Digital Restoration of Van Gogh's Painting *Field with Irises near Arles*

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ABSTRACT

Often the colors of paintings have been affected by pigment ageing. Art specialists and the general public alike value digital visualizations of how paintings may have looked just after their creation. This paper describes how such a visualization was made for Van Gogh's *Field with Irises near Arles* (May 1888). First, we captured multispectral data, and then corrected it for the presence of yellowed varnish. Based on visual and microscopic examination, analysis of paint samples and paint orders in Van Gogh's letters, the pigment palette for this painting was determined. With multispectral data, we estimated Kubelka-Munk parameters. Using industrial color formulation software for massive color recipe calculations, we processed multispectral data for 1.7 million pixels representing the painting to calculate concentration maps for each pigment. These maps were validated with XRF data, and confirmed by the highly accurate back-predictions of colors (average CIEDE2000 = 1.05), by microscopic examination and chemical analyses.

We estimated the original values of the Kubelka-Munk parameters by applying careful reconstructions of the historical pigments. Combining these with the calculated concentration maps we obtained a digital visualization of how the painting may have looked originally. The color changes thus identified are shown to be caused mainly by discoloration of a few pigments: cochineal, eosin and chrome yellow.

KEYWORDS: Conservation, Cultural heritage, multispectral imaging

INTRODUCTION

In many paintings, colors have changed because of pigment ageing and varnish yellowing. For several reasons it would be interesting to create a digital visualization of how these paintings may have looked originally, as intended by the painter. We have investigated the making of a digital reconstruction of a painting created by van Gogh in May 1888, *Field with Irises near Arles*.

For this investigation, we use multispectral image data. In a first step, we corrected this data for the yellowing of the varnish, as described in section 2. In section 3, we show how we calculated pigment concentration maps that quantify the spatial concentration distribution of every pigment. In the next section, we describe how we prepared physical reconstruction paints that represent the original versions of the pigments as used by van Gogh in 1888. We then determined the values of the Kubelka-Munk optical parameters for the reconstruction pigments.

In section 5 we combine all results to calculate the digital reconstruction, and summarize our main conclusions. We will show how the digital reconstruction leads to an improved understanding of this painting.

We note that the present article can only summarize the results from this project. Many more details are given in an upcoming series of papers [1][2][3][4].

MULTISPECTRAL IMAGING AND VARNISH CORRECTION

As the basis for our investigation, we used multispectral images captured from the painting when it was taken off display for a full cleaning and restoration treatment. Part of the treatment involved physical removal of the varnish layer that had yellowed over time. The varnish had not been applied by van Gogh, but by a conservator in 1927, long after the death of the painter. When the multispectral images were made, the varnish had been removed from approximately half of the painting.

For multispectral imaging, we used a line-scanning transmission grating spectrometer (Specim V10E), combined with a back-illuminated CCD detector. This produced a data-cube that contains 1416x1194 pixels, each containing spectral data for 217 different wavelength bands ranging from 405.4 to 955.3 nm. The resulting spatial resolution is 0.46 mm, and spectral resolution is 2.5 nm.

The measurements enabled us to develop a mathematical correction that takes into account the effect of the varnish layer on the spectral reflectance of the painting [1]. We did so by identifying eleven different spots in the varnished part of the painting, where experts on van Gogh's paintings (co-authors EH, MG and FL) assume that lead white pigment is used in unmixed form. Apart from that, we also identified the brightest spot on the painting where varnish already had been removed, and where the same experts also assume pure lead white pigment to be present. The spectral reflectance of each varnished spot was then compared to the values for the unvarnished spot. The non-hiding two-constant Kubelka-Munk equation then enabled us to estimate the optical parameters K (absorption) and S (scattering) as a function of wavelength.

Our results show that in the aged varnish layer, absorption is considerably larger than scattering [1]. Absorption is particularly strong for blue wavelengths, whereas scattering is strongest for larger wavelengths. This combines in the well-known appearance of a yellowish translucent ("milky") layer. Our calculations show that depending on wavelength, only 20 to 50 percent of the light is transmitted by the varnish.

PIGMENT CONCENTRATION MAPS

Several letters written by van Gogh list the tube colors that he ordered in the period this painting was created. With XRF (X-Ray Fluorescence) spectrometry on this painting, we obtained information on the spatial distribution of several chemical elements in the painting, which often can be related to specific pigments present in the tube paints he used. More information on which pigments actually were used in *Field with Irises near Arles* was obtained by analyzing paint samples that had been taken from the painting around 1930. As part of the present investigation, four new samples were also taken from the painting and prepared as paint cross-sections. These were examined using Optical Microscopy and SEM-EDX (Scanning Electron Microscopy with Energy-Dispersive X-ray spectroscopy). One sample was analyzed using HPLC (High Performance Liquid Chromatography) to identify the organic red pigment.

Table 1. Pigments occurring on the painting, and average color accuracy obtained from Kubelka-Munk back-predictions at selected spots where these pigments occur on the painting.

Pigment	CIEDE2000	Pigment	CIEDE2000
Lead white	0.0	Vermilion	1.8
Zinc white	7.9	Emerald green	3.4
Chrome yellow (field)	1.8	Viridian	2.6
Chrome yellow (dark spots)	2.5	Prussian Blue	2.4
Red lead	1.0	Ultramarine blue	1.9
Eosin (Geranium) lake	3.2	Cobalt blue	7.9
Cochineal lake (Carmine)	4.7		

We combined all this information to obtain a complete overview of the pigments used in the painting, as shown in Table 1. For five of the pigments thus identified, color experts were able to find spots on the painting where the pigment seems used in unmixed form: Lead white, Red lead, Eosin, Vermilion and Prussian blue. For each of the remaining pigments, we located spots on the painting where it occurs in a binary mixture, often with Lead white. By analyzing the spectral reflectance data from the multispectral data-cube, from any set of binary mixtures at various unknown concentrations, we were able to estimate Kubelka-Munk absorption and scattering parameters.

Table 1 shows that the optimized set of *K* and *S* values is able to back-predict spectral reflectance data to a relatively high degree of accuracy, with average CIEDE2000 < 3.5 for almost all pigments. In a next step, we processed the spectral reflectance data for each of the 1.7 million pixels of the multispectral data-cube [2]. For each pixel, we were able to fully optimize the concentrations of each pigment, using the hiding Kubelka-Munk model. These optimizations were only made feasible in terms of computing time by using color formulation software that had been developed in house for the car refinishes industry. It was rather unexpected that we could utilize software intended for the car repair industry to digitally 'restore' the colors in van Gogh's painting.

The calculated spatial distributions of all pigments were represented as Pigment Concentration Maps. Their accuracy was confirmed by comparison with the XRF maps, as illustrated in Figure 1 for pigment Prussian blue.

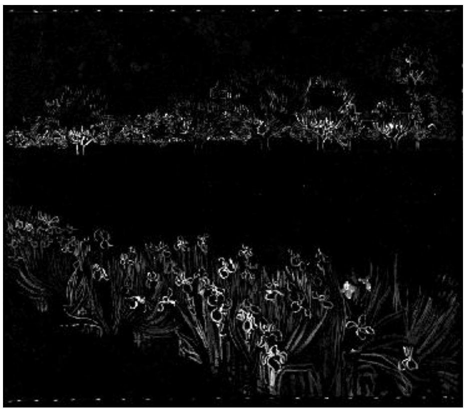

Figure 1: (a) Concentration map for pigment Prussian blue, according to (a) Calculations and (b) XRF measurements for element Fe-K.

PHYSICAL RECONSTRUCTION PAINTS

For each of the pigments mentioned in Table 1, we prepared physical paint reconstructions by following historical source instructions on raw materials and production processes [3][4]. The aim of these reconstructions is to replicate the pigments used by Van Gogh with the best possible historical accuracy.

The physical reconstruction paints were mixed in specified ratios with especially white and black pigments, and applied on standardized Leneta black-white charts. We measured the reflectance on both substrates using a Konica-Minolta 2600D diffuse sphere (d/8) spectrophotometer in Specular Component Included mode. This allowed us to estimate the non-hiding Kubelka-Munk *K* and *S* parameter values for each pigmented paint, as representing its original state when used by van Gogh [3][4].

MAIN CONCLUSIONS AND INTERPRETATION

By combining the Pigment Concentration maps (section 3) with the Kubelka-Munk *K* and *S* parameter values for each pigment in its original state (section 4), we were able to calculate the presumed original spectral reflectance at each pixel. This is shown in Figure 2. Comparing the digitally reconstructed colors with those measured for the present state of the painting, the color changes are striking. The red lake pigments cochineal and Eosin have faded significantly over time. As a result, the original wide variety of purple colors in the irises has become a rather uniform blue, thereby losing much of the vigor that is characteristic for the style of van Gogh. The pink flowers in the bottom left foreground and in the fields have similarly turned bleak white due to the same pigment fading over time. The digital reconstruction of the colour reveals that the pink touches served to break the uniformity of colors and to guide the viewer into the painting. .

Another striking effect of the discoloration is that the chrome yellow pigment has become much darker. The reconstruction shows that the fields were originally dominated by bright yellow colors, instead of the darker greenish yellows we now find in the painting. The sense of depth in the painting is much stronger in the reconstruction, because of the varied colors of the irises and the gradual change in color along the main diagonal in the field that separates the mown from the unmown parts.

Also, the play with simultaneous contrasts between the irises and the surrounding fields obtained by putting complementary colors next to each other according to the color theory of Charles Blanc becomes fully recognizable in the digital reconstruction. According to that theory, the intense yellow colors in the field make the purple color of the irises even more intense purple, while at other places where the field is green, the color of the irises would become more reddish instead.

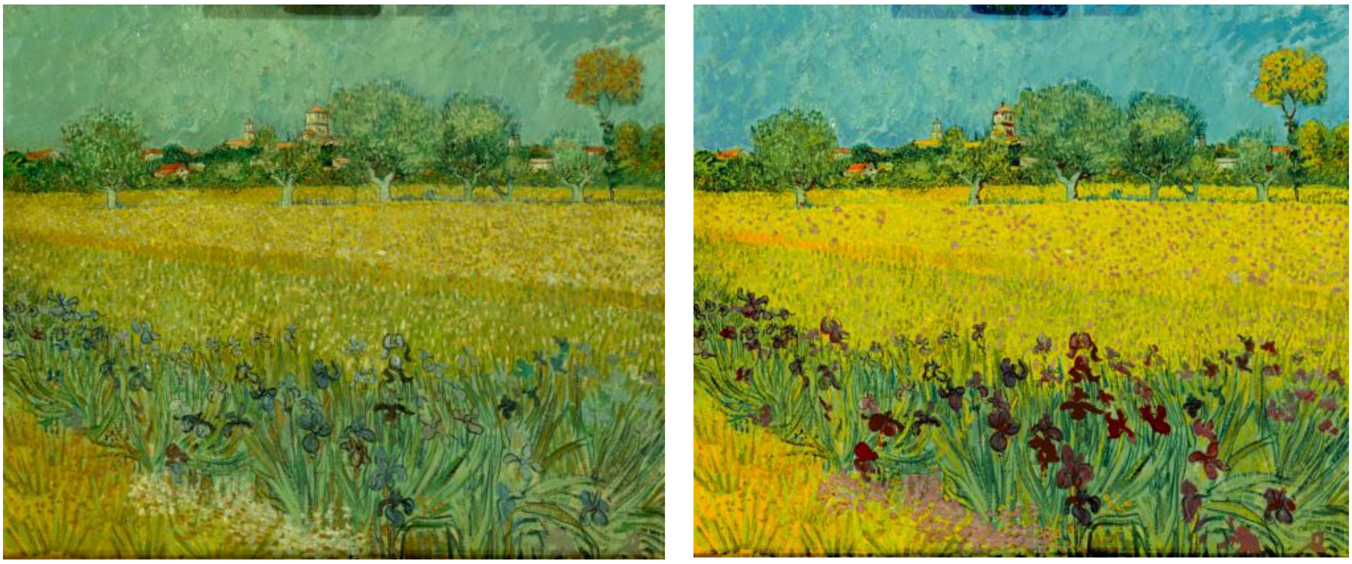

Figure 2: (a) Color representation of current, aged state of Field with Irises near Arles (after varnish removal), based on multispectral data. (b) Digital restoration of the original colors, based on current investigation.

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