Colorimetry Analysis of a 3D Model of Artwork for Forensic Examination of a Counterfeit in a Virtual Environment

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Abstract
This article describes an experimental analysis of an original artwork using color models. The text discusses color analysis in a 3D point cloud of a digital twin of an artwork. A digital twin of the artwork is created using the Structure of Motion photogrammetry method. CMYK and RGB color models are used for color analysis of the 3D model. The created color digital 3D model is then compared with the color values of the actual work of art measured by a colorimetric device. In the next step of the presented research, the exact values of the color attributes of the artwork are experimentally defined. The original artwork is digitized to a virtual art gallery environment for presentation purposes. The experiment aims to realistically reproduce art in a digital environment and define its originality in a virtual environment using color analysis. Accurate digitization of art into a virtual environment with defined color attributes is the primary goal of the experiment discussed in this text. The presented article also discusses other research possibilities in art digitization and the use of digitization methods in a virtual reality environment in art and social science.

Keywords: Colorimetry, Color Model, Photogrammetry, 3D Model, Digital Twin, Digital Art, Art Digitization, Virtual Reality, Art Gallery, Forensic Science

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Introduction

The progressive development of digitization affects almost all areas of human activity. Commercial fields, science, and research are forced to respond to the rapid development of modern technologies [1]. It is the same in the field of culture and cultural heritage. This rapid trend in the development of modern technologies was also reflected in art, exhibitions, media, marketing, and other fields. [1] This text discusses the issue of forgery within the digitalization of art. The black market for fakes is the third largest in the world. With the developing digitalization, there was also a need to respond to modern procedures in the area of counterfeiting. Digital image processing and its reproduction in the online and virtual environment in this direction provides excellent potential for research into this issue [2].

This text responds to the current needs in the digitization of art. The issue of identifying the originality of a work of art focuses on the area of color identification and the use of color models and spaces. The color, as well as the material and texture of the work of art, provides much information that can be used in the digitalization of art to analyze the image and research the mentioned issue. As part of the experiment and the creation of a digital twin, the question arose as to whether it would be possible to use some individual steps in the entire process of art digitization to identify original attributes [3]. These attributes could accurately describe specific properties of a work of art. This indicator could be precisely the colors and color properties of art. Image and color analysis can provide valuable information that could partially protect artworks from counterfeiting. In this experiment, we work with a digitized image. Colorimetry methods are therefore used here in the context of image processing, color vision, computer vision, and digitization of works of art [4].

The work of the Czech academic painter and master graphic artist František Peňáz (1912-1996), who was born in Pašovice in the Zlín Region and also lived and worked in the city of Zlín, was used in this scientific work [5]. Specifically, an original graphic work made using the artistic technique of lithography was used. The artwork was printed on handmade paper. It must be noted that this artistic technique and image reproduction always create an individually printed original. This artwork, therefore, provides a reasonable basis for color analysis of a digital reproduction of this author's artwork.

The first analysis of the originality of art is often a visual inspection by a human sign and an initial macroscopic examination, which reveals the difference in the tones and style of the painting, the dream of obtaining a patina. Standard methods for pigment evaluation include stratigraphy, using a polarizing microscope, scanning electron microscope (SEM), or electron microscope coupled to an electron dispersive spectrometer (EDS). However, these classic methods do not solve the forgery problem in a digital or virtual environment. Several approaches and methods are currently used to process and digitize the reproduced image. These methods depend on the methodology used. Research on the issue of forgeries of works of art, products, or misinterpreted photographs varies in their approach. This text presents new procedures for solving the problem based on image analysis of a 3D digital twin of a work of art intended for presentation in a virtual reality environment [6]. For image and color analysis, it uses modern methods of image digitization, photogrammetry, and colorimetry [4,7]. With their mutual connection, one can expect an accurate definition of colors in a digital environment compared to the color of an original work of art and its reproduction in a virtual reality environment.

Method of Art Digitization

The Structure of Motion method (SfM) was used to digitize and transform the artwork into a 3D model. This photogrammetric method works with a series of 2D photographs of the object. It works with an actual image. The essence of this method is to find points in space. After that, additional points are added based on triangulation. The number of photos used depends on the object's size, the complexity of its structure and texture, and the color and optical properties of its surface. These mentioned properties of the object can affect the quality of the resulting reproduced image. The artwork used in this study is printed using the lithography method on handmade paper, and its size is close to the standardized A5 format. Due to the size of the selected object, it was unnecessary to take many photos. A series of 14 photos of the object was used to create a 3D accurate model. Figure 1 below shows the process of digitizing an object and creating an accurate 3D digital twin of the artwork.

Figure 1: The 3D digitization of the artwork using photogrammetry:
2D photos of the artwork, a series of used photos, and the resulting 3D model.

Figure 1 shows three images. In order from left: The first image is a photograph of the original artwork chosen as the object for creating the 3D digital twin. The image in the middle shows a series of 14 photos of objects and their positions. The resulting digital 3D model from these photos is modeled in the software (SW) Agisoft metashape Professional, which shows the last image. The following table 1 lists the individual parameters of the image in comparison with the parameters and properties of the created 3D model.

PROPERTIES	PHOTO IMAGE	PROPERTIES	3D MODEL
Image size	4,21 MB	Point cloud	2 757 points
Apert. shutter	f/1,8	Key points	12,63 MB
Exposure	1/59 sec	Dense cloud	101 314 points
Resolution	4 032 x 3 024	Point color	3 bands/uint8
Bit dept	24	Faces	132 740
Color model	sRGB	Color model	RGB
Focal distance	3 mm	Focal distance	17 mm
ISO	320	Vertices	68 808

Table 1: Comparism of the properties photo image and 3D model.

This model and parameters are also the basis for image and color analysis using the principles of Colorimetry.

Application of Colorimetric Methods and Color Models

Colorimetry works with the human eye's principles of image and color perception. It works with color models, color spaces (gamuts), and light. Colorimetry describes colors in numbers. This study uses color models to analyze the colors of an original work of art reproduced in 3D and a virtual environment. Specifically, two color models and their gamuts are used. The CIE1931 trichromatic triangle, which has been standardizing work with colors since 1931, defines the color space. Figure 2 shows CMYK, RGB, and CIE1931 color models with the gamuts used in this experiment.

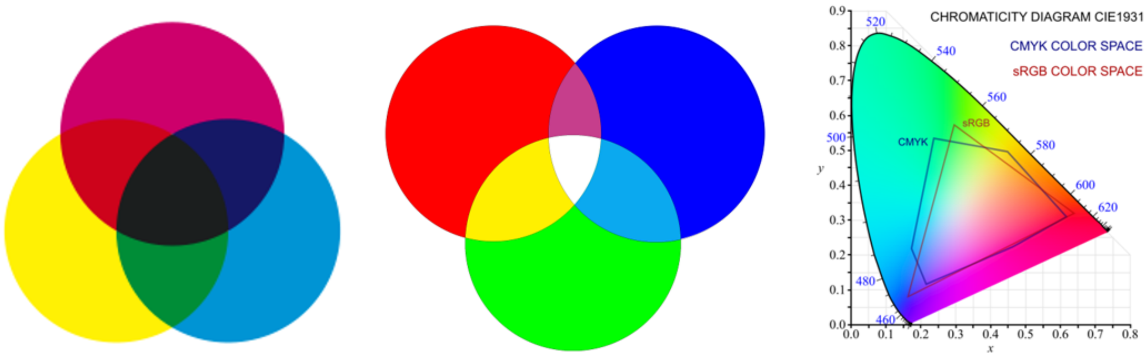

Figure 2: CMYK color model, RGB color model, CIE1931 with CMYK and sRGB gamuts.

Figure 2 shows the CMYK (Cyan, Magenta, Yellow, Contrast) and RGB (Red, Green, Blue) color models. These color models are suitable for this study. The CMYK model numerically describes the physical color applied to the material. In this experiment, a straight black color (Contrast K) is applied to hand-printed paper. The age of the artwork is estimated at 30-40 years. The color and the printed material can change its appearance and properties over time. The ambient conditions can also influence the accuracy of the color values during the scanning of the object.

Black printing ink (K) was chosen for this study, the pigment of which could change over time and thus affect the current numerical values. Measure the color values of black on the printed material; the Colorcatch Nano colorimeter is used, which measures the numerical values of all individual CMYK color components. At the same time, v is also experimenting with the RGB color model, shown in Figure 2 in the middle. This color model works with light, and the resulting colors show all digital displays. The third image shows the CIE1931 trichromatic triangle, in which the CMYK and sRGB color spaces are marked. The color space (gamut) defines the maximum range of color values. In this study, the sRGB gamut was chosen for RGB. Most current display devices display a range of colors in this color space. The simultaneously used measuring device (colorimeter) of color values also gives numerical values within the sRGB gamut.

The Digital Artwork in a Virtual Art Gallery Environment

Defining the colors of an artwork in digital form is problematic for its reproduction in virtual reality. Creating a virtual environment includes many aspects that need to be considered. In particular, they were concerned with creating a realistic virtual environment. In this case, the goal is a realistic perception of the user embedded in a virtual environment. In this experiment, the goal is a realistic reproduction of the artwork and the definition of its color properties. This study used the freely available VR environment creation software Unity 2021 for creation and visualization. One of the tools in creating a virtual environment is light. Working with light is essential in this study. The virtual presentation of works of art in virtual galleries is also conditioned by the realistic lighting of the exhibits and the overall virtual space. In this study, the focus is primarily on the visual reproduction of said work of art. The goal is a realistic digital color reproduction of it for a virtual art gallery. Figure 3 shows the influence of the choice of lighting in the VR environment on the color reproduction of the artwork.

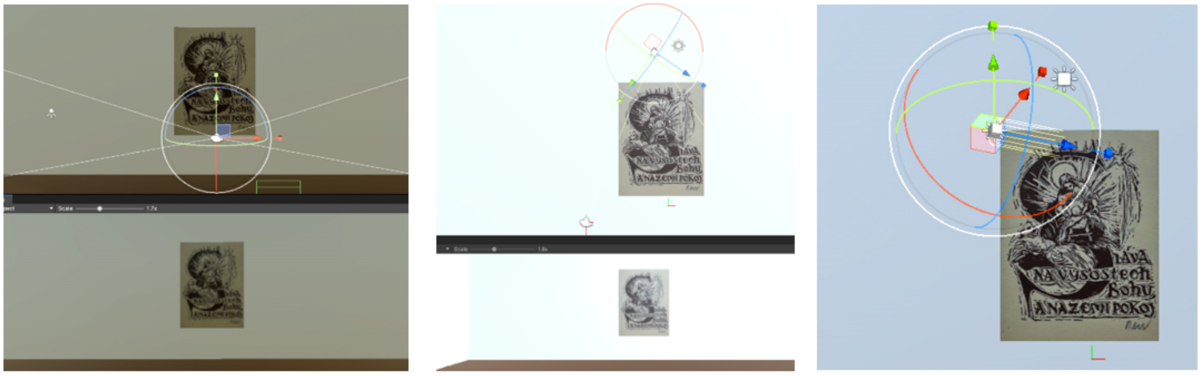

Figure 3: The effect of lighting in a VR gallery on visualizing a digitized work of art.

Figure 3 shows an unlit virtual space where the artwork blends into the natural background. In this case, the lighting in the created VR environment does not work. The middle image shows a VR environment using dispersed white light, reflected in the artwork's color and the overall environment. The third picture visualizes the use of a spotlight to illuminate the exhibit. In this case, more criteria had to be used to determine the spotlighting so as not to suppress the color of the digitized artwork. In Figure 4, a detail of the artwork and the lighting effect in the VR environment are visualized.

Figure 4: The effect of lighting in a VR gallery on visualizing a digitized work of art.

Figure 4 shows the effect of light has a significant influence on the display of the artwork in the virtual environment. By choosing the type of lighting and the object's location in 3D space, we can significantly increase or degrade the quality of its display. Therefore, the lighting attribute must be considered when creating a virtual space.

Results and Discussion

The artwork was made using the technique of lithography and the printing process of black ink (Kontrast) on handmade paper. This object is, therefore, the carrier of several specific attributes. This text focuses on the analysis of color and its reproduction in virtual reality. The process black color (K) was measured with a Colorimeter. One place in the entire reproduction was measured, and the absolute value of Contrast in the CMYK model (170, 0, 0) was measured. That corresponds to the assumption of using a printing ink containing a natural black pigment that can fulfill these absolute values and perfect coverage of the printed material with a very rough texture. At the same time, the absolute value of K was used to define all the points in the point cloud forming the 3D model, as shown in Figure 5. This 3D model is one of several stages of creating the final 3D textured model.

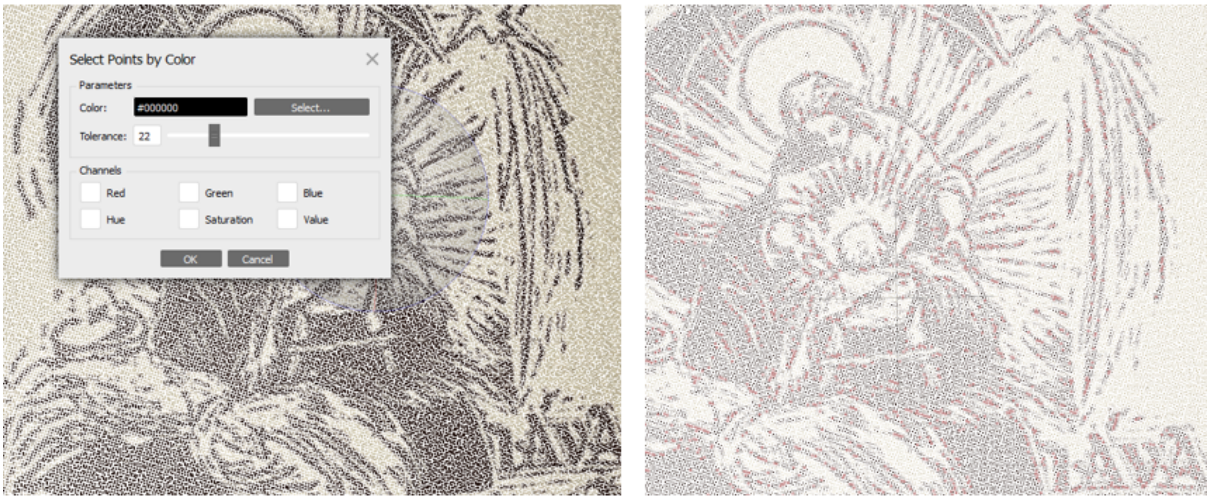

Figure 5: 3D model of point cloud with an active absolute K points.

As seen in Figure 5, it was necessary to convert the absolute value of the color component K from the CMYK model to the mathematical representation of Hexa. The values 170,0,0 converted as #00000 in the hex model. The number of points with this precisely defined value in the overall point cloud represents one of the attributes that can be used to transform the object and its texture into a virtual environment.

Discussion and Conclusion

In this experiment, the possibility of using the color attributes of a work of art to identify its originality was practically analyzed. The color properties of an object digitized and converted into virtual reality remarkably influence the quality of digital reproduction. This study digitized and reproduced a work of art using the lithography technique on handmade paper. The printing color transferred to the material was only black (K). Colorimetry method was used to analyze this color using CMYK, RGB, HEX color models, and the sRGB color space. Black values were measured using the Colorimeter measuring device. After carrying out and repeating several measurements, it was evident that the black color has an absolute value (K 170,0,0). This fact presupposes using a natural black pigment for graphic printing, which has properties for these values and the permanence of the color of the pigment if it is not exposed to sunlight for a long time. This absolute black value was applied in the next steps of the practical experiment.

The 2D artwork was digitized using classic digital photography. A series of photographs was taken that contained a total of 14 photographs. This number of images proved to be sufficient for creating a 3D model. The scanned art object was made in actual A5 format. The next step was to use the SfM photogrammetry method. In this step, a basic 3D model of the object was created. A 3D point cloud was created and analyzed in the next phase of model creation. In this step, it was possible to analyze the color values of individual points. Using the absolute K value converted from the CMYK color model to the HEX model (#00000), points with this color value in the point cloud were identified and segmented.

The next step in digitizing the artwork was reproducing the 3D model into the virtual environment of the art gallery. In this step, a problem with the resulting reproduction in VR manifested itself precisely in the case of color. Although the 3D model was marked with color attribute identifiers, the resulting display of the object's color was significantly influenced by the lighting of the virtual gallery. This problem thus represents a separate challenge and a future continuation of the experiment. Several simulations of lighting types and intensity were experimentally used in the virtual art gallery. Each of these types significantly influenced the final appearance and color of the digital artwork. It is therefore necessary to add work with light and its simulation in the VR environment as another factor to increase the quality and display of 3D reproduction of art in VR. This attribute also represents another attribute for use in the field of anti-counterfeiting. The presented experiment created further challenges for research and development in the field of art digitization and the presentation of artworks in a virtual environment.

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