Analysis of Counterfeits using Color Models for the Presentation of Painting in Virtual Reality

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Abstract. The black market for counterfeit works of art is the third most lucrative in the world. The digitalization of art and introduction into the virtual environment allows for a high rate of these counterfeit works. The issue of verifying original works in the online environment currently brings new challenges in the field of forensic science, in particular fields of color vision and working with light, colors, and color models, thus opening new approaches of art verification and presentation. This article deals with image processing and digitalization in color fields and their definition in color spaces. In order to determine a color model of a digitally processed image and for a specific color used, authentic artwork is analyzed by graphic software. This text aims to find and define the same color tone with the actual color tone of the original artwork in the digital environment and color spaces. The definition of color can be an attribute for verifying the originality of a work of art in a digital environment. At present, a precise definition of the color of a painting can help to achieve more accurate reproduction of artwork in a virtual reality environment and its visual perception by the user.

Keywords: forensic art; counterfeits; color model; virtual reality

1 Introduction

Forensic science is a multidisciplinary field that is an integral part of criminology, and it plays an important role in investigating crime and detecting potential perpetrators, primarily because the information and evidence that individual fields of forensic science can provide are based on detailed research. Crimes are reconstructed; crimes committed are detected; the personalities of suspects are analyzed; the evidence is presented in court proceedings. [1] One of the disciplines of forensic science is forensic art, which significantly contributes, among other things, to the possible disclosure of a perpetrator's identity. The appearance of a crime can be detected through the reconstruction of evidence fragments, evidence demonstration, victim identification (in case of an accident), or body decay. At last but not least forensic art can be used in the detection of counterfeit products, counterfeit artworks, and other valuables. Especially in the art field, the gradual advent of digital technologies has created new challenges in this area. New methodologies and procedures for the detection of counterfeit works have been developed. Digital image diagnostics are used to evaluate the attributes of artworks. Computer imaging technologies can obtain evidence of possible manipulation or various information about the origin of the artwork. The possibility of applying modern forensic algorithms to the original painter's work for a diagnostic purpose can help detect and document the potential forgery of an artwork. [2] The use of the theories of light, colors, and color models can complement the detection and documentation of some attributes of artwork. Achieving the most exact representation of colors and structures of artwork depends on the fidelity of the digital reproduction of the image.

This article deals with the possibilities of classification and documentation of the original artwork in terms of colors used in combination with color models and areas for the most accurate reproduction of the image in a digital environment. [3] Experimental scanning and digitalization of an object are performed in order to identify the physical color in a digital environment and define the values of the color. A clearly defined color tone value is necessary for other color applications, especially in other color spaces or in subsequent artistic reproduction printing techniques, for digital archiving of artworks and reuse of color values in further digital image processing.

In the case of precise capture of artworks for further processing, evaluation of a definite attribute, and digital archives, it is desirable to have a quality device with an appropriate optical system for capturing the whole and partial specific parts. Primarily, if the goal is to present a work of art in virtual reality, the user may have an inaccurate visual perception of the object due to the light and textures in the virtual environment scene. By optimizing the elements that make up the virtual scene, the colors, and the display device, faithful reproduction of a work of art in virtual reality can be achieved.

2 Methods

Counterfeiting artworks are simple, and often even the author of an artwork cannot distinguish between counterfeit and original. Counterfeits often appear in the depositories of museums and galleries. Currently, there are modern and complementary methods for distinguishing counterfeits from the original. Options and methods for analyzing the original image may be combined. The choice of the methods also depends on the type of the painting and the purpose of reproduction.

2.1 Visual Cues Method

The initial *macroscopic examination* of the original work evaluates the features that are visible to the human eye. Differences in color tone and painting style may be evident in an artwork. We can also see, for example, the effort to obtain a credible patina that damaged the layer of painting, as well as the canvas to obtain the necessary old look of the artwork. *This stratigraphic method* can be used to evaluate used color pigment as well as the age of drawing. Some pigment can be identified by *polarizing microscopy* and scanning *electron microscopy* (SEM) or *electron microscopy* in conjunction with an *electron dispersion spectrometer* (EDS). The pigment can also be identified by a *microchemical test*.

The style of visual art is usually determined after the creation of the artwork. The style should be significantly different from other styles. Styles can overlap or complement each other. An artist can use more styles in his artwork. There is no specific definition of a visual style. However, we can apply some visual cues from paintings, such as color palette, scene, composition, lighting, contour, and brush strokes. [4]

2.2 RGB to HSL Color Model Conversion

The RGB and CMYK color models are two models used in computer graphics and are directly related. Their abbreviation represents the primary colors; by mixing, we achieve other colors of the color spectrum. These are the example of the primary and secondary colors and their complementary. The RGB and CMYK color models are shown in Figure 1.

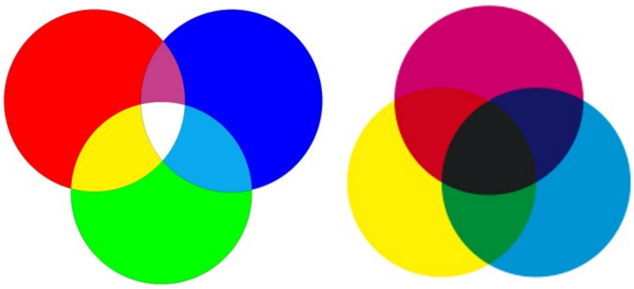


Fig. 1. RGB color model / CMYK color model.

All-digital display devices (such as scanners and monitors) using the RGB (red/green/blue) model, while the CMYK (cyan/magenta/yellow/contrast) color space works with real colors and outputs those colors to different materials. For this reason, it is necessary to recalculate the colors of the individual rooms according to the nature of the input and output information to minimize the loss of color information or to make the resulting display as faithful as possible to the original input information. [4] The HSL color model is very similar to the RGB model but works with different values. This model describes color relationships more accurately and is easier to work with. HSL color model works separately with tones and corresponds better to the color perception of the human eye. The HSL color model can provide other valuable information such as color grade, color saturation, and color brightness. [5]

The advantage is a smooth change of tone. This color model is a favorite in digital graphic art. The color perceived by the human eye depends on the external environment and reaction to changes in it. Mainly lighting conditions significantly affect the resulting color perception.

2.3 Color Measuring Equipment

There are more or less accurate methods of measuring color. The following instruments are used for the measurement of color.

- *The photometer* is mainly used for display devices such as monitors.
- *The fluorometer* (fluorescence spectrometer) is used to measure photoluminescence.
- *The colorimeter* is used for direct measurement of color coordinates or *xy* from *trichromatic values*. This instrument is more accurate than the densitometer below and checks precisely specified and specific colors.
- *The spectrophotometer* is practically the most accurate of all the above instruments. It measures the spectral characteristics of direct or reflected light. With this device, it is also possible to find out the change in hue color depending on the type of lighting used.
- *The densitometer* measures the optical density (density) both in reflection and in the passage of light. These devices are especially suitable for determining the color thickness of layers. The densitometer determines:
    - Transparency (T), i.e., material permeability
    - Opacity (O), i.e., is impermeability rate. It is inverted transparency [6]

Density calculation for individual CMYK process colors using image analysis:

$$D_{cyan} = \log_{10} \frac{I_W}{I_R} \tag{1}$$

$$D_{magenta} = \log_{10} \frac{I_W}{I_G} \tag{2}$$

$$D_{yellow} = \log_{10} \frac{I_W}{I_B} \tag{3}$$

$$D_{black} = \log_{10} \frac{I_W}{(I_R + I_G + I_B)/3} \tag{4}$$

where D_{cyan}, $D_{magenta}$, D_{yellow}, D_{black} are the optical densities of the individual process colors, I_W is the intensity of the comparative white, I_R is the intensity of the pixel red, I_G the intensity of the pixel green, I_B the intensity of the pixel blue.

The experimental study focused on specific artwork and worked with colors and color models to obtain plausible color reproduction in a digital environment. The artistic image belongs to a serial of paintings called Contrasts. The author of the picture, Michal Pasma, likes to use many different styles in his artworks.

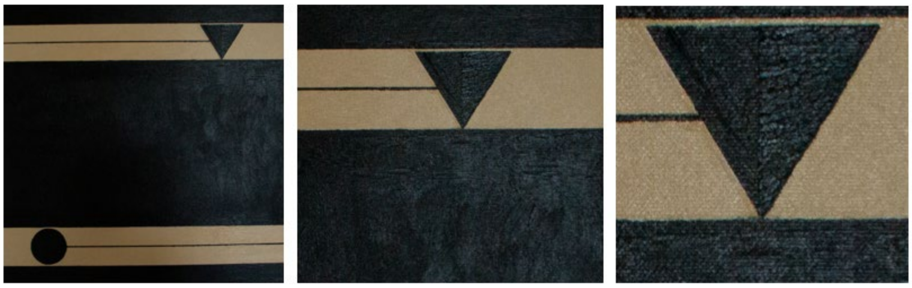


Fig. 2. Structure of painting acrylic on canvas / structure detail enlarged +100% / structure in detail enlarged +200%.

The artwork was a painting with the acrylic technique on canvas, where one color is known. The material structure, stroke direction, and length are captured, as shown by the enlargement of the image in Figure 2. The color measuring devices are not used in the experimental study.

3 Image Capture an Original Artwork

An artistic painting chosen for the experimental work was an artwork painted with acrylic paints on canvas. Three direct acrylic paints from Koh-i-Noor have been used: black 0700, white 0100, ocher 0600. The focus was only on the black paint, shown in Figure 3. [7]

Fig. 3. Artwork on canvas painted with Koh-i-Noor acrylic paint black 0700. [7]

At the time, it was not possible to precisely define the values and characteristics of the light in the room. This artistic acrylic paint for painting is dilutable with water and fixed to the substrate. It is a high-quality dispersion paint with a high number of pigments and colorfastness. The paints can be used on any non-greasy substrate and, after drying, create an age-resistant color film. From the three acrylic colors mentioned, only black was used for the experiments because the other two colors were mixed from other color shades in the artwork. The black color can be theoretically related to the CMYK color model as a direct color.

The art object was photographed in not very good conditions, at dusk, with the spotlight at the space, without the proper lighting of the object. There was no color reference scale for the use of a DNG profile or unification. As expected, the scanned image had to be calibrated manually in a graphic program. The subject was captured with a Pentax K-50 mirror camera with the basic lens without the use of automatic or external flash. The properties of the reference image and the scanning device are shown in Table 2.

Table 1. Properties of the reference image.

Image size	19,3 MB
Image dimensions	4928 × 3264 px
Resolution	96 dpi
Bit depth	24 bit
Color range	sRGB
Aperture shuter	f/5
Exposure distance	1/200 s
Focal distance	35 mm
ISO	177

An important aspect when working with color and image digitization is the color calibration of input and output devices. This was used to define them and create their color scales to further refine colors and tones similar to original images. For these purposes, it is easiest to use a standardized color combination, and each sub-photo with the DNG (digital negative) profile needs to be created. It is reusable between sets of photos and between cameras. RAW files used to archive images may generate digital cameras differently, and specifications are not always available. DNG format is suitable for editing, simple archiving, and providing easy access to archived files.

The DNG format is supported by software vendors and used by manufacturers of cameras and 3D imaging devices. The classic standardized reference scale with 24 color fields for creating a DNG profile is used nowadays. The standardized reference color scale is a part of the chromatic triangle (chromaticity diagram) *xy* CIE 1931, as shown in Figure 4. However, this color scale was not available when capturing the image. It was incorporated by subsequent image processing and onerous editing. Image processing, calibration, and conversion of colors and profiles were thus made only in graphics programs.

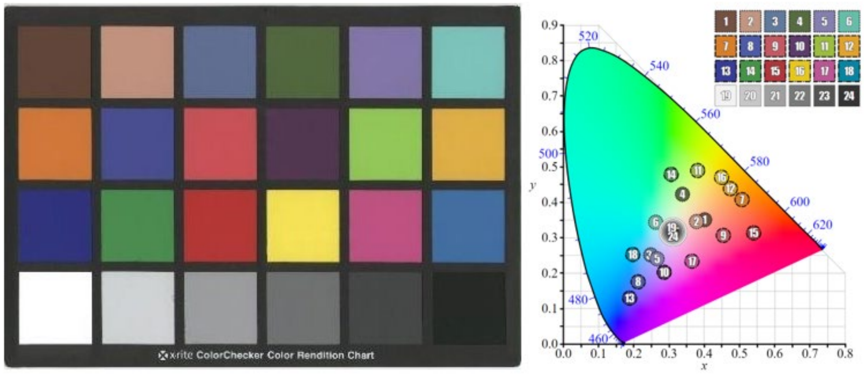


Fig. 4. Scale of 24 color fields and their position in the chromatic diagram.

This article is focused on specific works of art and artworks with colors, color models, and spaces to obtain reliable reproduction and definition of colors in a digital environment. When an image of an object is captured under less favorable conditions, without proper illumination, a calibrated scanning device, or a basic standardized color gamut, it provokes several other questions about the image in terms of color processing. Above all, how to define black color paint in a digital environment. The following chapter describes color calibration, working with color models and spaces to approximate the tone of color spots and define the color and its properties in digital form.

4 Digital Processing of the Scanned Image

The selected artwork contains contrasting transitions and geometric elements. It was possible to work better with the image and the primary color. The light color on the paintings was mixed with ocher and white for the final shade. The painter used three colors. The color black was chosen for the experiment. This color could be theoretically related to the CMYK model as a primary color.

The original RAW format was loaded into the Camera Raw 13.1 [8] software workspace and then made basic adjustments to the digital image. Basic adjustment and color calibrations were adjusted in the RGB model, as well as the hue and saturation. Subsequently, the curve of the light and shadow values was corrected. This process is shown in Figure 5.

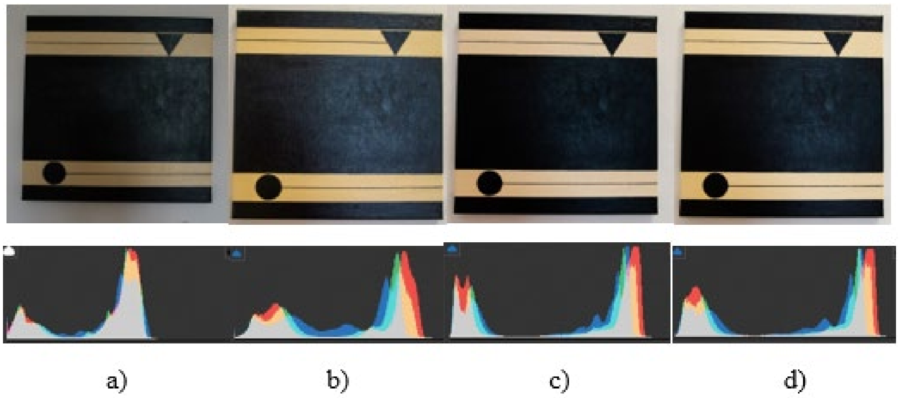


Fig. 5. Images and histograms after individual adjustments of the digitized image: a) of the original image in the RAW format before the adjustments; b) basic adjustments of the digital image. The basic parameters values adjusted from the initial values: hue; exposure; contrast, lights; shadows; and saturation; c) color calibration R, G, B; d) adjustment of the image curve values: light; shadows; white and dark values.

After basic adjustments, there were further image adjustments with emphasis on color transitions and color mixers in connection with the color model HSL. This color model is the most widely used in the digital graphics environment. Its advantage is the smooth transition of colors in tones compared to a similar model HSV. Further image adjustments are shown in Figure 6.

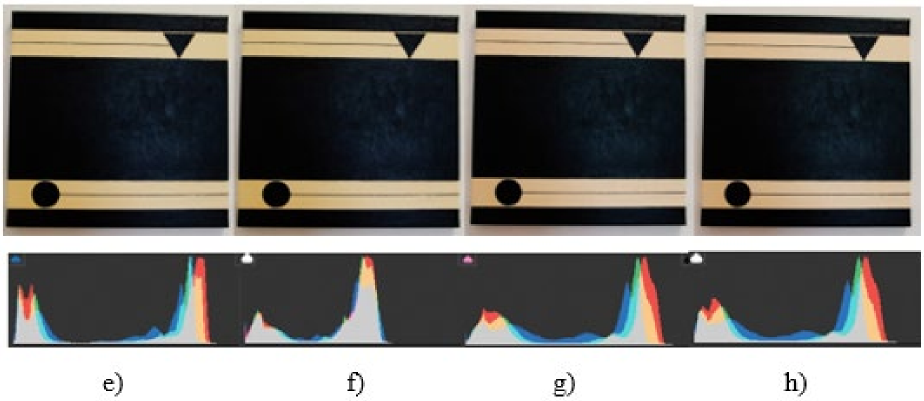
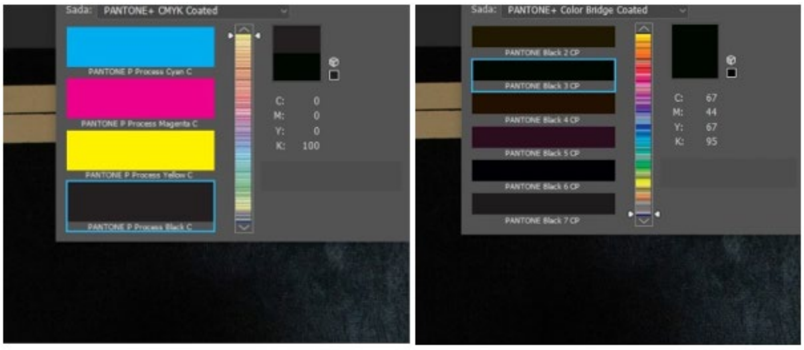


Fig. 6. Images and histograms after further adjustments of the digital image: e) adjustment of the amount and hue of the purple and green components in digital image reproduction; f) adjustment of color transitions in mid-tones, shadows, and light; g) color mixing and adjustment of individual colors RGB, CMYK, purple and orange to the HSL model; h) adjustment of color transitions in the HSL model.

After these adjustments, the digital image was evaluated and was recalculated as the object into the Adobe Photoshop [8] work environment. This image was center by rotating the canvas 2 degrees to the left. Then the image was cropped to clean the background. In this case, it was walls. Further calibration of the RGB color values was applied, and the area with the highest possible black value was selected. The goal was to find the same shade of black that matches the color from this place. There were defined the color value of the painting's black color in the CMYK color model. The hue of the corresponding color was select from many color scales and spaces that the graphic program offers.



a) b)

Fig. 7. Comparison of the color Pantone scale with the color in the image area: a) the color Pantone Process Black C; b) the color Pantone Black 3 CP.

Figure 7 shows a comparison of two colors from the Pantone scales [9]. The first is the color Pantone Process Black C. This color is a process color from the colors of the CMYK Coated swatch. The second color is Pantone Black 3 CP from the Pantone Color Bridge Coated color range. This color was the same as the black tone on the image area. In the CMYK color model, it corresponds to the color values C = 67; M = 44; Y = 67; K = 95. Figure 8 shows both shades of black from the Pantone scales. The difference between them is obvious to the human eye.

Fig. 8. Comparison of the color Pantone Process Black C and the color Pantone Black 3 CP. [9]

Table 2 gives the exact numerical definition of the black tone on artwork in color models.

Table 2. Numerical definition of the black tone.

Color model	Black color numerical definition
Hex	#262d26
RGB	rgb(38, 45, 38)
CMYK	cmyk(67, 44, 67, 95)
HSL	hsl(120,8.43%, 16, 27%)
RGBa	rgba(38, 45, 38, 1.00)
Lab Xyz	xyz(2.0876, 2.4288, 2.1927)
HSV	hsv(120,15.56%, 17, 65%)
HSVa	hsva(120,15.56%, 17.65%, 1)

5 Visual Comparison of Artwork in Virtual reality

Currently, the virtual reality environment offers many possibilities. Virtual reality is a new opportunity for the presentation of artists and their artistic work. Galleries and museums are already using this technology. The exhibits can thus be presented to the public indirectly virtually in an online environment. Accurate reproduction of the object in a virtual environment is necessary. The virtual environment that is created affects the object and its presentation, primarily working with light in software to create virtual environments.

The artwork was embedded in a 2D virtual reality software environment. Primary virtual 3D space has also been created. In this study, Unity software [10] was used to create virtual reality. Figure 9 shows the effect of software on the quality of the reproduced image. The original image and the color-optimized image are placed side by side in the software's 2D and 3D graphics environment.

a) b) c) d) e) f)

Fig. 9. Comparison of the original image and the optimized image of the works of art: a) the initially captured image; b) an image calibrated in color in a graphics program; c) the captured initially image displayed in a 2D environment; d) a color-calibrated image displayed in a 2D software environment; e) the initially captured image displayed in the 3D software environment; f) a color-calibrated image displayed in a 3D software environment.

Subsequently, the work of art was inserted into a virtual environment with the wall's texture behind the painting and the wooden floor. The textures were created from the free Unsplash database [11]. Light first affects the perception of image and space in virtual reality. The white spotlight is used to illuminate both images at the center point between them. This light first affects the visual perception of the colors of both images. Figures 10 and 11 show the effect of light on the scene and the color perception of the two types of images.

Fig. 10. The scene without the spotlight.

Fig. 11. The scene with the spotlight.

Both the original and the optimized artwork look in color, as do all the types of images in Figure 9. The images differ in the scene created to present the artwork in virtual reality. At first glance, the images and their colors are different in Figures 10 and 11 compared to the images in Figure 9. The images are also different when observing scenes with and without lighting. The background and its structure influence the perception of works of art in the scene. The light and lighting of scenes must be optimized for the reproduction of works of art in virtual reality. Color analysis in color spaces to clearly define colors in virtual reality will include the following studies as well.

6 Conclusion

Colors and color models are very narrow and have specific issues. In the case of artworks and counterfeits, colors play an important role. Their chemical and optical properties, as well as other properties, significantly varies not only in terms of time but also environmental influence on color sustainability. In the case of original artwork, its quality in digital reproduction can not only be preserved but its artistic value can also be transferred to other presentation channels and thus reach people all over the world. In terms of color reproduction, this is the most faithful approximation to a reused dye in a physical environment. There are many ways to achieve this, not only in terms of new uses but also for defining individual colors and outputs in different channels.

In this article, an experiment was demonstrated concerning a process of color definition for its further use in a digital graphic environment. The subject of the research was the black acrylic paint Koh-I-Noor 007. The original painting was painted using the acrylic technique on canvas. This paint is characterized by a high number of pigments, and its coating is fixed. The experiment included transferring artwork to an online environment, adjusting and calibrating colors, and further eliminating other aspects that have arisen in image capture, where there are no other high-level professional scanning techniques, no other accessories for working with colors and their properties. As can be observed, working with color and color spaces, and mixing channels thus requires considerable patience and time. The above-mentioned color was defined specifically in the form of a shade in the Pantone color swatch as Pantone Black 3 CP, and then it was specified for use in other color spaces.

The color defined in this way can serve as a basis for a faithful printed reproduction or further reproduction of the original in an online environment or in virtual reality with a clear specificity. In the case of two more colors, ocher and white, from the same manufacturer, the most appropriate methodology would probably be to perform direct measurements by instruments designed for this purpose and presented in this article. The main focus of this research was on using spectrophotometer or densitometer as the two most important methods concerning debated issue.

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