual spectrum (VS), and the other in the near infrared (NIR) spectrum. This paper introduces a prototype for a device which should record these two states: an image in the NIR as a Z monochrome record and image in the VS as a RGB record. These two independent images are representing properties of substance in the wavelengths region of the electromagnetic spectrum from 400 to 1000 nm. These can be paintings, reproductions, banknotes and secured documents, or even scenes from nature. With this device through developed software it will be possible to quantitatively determine the difference between information from RGB to the Z state of matter for each pictorial element. The device operates under the daylight, without a separate built-in IR source, which enables recording of close and very distant objects at the same time.

Keywords: *graphic technology, infrared, innovation, prototype*

Razvoj prototipa ZRGB INFRAREDESIGN uređaja

Izvorni znanstveni članak

Infraredesign teorija je razvila metodu izvedbe grafike koja nosi dvije informacije, prvu vidljivu u vizualnom spektru (VS), a drugu u bliskom infracrvenom (NIR) spektru. U ovom se članku predstavlja prototip uređaja koji će snimiti dva stanja: slike u bliskom infracrvenom spektru kao Z monokromatski zapis i slike u vizualnom spektru kao RGB zapis. Ove dvije neovisne slike predstavljaju svojstva tvari u području valnih duljina elektromagnetskog spektra od 400 do 1000 nm. To mogu biti slike, reprodukcije, vrijednosnice, ili prizori iz prirode. Ovim uređajem putem razvijenog software-a moguće je kvantitativno odrediti razliku između informacija iz RGB do Z stanja materije za svaki slikovni element. Uređaj funkcionira na dnevnom svjetlu, bez zasebno ugrađenog IR izvora, što omogućuje istovremeno snimanje objekata u neposrednoj blizini i na velikoj udaljenosti.

Keywords: *grafička tehnologija, infracrveno, inovacija, prototip*

1 Introduction into the Infraredesign theory
Uvod u Infraredesign teoriju

The new Infraredesign (IRD) technique of protection is implemented for detection in the range of 450 nm to 1000 nm [1]. Fig. 1 shows an example of concealing the image of old town in a printed image of horsemen using the IRD method with three filtering: 570 nm, 715 nm, 1000 nm. In such a way one printed image carries two-image information. One is visible to human eyes and the other is only seen in the NIR (Near InfraRed) range of the spectrum.

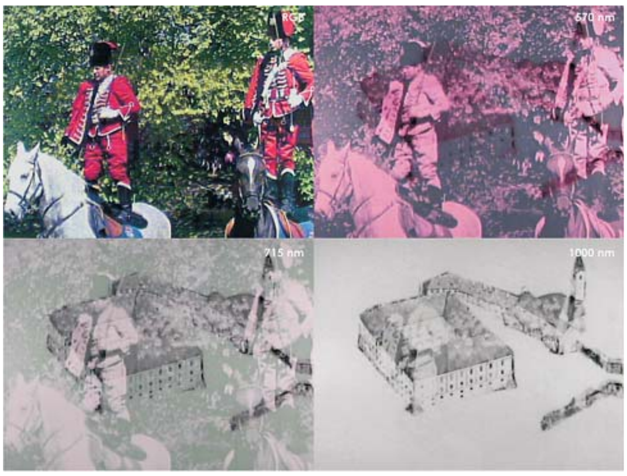

Figure 1 *Print with Infraredesign effect shown in the visible part of the spectrum - RGB and the image of old town invisible to human eyes with three filters: 570 nm, 715 nm, 1000 nm*
Slika 1. *Otisak s Infraredesign efektom prikazan u vidljivom RGB dijelu spektra i slika starog grada nevidljiva za ljudske oči s tri filtera: 570 nm, 715 nm, 1000 nm*

IRD theory has many practical applications and methods of implementation. It brings a completely different approach to looking at the color and dyes, processing of digital images and their final reproduction. All of today's advanced methods of algorithmic creation of color structures for reproduction are directed to the area of human vision. Methods such as color separation for printing CMYKcm [2], CMYKRGB printing process [3] and multi-ink color-separation algorithms [4] are intended for improving image quality in printing technologies with different kinds of inks. This method is completely nondestructive, as some others, for example those used in the study of manuscripts and prints [5], which gives it a particular value in addition to speed of detection and simplicity of use.

IRD area is certainly of interest for this development project because it will simplify and improve the system and method of detecting reflection and absorption of NIR wavelengths from the surface of matter. There was a developing need for a handy device that detects the state of graphics and nature in two different states. This will enable further development of dual image in evaluation of IRD theory; in the experiment phase, in the preparation phase of mixing colors, in the printing phase and at the end at the final control of finished IRD product. Such a device would also be intended for expansion of the security system designing.

Introduction of a completely new way of designing and coding information with new technologies is a very complex task, which was the subject of research in areas such as typography. How to even introduce infraredesign technology to the field of typographic tagging and design? Therefore ZRGB system is also useful for designing and planning of the messages that are intended for embedding. Design and marketing messages based on infraredesign would be instantaneously adjusted and finalized.

2
Analysis of the present state of technology
Analiza trenutnog stanja tehnologije

Today there are many devices that can be used for observation in the NIR part of the spectrum. This is the merit of the development of CCD technology which is widely used in all types of digital photo cameras and video cameras. Infrared (IR) cameras are used for detecting the infrared part of the electromagnetic radiation spectrum. IR spectrum is divided into 3 parts according to the CIE (The International Commission on Illumination): IR-A 700 nm-1400 nm, IR-B 1400 nm-3000 nm and IR-C 3000 nm-1 mm. Field of IR-A is considered near infrared (NearIR) area as a basic part of the spectrum for the observation in this system (Fig. 2). The end of examination areas of the spectral characteristics of interest is from 1075 nm because CCD sensors are based on silicon and with their compounds limited to the upper wavelength of 1100 nm, where their relative sensitivity drops to zero.

Indicated in Fig. 2 is the area used by classic digitizers, through RGB filters, in today's digital cameras that have built-in IR filter for illuminating the CCD only with wavelengths below 700 nm. Today's digital photo cameras and camcorders have CCD fields that are sensitive, in addition to the visible part of the spectrum, even to a broader part of the spectrum invisible to the eye. In the construction of IR cameras, i.e. photo cameras, we distinguish between two types of cameras: a camera with an IR source and a camera without an IR source. The main difference is that the first type (cameras with IR diodes) requires complete darkness of the visible part of the spectrum, while the second type requires more electromagnetic radiation, because it does not rely on the reflection of artificial IR source. The present state of technology in the form of classification of spectral characteristics of light source, the classification of spectral characteristics of optical filters, and at the end the spectral characteristics of the CCD sensor are shown in Fig. 3 [6]. This is a graph of normalized values of relative energy of IR sources, relative spectral transmittance of IR filters and relative spectral sensitivity of CCD sensors. From these characteristics a cross section is indicated of the infrared light source, those filters, and those CCD sensors that have the best feature of observation in the NIR spectrum. These characteristics largely depend on the different production technologies, and on the type of materials used to produce coating on the filters, a type of semiconductor light source element, and on manufacturing method of the CCD sensor. Using the generated categorization of infrared light sources, IR filters and CCD sensors Fig. 3 shows the cross section of favorable camera structure containing I1 or I2 filter, F1, F2 or F3 CCD sensor, and B2, B3, in some cases C1 infrared source of light. F1-type CCD sensor is sensitive in a good part of the visible and NIR spectrum, and the relative spectral sensitivity starts to decrease only at 850 nm, and at 1000 nm is at 8 %. CCD type F2 has sensitivity of nearly 96 % in the entire visible part of the spectrum, in the NIR part from 90 % up to 10 % at 1000 nm. CCD type F3 that enters the NIR part of the 700 nm has increased sensitivity of 95 % and only at 850 nm starts to decrease, and at 1000 nm the F3 CCD sensor achieves a relative spectral sensitivity of 35 %. Infrared light sources of type B2 and B3 are IR LED diodes with a maximum relative emission at 950 nm, while their spectral width of emission is from 880 to 1030 nm. For better emission multiple LED can be used to increase the energy and power of emission. Type C1 is the daylight that has a good spectral characteristic in the NIR area with the relative energy of 0,44 on wavelength of 1000 nm.

This invention solves the problem of simultaneous, parallel viewing of two different parts of the electromagnetic spectrum: the visual region (400 nm to 700 nm) and the near infrared NIR (Near InfraRed) region

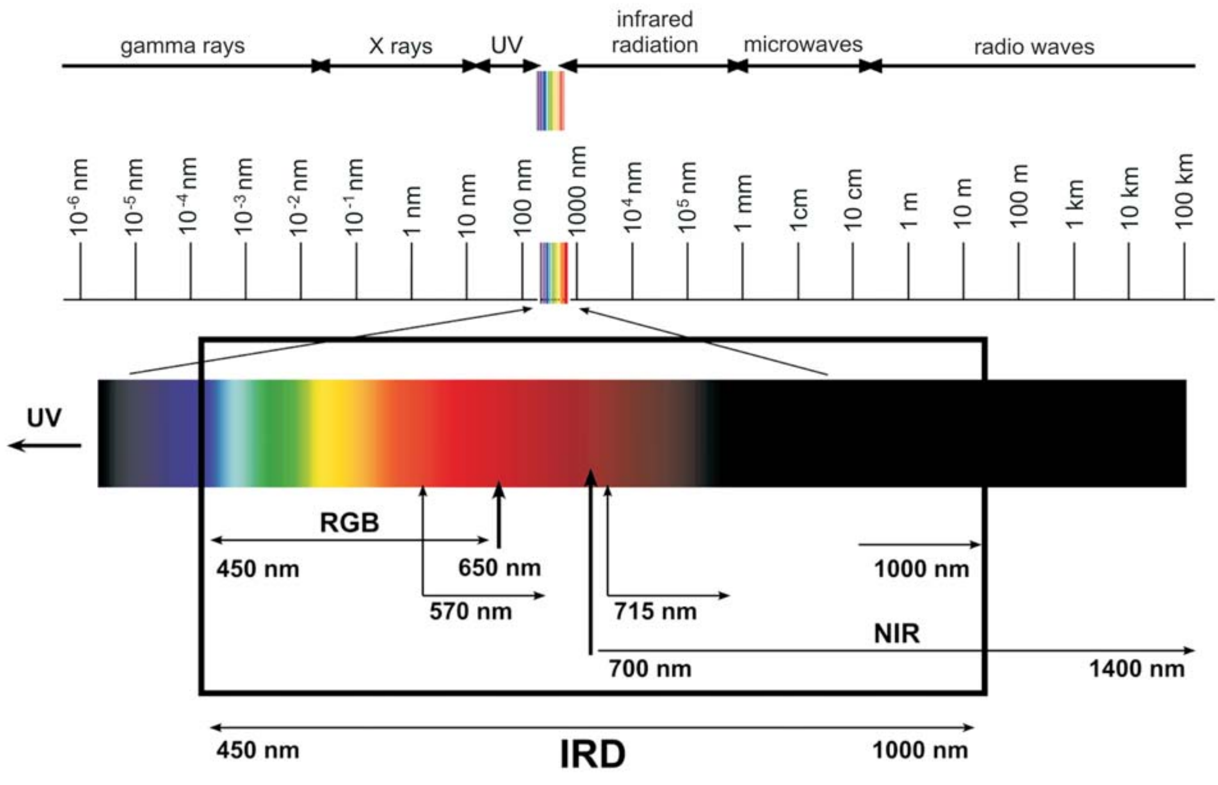

Figure 2 *Preview of the electromagnetic spectrum and ranges of interest*
Slika 2. *Prikaz elektromagnetskog spektra i područja interesa*

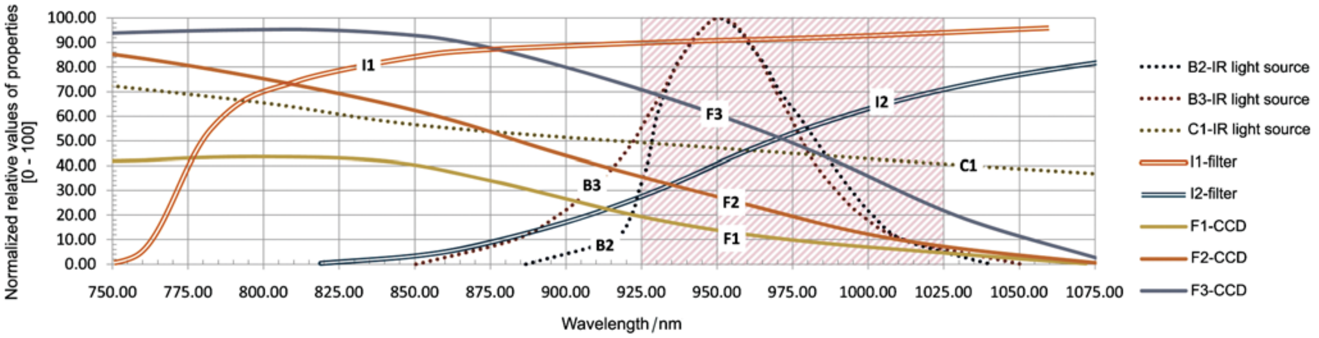

Figure 3 *Cross section of classification of IR sources, IR filters and CCD sensors* [6]
Slika 3. *Presjek klasifikacija IC izvorišta svjetla, IC filtera i CCD senzora* [6]

(800 nm to 1000 nm). There are many devices that can independently look into the NIR region in the so-called 'night modes of operation' (Night Vision), or specialized scanners with barrier NIR filters, but there is no effective portable system for parallel, simultaneous viewing in the visible and NIR region in one geometric position. In many domains of human work there is a need for simultaneous viewing and recording of visual and NIR fields, from medicine to security and protection of documents or in art authentication.

The main technical problem with the existing devices for NIR viewing is the lack of two independent CCD fields, where one is in charge of display and recording of RGB images of the optical portion of the spectrum and another for display and recording of response in the NIR portion of the spectrum as Z monochrome image and visible instrumental in order to perfect overlapping of pixels from two images with the same address. Simultaneous observing in this way is a prerequisite for viewer to decide whether he will want to record the RGB and the Z image in memory for archiving purposes and later analysis or current experimental fact.

3
Development of a prototype for the ZRGB device
Razvoj prototipa za ZRGB uređaj

The solution for technical problems is the creation of ZRGB device for dual detection, which consists of one digital camera with screen in RGB standard, movable on axis of rotation, and a second digital camera, connected to the first one through a joint stand, with Z response in the near infrared NIR, movable on the remaining two axes. This designed device, the Z digital camera, according to its characteristics of resolution (CCD array) and optics, is the same as the RGB camera except that it is processed with the NIR filter so that its CCD field is illuminated only with the NIR response which is recorded as Z file.

There is no unique device that scans four areas: Z, R, G and B so that the same pixel is observed for all four parameters. In such preferred simultaneous observation, there are technical problems arising from the conditions of observation and the construction of a joint base. Construction of a joint base is never perfect because of the possible use of different materials in the final making of the base or the inability to maintain the initial conditions in the same position during the system's life span. Therefore, a possibility of adjusting observation and photographing of images in the Z compared to the RGB image should be designed.

In the authentication process of security documents using the Infraredesign protecting technique there is a technical problem in seeking position of embedded protected information. In this way a person can simultaneously, all the time, observe in the same frame protected document in the visible part of the spectrum and in the NIR part of the spectrum. Whenever desired a simultaneous digital photographing of RGB and Z images can be done. Such pairs of images can be placed in the archives of forgery or with them it is possible to create original database for future authentication of documents.

The device consists of two digital cameras interconnected through the stand. One camera is set in a classical RGB standard and it is called the RGB camera, and the other is adapted for a single-channel viewing of Z response in the NIR region and we call it the Z camera.

In the proposed system the Z digital camera is remade so that the protective classic infrared filter is removed and experimental filtering was made with I_0 (570 nm), I1 (715 nm) and I2 (1000 nm). Both cameras in the device work under daylight without a built-in IR source. This is a very important feature that can detect the hidden images at larger distances and in open spaces. If there is not enough daylight then a flash light can be used since it has sufficient NIR radiation for the desired detection.

That is why the device has built-in interchangeability of Z cameras that have different barrier filters installed i.e. they have different detection properties. These properties differ depending on external light which can be natural daylight or it can be artificial light in the range of internal or external flash light, artificial lighting, and halogen lamps up to the infrared reflectors. The experimental part of this paper will show results for the Z cameras that provide detection at different wavelengths. Their detection can be also adjusted by using various light sources.

Thus, the system can be designed to produce two paired RGB and Z images that can be used for further analysis. The system of Z digital camera is by characteristics of CCD fields and optics identical to the RGB camera. The necessity for construction with identical optics simplifies the programming of controlling aberrations and deformations of the recorded RGB and Z images. In this way the resulting pictorial RGB and Z pair is the same by the number of pixels in rows and columns. It is of great importance if we want to maximize overlap of the RGB and the Z information in case we want to make programmatic analysis of image pair pixels. To obtain this goal a software tool is developed for merge and targeted analysis of RGB and Z image pairs. Due to imperfections in the positioning of RGB pixels on Z pixels a mathematical algorithm is developed that uses markers on images as referent positions on both images.

Z digital camera has the ability to move around two axes to adjust the Z image with parallel RGB digital camera that can be rotated on the third axis, which is particularly important for parallel, simultaneous viewing and recording of close and distant objects, and for the correction of imperfect, initial, mutual positions of the RGB camera and Z camera on a joint base (Fig. 4).

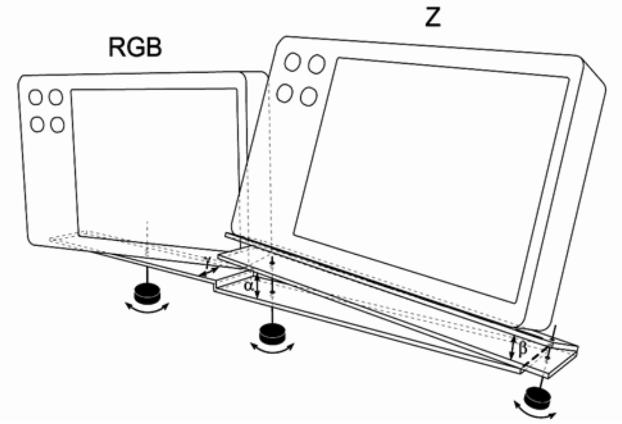

Figure 4 *Construction of ZRGB device that allows adjustment of focus and alignment in order to record the same ranking pixels with minimal program adjusting of the desired overlap*
Slika 4. *Konstrukcija ZRGB uređaja koji omogućuje podešavanje fokusa i usklađivanje kako bi se snimio isti rang piksela s minimalnim programskim podešavanjem željenog preklapanja*

RGB camera rotates (γ) while the Z camera is adjusting through two degrees of freedom (α and β). Adjusting is done through three degrees of freedom with parallel viewing on two screens, and for a high quality overlapping four sets of markers are used depending on the dual characteristics of the observed physical object. Since markers must be clearly distinguished against the background on which they are placed, their selection when marking is viewed parallel on the RGB and Z display and is chosen between these combinations: dRGBdZ marker - dark RGB record and dark Z record, dRGBlZ marker - dark RGB record and light Z record, lRGBdZ marker - light RGB record and dark Z record, lRGBlZ marker - light RGB record and light Z record.

Recording is done with markers so that we can, by using morphological software tools, precisely adjust the positioning of all pixels in research. The very structure is the technical maximum in order for further software adjustments to have less strain. Precision of pixel positions in double images is needed for quantitative evidence of Z and RGB parameter association for a particular matter. Thus, for a particular way of mixing colors it is possible to set quantitative values of relations between Z/RGB that can be stored in a database as the fingerprint of that color.

4 Use of ZRGB device
Upotreba ZRGB uređaja

ZRGB device is an instrument for separation of double ZRGB image. This device records two specifically designed RGB states: RGB and Z state. Convenience of the ZRGB device for dual detection is achieved with construction that is portable and insensitive to disassembly and random bending because parallel viewing is always quickly adjusted with three degrees of freedom. At the same time each camera can be also used completely independently for individual viewing and recording.

Process of using ZRGB device consists of these basic phases:

1. Turning on the RGB camera and the Z camera;
2. Selecting desired frame through the RGB camera, and parallel on the Z camera is seen NIR response. Frame adjusting of the two cameras for observation of distant and nearby objects can be done through three axes on the pure visual basis, that is through the reticular tester of visual adjusting of geometry for the high-quality overlays;
3. If we want to adjust the Z frame on the RGB frame in order to perfectly overlap, markers must be attached on the objects. Markers that will be perceived separately in the RGB view, and separately in the Z view, which is achieved by appropriate selection of the four categories of markers;
4. Additional framing of the Z camera is done through adjusting of the three axes so that all markers are closer to the RGB camera positions;
5. Triggering the RGB and the Z camera and making of the Z and the RGB image on separate memories.

5 Experimental results and discussion
Eksperimentalni rezultati i diskusija

The possibility of observing and recording that is dual, simultaneous in the RGB and in the NIR area is needed in many areas of human work and research. Dual viewing and archiving of RGB and Z digital recording is necessary in the area of medical research as well as in research of nature from wildlife to plants (Fig. 5).

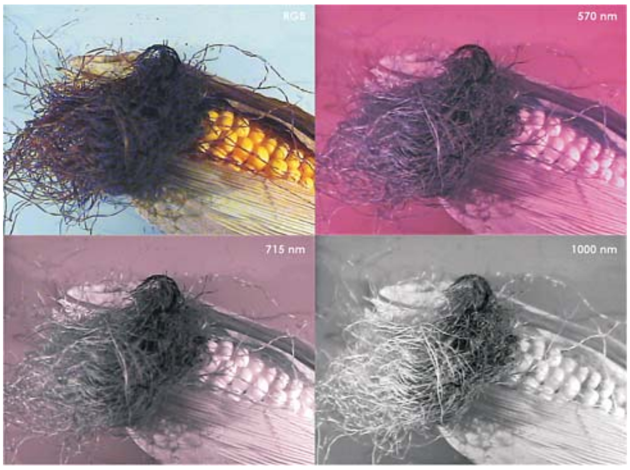

Figure 5 *Photo of corn in the visible part of the spectrum (RGB image) and the response in the NIR range under 570 nm, 715 nm and 1000 nm (Z image)*
Slika 5. *Snimak klipa kukuruza u vidljivom dijelu spektra (RGB slika) i odziv u NIR području kod 570 nm, 715 nm i 1000 nm (Z slika)*

The creation of such device allows detection of steganographic images embedded through the Infraredesign method. Fig. 6 shows example of print with embedded hidden image, which was experimentally recorded with the ZRGB device.

In the example of steganographic image of the Stone Gate in the city of Zagreb, with hidden image of Miroslav Krleža (Fig. 6) experimental measurements were implemented using ZRGB device. Printed image produced on the 8 color Xeikon digital electrophotographic machine was placed in front of the device. Recording was made with

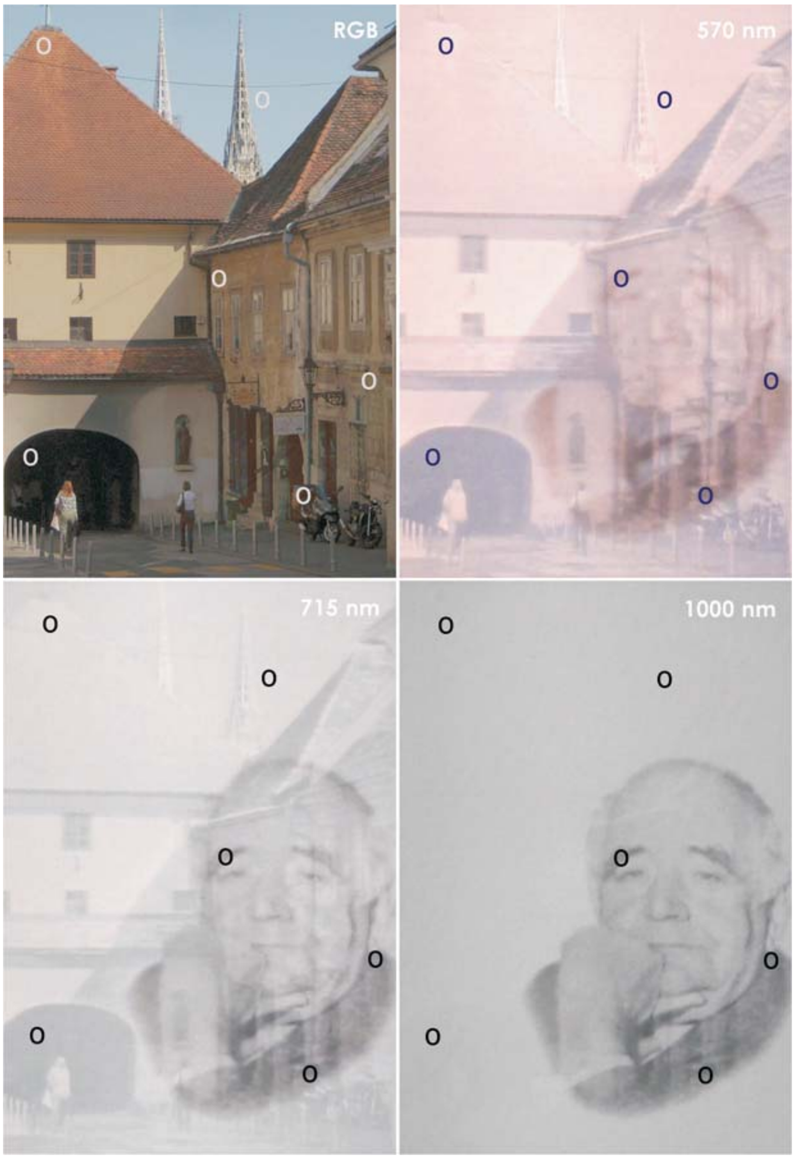

Figure 6 *Experimental ZRGB recordings of printed image of Stone Gate (Kamenita vrata) in Zagreb with embedded hidden portrait of Miroslav Krleža using the IRD method under 570 nm, 715 nm and 1000 nm*
Slika 6*. Eksperimentalna ZRGB snimanja otiska Kamenitih vrata u gradu Zagrebu s ugrađenim skrivenim portretom Miroslava Krleže pomoću IRD metode kod 570 nm, 715 nm i 1000 nm*

Table 1 *Measuring results of Infraredesign print from the Figure 6*
Tablica 1. *Rezultati mjerenja Infraredesign otiska sa slike 6*

T	CMYK, 400-700 nm		570 nm	715 nm	1000 nm
	RGB	CMYK % print	RGB	RGB	Z %, R=G=B
1	171, 134, 110	30, 48, 43, 0	254, 211, 208	214, 205, 206	34, 169
2	159, 175, 190	42, 18, 11, 0	248, 210, 212	211,206, 208	31, 176
3,K	110, 93, 73	45, 51, 53, 27	178, 145, 149	151, 144, 149	50, 126
4,K	111, 102, 82	42, 42, 51, 38	155, 130, 131	139, 134, 136	54, 120
5	20, 23, 25	99, 93, 93, 0	156, 149, 163	167, 171, 170	35, 166
6, K	53, 38, 27	72, 79, 79, 40	123, 106, 110	115, 113, 114	55, 116

the ZRGB device with three versions of the Z camera: 570 nm, 715 nm and 1000 nm.

Tab. 1 shows measuring results at 6 measuring points that are highlighted in Fig. 6 and their index is the same in the order from the top to the bottom. Points that are in the position of the cross section with a hidden portrait of Krleža are marked with K in the table. In the first RGB column are readings that came from the RGB camera in the VS area after the shooting of the CMYK printed template. Values of each channel are from 0 to 255 (8 bit RGB recording per channel), while the second column shows the percentage of coverage for four CMYK colors which were entered into the process before printing. In this way we can correlate the amount of the desired RGB color after printing with the given CMYK print prior to printing. In this case recorded RGB values were good in comparison to the desired values arising from color setting for Xeikon machine and associated paper that was used when creating images of Krleža with Infraredesign. Other RGB values are derived from the Z camera with associated filters. At 570 nm information is fully seen from cyan channel and black channel, partially from magenta while the yellow part of the image is completely missing. This results in the appearance of Krleža's portrait, but still with a very visible Stone Gate i.e. image carrier.

At 715 nm only a reflection from cyan and black remained. From magenta only traces are left. Measurements at 1000 nm show that cyan, magenta and yellow do not absorb NIR. Only carbon black remains. Carbon black is represented with values from 50 % to 55 % in the column Z which denotes the intensity of the NIR response. All other areas show the value of Z in the range from 31 % to 35 %. Completely rejected values for CMY at 1000 nm are the reason for the proposal of assigning Z values to dyes at that wavelength. Bright areas in the image at 1000 nm (points 1, 2 and 5) have values of Z as a minimum gray level. Recording with the Z camera shows that these values are mutually equal (R=G=B)

In the process of authentication of the original or the counterfeit it is possible at all times to simultaneously observe protected document in the same frame, in the visible part of the spectrum and in the NIR part of the spectrum (Fig. 7).

***Figure** 7 Highly secured document with security pattern that has a hidden text in the NIR (Z image)*
***Slika 7.** Visoko zaštićen dokument sa zaštitnim frizom u NIR području u kojem se pojavljuje skriveni tekst (Z slika)*

Whenever we desire digital photographing of the RGB image and the Z image can be done. Such pairs of images can be put in the archive of forgery or with them it is possible to create a database of the originals for future authentication of documents.

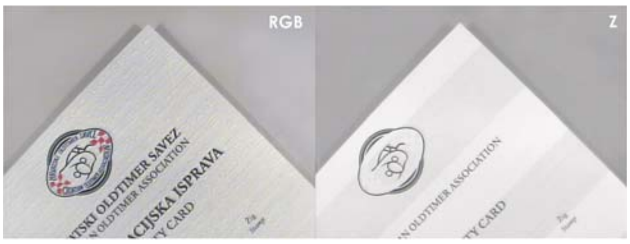

***Figure 8** Photos of IRD-protected driver's license with the ZRGB device: RGB image (visible text and logo) and Z image (part of the text and the logo is gone)*
***Slika 8**. Snimci IRD-om zaštićene vozačke dozvole s ZRGB uređajem: RGB image (vidljivi tekstovi i logotip) i Z image (dio teksta i logotipa je nestao)*

We created the possibility of light portable authentication system for detection of existence or nonexistence of the Infraredesign protection on textile products, pharmaceutical products, all kinds of secured packaging and highly secured documents from passports, ID cards to the banknotes and driver licenses (Fig. 8).

The ZRGB device for dual detection improves the authentication of works of art as shown in Fig. 9. Today we have a widespread use of the qualitative assessment of differences between one artistic image from the other, or the original from the forgery based on the IR response.

***Figure 9** ZRGB recording of painting with applied markers, where in the Z image the bird has disappeared together with the woman, the horse and the second author's initial*
***Slika 9.** ZRGB snimanje umjetničke slike s primjenjenim markerima gdje je u Z slici potpuno nestala ptica, žena, konj i drugi autorov inicijal*

With this device we will be able to explore the quantitative assessment of differences, as a new field in works of art research because our interest is in the difference between the Z value and the RGB value for the same positioned pixel as an opportunity to determine the correlation between the RGB and the Z variable in the entire digitized scene.

Such device opens up completely new possibilities of innovation in reproducing images using a pixel pair created from the same positioned RGB and Z pixels. That would be a reproduction of the RGB image on the Z image. Artistic images can be archived in the RGB recording and in the Z recording, and with supplemental integrated algorithms they can be reproduced in special catalogs with authentication characteristics.

Implementation of the ZRGB device is also in the detection of protection for portrait's reproductions that have secured portraits on the secured documents (Fig. 10). Therefore, at the customs, police stations and other places of *authenticating people*, it can be recorded separately and simultaneously, the visible image from the front of the document as RGB file and hidden image of the person's profile in the picture as image Z (NIR response).

With this new method it is possible to enter completely new concepts of VR (virtual reality) technologies as a new interaction paradigm. In this way, the virtual source may be incorporated into the printed picture itself, and a revival can be achieved with ZRGB device with which the 'avatar' information is digitized and still lives in VR technologies. The concept of designing computer games and related VR applications could be changed.

Figure 10 *Recording results of Infraredesign secured portraits with embedded hidden photo of profiles for the security documents (RGB image, Z image)*
Slika 10. *Rezultat snimanja experimentalnih Infraredesign zaštićenih portreta sa skrivenom slikom profila za sigurnosne dokumente (RGB slika, Z slika)*

Combining the visible (RGB image) and invisible (Z image) it is possible to enter into completely new research areas of the shape emergence and the vision of shapes. It could be easier to approach redesigning of the barcodes on all possible types of packaging because the device can simultaneously record the image that is "seen" by the barcode reader and the image seen by a person.

With such a device and software processing the identification of art painting colors with the same ZRGB properties can begin. With numerical verification of the relationship between Z properties and RGB properties for individual tones in two different originals, it is possible for equal matter with which images are made to be quantitatively detected. Thus prepared parallel software provides quantitative research and defining of structure for color properties.

6 Conclusion
Zaključak

The ZRGB device is a new tool in the area of security: detection of dual images, hidden information on banknotes and secured documents, and determination of artwork originality. The ZRGB device takes testing of infrared colors from the lab, allowing control of infrared state of dyes in the mobile space. This applies to industrial applications, the area of forensics and the study of flora and fauna in realistic outdoor conditions. Simultaneous and equal positioning of the dual range of light radiation is the source of a new way of collecting, storing and processing information about the state of matter, which by nature or intentionally reveals its authenticity. The ZRGB device is used for quality control of mixing dyes in textile, printing and leather industries by introducing planned response of these dyes in given wavelengths of light. Two paired cameras with different properties of taking signals are based on construction that is subjected to the final task: different areas of the light source and precise positioning of the paired image elements. The device is designed to function under the daylight without a built-in IR source, which allows viewing and recording of distant objects, not just close ones. It allows the use of sub-versions of the Z camera with built-in different filters. By changing the Z camera together with changing conditions and light sources, and thus the amount of electromagnetic radiation it is possible to investigate and to record responses at multiple wavelengths. This new approach certainly increases the visual power as a degree of visual stimulus emanating from a given design, but of course with viewing through the ZRGB device. Based on the development of such device an algorithm has been developed for determining absorption and reflection properties of matter in a broad range of radiation of human vision which enables further quantitative study on properties of individual structures of dyes.

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