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FILM2PAINT: Transforming photographic documentation on reversal film into paintings' accurate colors

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Abstract

Displaying the past appearance of artworks by reversing degradation phenomena holds significant value for art historians, conservators, museum curators, educators, and the wider public, as it seeks to estimate the original artist intention. In this work, we aim to restore the past colors of a painting from documentary records done on reversal film photographs. The challenge with these photographs is that due to film-specific chromogenic processes, their colors are inaccurate with respect to the captured object. For this reason, we test the performance of four color correction methods in compensating for the color distortions inherent to each film type by using a dataset of reversal films of two color targets, X-Rite ColorChecker Digital SG and Coloraid IT-8. Furthermore, we apply the same method to detect changes due to aging and/or conservation treatments in the painting Junger Proletarier (1919) by Paul Klee, by comparing a color corrected film record from 1995 with a more recent digital capture of the painting from 2005. Our results indicate that the method which best accounts for the film chromogenic processes to reveal the actual colors of the photographed object is based on non-linear optimization using a neural network.

Introduction

Since the 1960s, numerous museums have been documenting artworks by capturing images on reversal color film, often choosing Ektachrome for its widespread availability. However, this practice poses certain challenges, as photographic documentation ideally seeks to provide a faithful representation of the object, while reversal film was mostly marketed for its ability to produce visually appealing images with vivid colors and enhanced contrast—not necessarily accurate.

Starting from the 1980s, there has been a growing interest in monitoring the condition of paintings with precise colorimetric accuracy, and multispectral imaging systems have been tailored for this purpose [1]. With the advent of digital cameras at the turn of the century, museums gained the ability to achieve more precise color control using relatively affordable equipment.

Over the course of approximately four decades (1960s to 2000s), photography departments in museums worldwide have relied on reversal color film to capture images of artworks. Often, these images represent the sole visual documentation of museums' collections from this era. This photographic record has the potential to serve as a relevant source of information in reconstructing an artwork's original appearance and tracking its evolution over time.

This paper describes the endeavor to rectify the color of reversal film, aiming to obtain a faithful representation of the object as it appeared at the time of photography. This involves correcting the color distortions introduced by the specific film type.

Additionally, considering the span of time since the photographs were taken, the fading of film dyes, particularly pronounced in photographs captured prior to the 1980s due to the use of more fugitive dyes, adds an additional layer of complexity to the accurate interpretation of chromogenic colors.

The rectification of the photo-chemical colors must be based on reference colors present in the photograph. These can be represented by color charts placed beside the artwork or by the artwork itself, as long as spectral/colorimetric investigation have been conducted on it, including the assessment of the stability of its pigments and dyes (e.g., micro-fading tests) [2]. Additional knowledge on the fugitivity of the materials is especially important when the reference color control patches are not particularly stable. For instance, Leao [3] showed that Kodak color control patches manufactured in the 1970s-1980s do not have a high color reproducibility even when comparing two batches of the same film. At the same time, the Kodak grayscale patches are more stable, because they are manufactured with silver emulsion, which is a more stable material than the sensitive dyes.

Extensive literature describes methods to correct the colors of digital images by accounting for the digital camera color sensitivities and shooting conditions (also referred to as color management and cross-media reproduction). Selva et al. [4] proposes a method for improving the color accuracy of digital images, where the reference values are selected by summarizing the representative colors of the captured scene. Then, based on this palette, a translation is computed between the RGB values of the digital image and the corresponding CIE L*a*b* coordinates, obtained from spectrophotometric measurements of the scene. The translation is done using first-order, second-order and third-order polynomial modelling. In a study for designing an accurate color calibration between scanner and printer reproductions, Kang and Anderson [5] compare the performance of polynomial modelling to that of neural networks and conclude that the neural networks give more accurate results thanks to their ability of learning complex non-linear relationships between input and reference.

The correction of digital images presents fewer challenges than the correction of digital captures of analogue photographs, because in the latter case, we are dealing with highly complex mechanisms of the capturing medium (the film) and often with many unknowns regarding the acquisition settings and illumination condition. Nonetheless, the rationale is similar in both cases: build a transformation function that will make the captured colors become more similar to a set of reference values. For this reason, in this paper, we adopt methods from traditional color management for correcting scans of analogue photographs.

Materials and Method

Dataset

In this work, we develop a color correction framework for reversal film aiming to obtain faithful colors of the object photographed. This would ultimately leverage the abundant analog photographic documentation housed in museums worldwide, enabling us to reconstruct the accurate colors of artworks in the past.

To this purpose, we use a dataset of films of reference color targets, namely targets X-Rite ColorChecker Digital SG and Coloraid IT-8, that was collected in 2009 in the framework of a PhD project at the University of Basel about the aesthetics of film photography [6]. The dataset covers a variety of film stocks, as listed in Table I.

The ColorChecker Digital SG target is made of 140 color patches and was photographed using D50 Bron Tungsten Flashbulbs with Softboxes with a color temperature of 5500 K, as shown in Figure 1. The films were shot at various exposures. However, there is one exception to the setup displayed in Figure 1 and that is the Kodachrome film, which was shot under daylight. The Coloraid IT-8 target contains 288 patches generated with a film recorder.

By scanning the films with a colorimetrically accurate digital imaging system (hyperspectral camera), we get the input to our color correction method (calculated with the D65 standard illuminant and the 1931 2° standard observer [7]). The relation between the scanned colors of each film and the known, ground-truth colors of the ColorChecker Digital SG represents the color distortion introduced by the chromogenic process of each film stock and the light exposure conditions.

Table I: Dataset of color targets on various film stocks.

Coloraid IT-8 Targets	Format
Provia, Astia, Sensia	35mm Slide
Velvia, Astia, Sensia 100 F	35mm Slide
Kodak Ektachrome	35mm Slide
Fujichrome Velvia, (RVP50)	35mm Slide
Agfa RSX	35mm Slide
Colorchecker SG	Format
Fujichrome Velvia 50	120
Kodak Ektachrome 100	120
Kodak Ektachrome 100 exposure1	35mm Slide
Kodak Ektachrome 100 exposure2	35mm Slide
Kodachrome	35mm Slide
Fujichrome Velvia	35mm Slide

Due to its standardized, consistent manufacturing process (film recorder), we use the Coloraid IT8 target to compare the differences of the various films in rendering the same spectral stimuli (see Figure 3). As opposed to the samples containing the ColorChecker Digital SG target, here the variation in the resulting chromogenic colors is due solely to the film type, as the light exposure was the same for all slides.

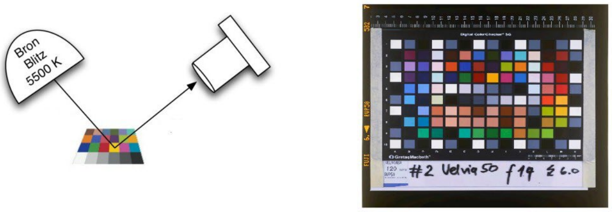

Figure 1: Analogue photography setup (left) and a digital image of the ColorChecker Digital SG target shot on Velvia film (right). Illustrations adapted from [6].

Figure 2: sRGB color rendering of the ColorChecker Digital SG shot on Kodachrome film, under daylight conditions.

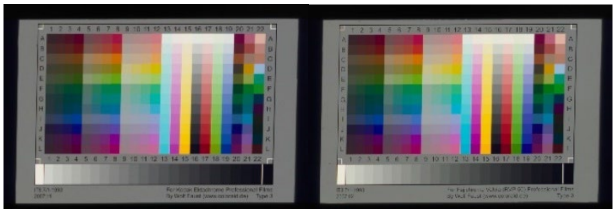

Figure 3: sRGB color rendering of digital scans of the Coloraid-IT8 target Ektachrome (left) and Fujichrome (right) films. The Fujichrome film has a larger color gamut than Ektachrome, as shown later in Figure 6.

Furthermore, we apply our color correction method on the painting *Junger Proletarier (1919)* by Paul Klee, part of Zentrum Paul Klee's collection in Bern. An analogue record of the painting was shot on Kodak Ektachrome film in 1995. This film contains gray and color control patches, which are used towards color correction. Here, the reference is given by spectrophotometric measurements of the Kodak color control patches, gathered in 1989 and taken from an online spectral library [8].

Later, in 2005, the painting was captured with a digital color camera. In the same year, the painting underwent a conservation treatment where the protective wax was regenerated. Although it is uncertain whether the digital photo was captured before or after the treatment, judging by the major difference of the painting's appearance in the digital image with respect to the film, we assume the digital image was captured post the conservation intervention.

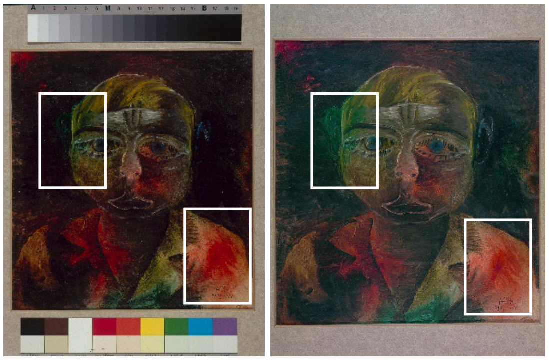

Figure 4: The digital scan of the Kodak Ektachrome film (1995) of Paul Klee's Junger Proletarier painting (left) and a digital image of the painting in 2005 (right), after a conservation treatment was supposedly applied. The white boxes highlight areas that changed in a visually obvious way.

Color Correction Approach

We developed four color correction methods that minimize the difference between the reference colors and the film colors.

The first method finds three lookup tables (one for each color channel in the Adobe-RGB 1998 space) and a first-order polynomial modelling without a constant term that results in a 3 x 3 matrix. Each lookup table is represented as a curve defined by four nodal points (the black and the white points plus two midpoints). An optimization process finds the best position of the nodal points and the values of the matrix through a multistep minimization process based on the Nelder-Mead simplex algorithm [9], where the objective function is the mean absolute difference. Hereinafter we refer to this method as baseline method.

The second method fits a second-order polynomial between the reference and film colors in the CIELAB space. Thus, the color of each patch is expressed as a linear combination of 9 terms modelled from the individual color channels plus a constant term. The corresponding coefficients of the polynomial terms are found through an optimization process using the Nelder-Mead simplex algorithm that minimizes the mean absolute error between the color of the patches in the reference and film, respectively. Similarly, the third method fits a third-order polynomial, where 20, instead of 9 terms are found through an optimization process.

The fourth method uses a shallow feed-forward neural network to make a non-linear translation between the input and reference colors in the CIELAB space. As can be seen in the diagram in , the neural network is made of two layers: one hidden layer with 10 units and the output layer. The network learns the weight and bias values according to Levenberg-Marquardt optimization [10], using Bayesian regularization [11] for a better generalization.

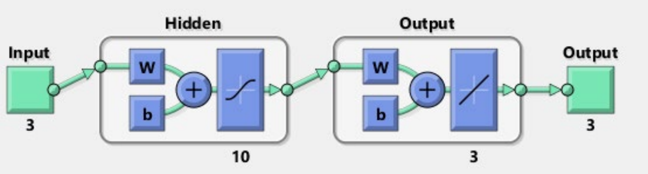

Figure 5: The architecture of the shallow feed-forward network used to fit between reference and film color targets.

Results

Same Object – Different Film – Different Colors

To show the difference between the chromogenic colors produced by the various film types, we plotted in Figure 6, the 2D gamuts based on the color signals of the 288 patches in the Coloraid IT-8 target, from each slide. More precisely, for each two dimensions in the CIELAB space, we computed the convex hull and plotted the boundaries of the resulting shape. From Figure 6, it emerges that there is a variation between the range of colors that each film type can reproduce. To support the graphical representation, in Table II, we report the gamut volume for each film type, which is the volume of the 3D space given by the convex hull all three L*, a*, b* coordinates of the 288 patches. The smallest color gamut belongs to Agfa RSX, followed by Kodak Ektachrome, Provia Astia Sensia, Fujichrome Velvia, and lastly Velvia Astia Sensia. Because the gamut of the films is limited by the color variation of one single target, it is important to mention that the reported values are not to be considered as absolute boundaries, but instead as a common ground for comparing how differently the various films can reproduce the same object. This emphasizes the need to perform film type-specific color correction, when analogue photographs are used to visualize the original colors of the objects they represent.

Table II: Color gamut volumes for each film type, computed as the volume of the convex hull of the 3D space given by the L*, a*, b* coordinates calculated for D65 standard illuminant and 1931 2° standard observer.

Film Type	Gamut Volume
Agfa RSX	**434121**
Fujichrome Velvia	540249
Kodak Ektachrome	463894
Provia Astia Sensia	486133
Velvia Astia Sensia	**546694**

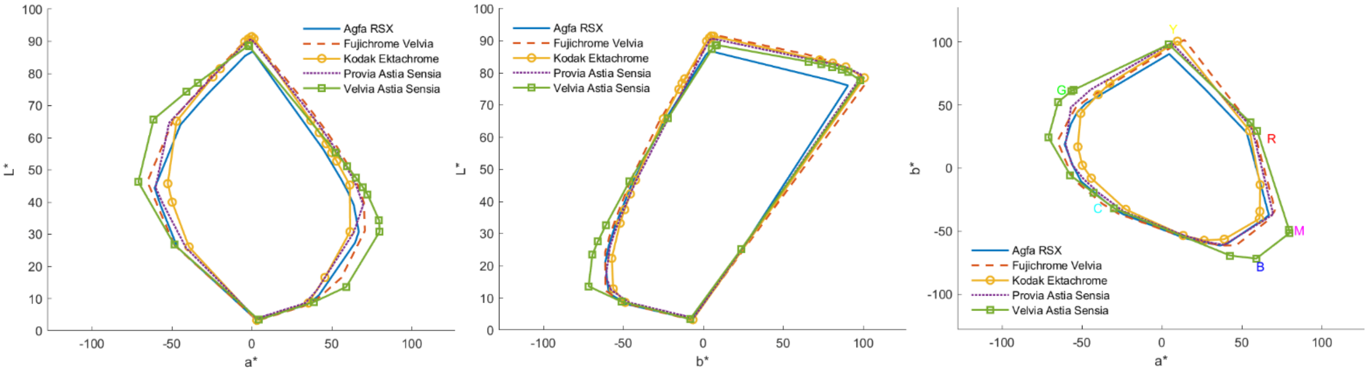

Figure 6: The different gamuts of the films, plotted as the boundaries of the 2D spaces made by the L-a*, L*-b*, and a*-b* color coordinates. The gamuts were computed as the convex hull of the 288 color values of the patches in the Coloraid IT-8 target. The variety between the films is obvious, where Velvia Astia Sensia has the largest gamut and Agfa RSX has the smallest gamut.*

Color Correction Performance

ColorChecker Digital SG

To validate and compare the performance of the four correction methods, we selected 14 patches with a wide distribution in the color gamut of the Digital SG target (see Figure 7) for test. The remaining patches were used for training. Each method is evaluated according to the average color difference CIEDE2000 for train and test, listed in Table III. The numeric results suggest that the neural network (NN) correction achieves the best color difference for the train patches, followed by the polynomial modelling, and lastly by the baseline method. This implies that the neural network is able to better learn the relationship between the films' chromogenic colors and the actual object's colors. The film type that facilitates the highest color accuracy is Kodachrome. There seems to be no significant difference between the quadratic and cubic polynomial models, which suggests that a higher complexity doesn't necessarily bring an improvement.

Another important finding is that the exposure seems to play an important role. The two Ektachrome films, that vary only in exposure give different results for the test patches. This suggests that the color correction methods are influenced by different illumination conditions.

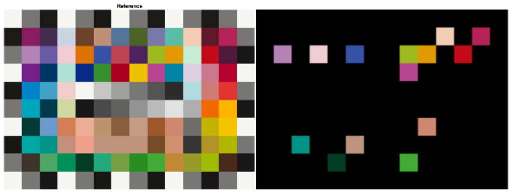

Figure 7: Synthetic image representing the 140 color patches in the Digital SG target (left), out of which 14 (right) are selected for testing the performance of the color correction methods.

Table III: Comparison of the methods used for color correcting the films of the Digital SG color checker, based on average CIEDE2000 for train and test patches. Neural network method performs best for all film types, for all patches.

	BASELINE		**NN**		**POLY2D**		**POLY3D**	
Film Type	Train	Test	Train	Test	Train	Test	Train	Test
Kodak Ektachrome 100 (120 format)	4.04	4.62	2.35	**3.75**	4.22	4.58	4.10	4.31
Fujichrome Velvia 50 (120 format)	4.91	7.07	2.69	**5.07**	4.52	4.66	4.19	5.37
Fujichrome Velvia (35 mm)	4.25	6.63	2.20	**3.23**	3.70	4.18	3.53	4.84
Kodachrome (35 mm)	3.78	5.69	1.91	**3.04**	3.77	4.46	3.28	4.16
Kodak Ektachrome 100 (35 mm) exposure1	5.91	9.40	1.96	**5.12**	5.20	7.15	4.78	7.76
Kodak Ektachrome 100 (35 mm) exposure2	3.94	6.42	1.84	**3.40**	3.11	4.00	2.66	4.56

Film to Painting

In the attempt to use the archival film as a testimony of the past colors of Klee's *Junger Proletarier,* we first need to correct the possible inaccurate colors that might show up in the film due to the intrinsic color distortion of the chromogenic processes. Thus, we apply the four color correction methods on the Kodak Ektachrome film record from 1995, using the Kodak color and grayscale control patches. As objective of the correction, we use a spectral reference of these control samples, measured in 1989. In the plot in Figure 8, we can get a hint of the discrepancies we need to account for between the L*, a*, b* colors of the patches in the film with respect to the reference colors. The distances are smaller for the grayscale correction, that seem to be overall darker in the film. However, as far as the color patches are concerned, there are bigger gaps, especially for the magenta patch, that seems to have lost the blue component. This is because the arrow in the plot between film-> reference shifts towards the negative quadrant of the a* (green-red axis) and b* (blue-yellow axis) coordinates, meaning that the film color is less green and less blue than the reference. This is consistent with the well-known change of the cyan dye in chromogenic films [12].

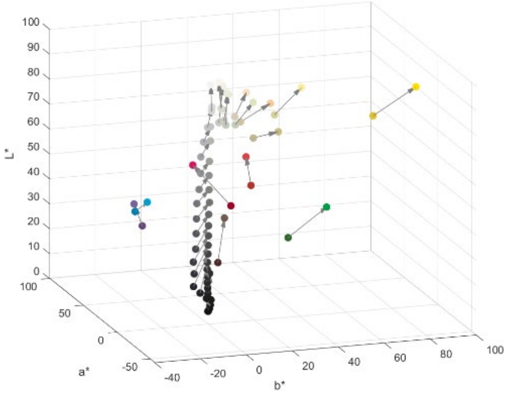

*Figure 8: Mapping from object->reference of the colors of the Kodak color control patches in the CIE L*a*b* space, where the object is the Kodak Ektachrome film of Klee's painting. The reference colors are generally brighter.*

Once we adjust the film scan with the four correction methods trained on the Kodak control patches, we compute the color differences between the reference and corrected values for the training set. In addition, we compare the corrected film with the digital scan of the painting from 2005 to see the magnitude of the changes that occurred in the painting (the test). Prior to this, we registered the two images to bring them to the same resolution. Apart from the average color differences shown in Table IV, we display the spatial extent of the change with 2D maps in Figure 9. Consistent with the results for the Digital SG color checker, the method that gives the lowest color differences with respect to the reference is the neural network model. By applying the color correction with the neural network and the cubic polynomial, we manage to lower the average color difference between film and painting by around $3\Delta E_{00}$ with respect to the non-corrected film. Moreover, in the film-painting comparison, the neural network highlights areas of differences distinct from the other methods. These areas overlap with the visual assessment of changes from Figure 1. Ideally these differences would reflect the major changes in the painting due to some sort of intervention, which in this case could be the wax regeneration conservation treatment. However, as of now, we do not have a ground-truth of the fugitive materials and their distribution in the painting, nor do we have a reference map of changes. For this reason, it is difficult to say with certainty whether the differences shown in Figure 9 are solely due to the changes in the painting or include the imperfections of the color correction methods as well.

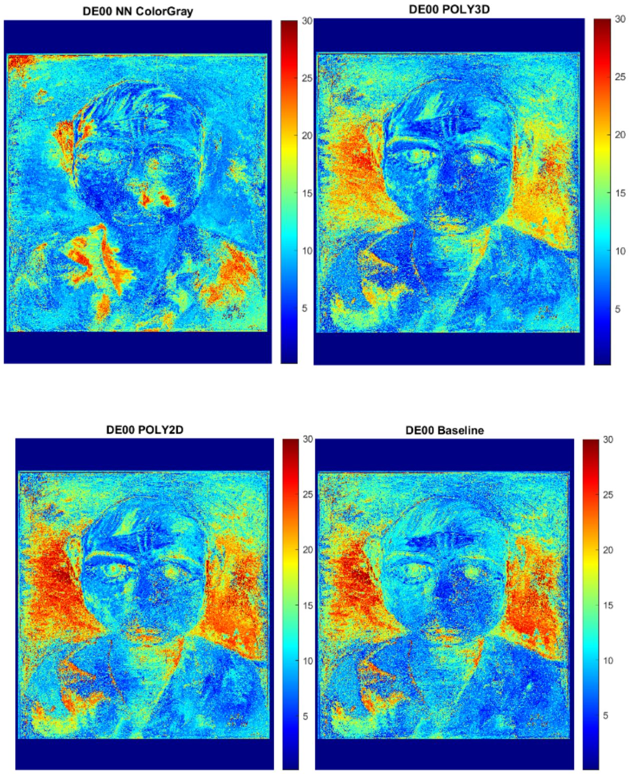

Figure 9: Color difference maps between the color corrected Ektachrome film (1995) and a digital scan of the painting (2005). The NN-based color correction highlights different areas of change with respect to the other methods.

Table IV: Average CIEDE2000 for the train patches used for the color correction of the Ektachrome film (Kodak Grayscale and Color control patches); Average CIEDE00 between color corrected film and the recent digital image of the painting.

Not corrected Test Klee	14.08
Baseline Train	4.91
Baseline Test Klee	12.5
NN Train	0.80
NN Test Klee	**11.17**
POLY2D Train	3.34
POLY2D Test Klee	13.36
POLY3D-Train	2.69
POLY3D- Test Klee	11.93

As a matter of fact, the images in Figure 10 shows that although the neural network performs best according to the average color difference, there are some unnatural colors that appear in the red regions. At the same time, the brightness in the background around the face of the character in the painting seems to be better restored in this version of the color corrected film.

It is noteworthy to mention that the performance of the color correction methods might also be limited by the gamut volume of the Ektachrome film, which might fail to capture the whole range of colors in the real object. This assumption is justified by the study on the Coloraid IT-8 target (see Figure 6 and Table II), where we saw that the Kodak Ektachrome had the second smallest color gamut volume. Although the color transformation seeks to expand the original gamut of the film, if a set of input colors with the same values in the film map to different target colors in the painting, then the transformation is not bijective, which might result in information loss.

Figure 10: sRGB renderings of the: original film (top left), painting (top right), color correction of the film with neural network model (bottom left), color correction of the film with the third-order polynomial (bottom right). Although in terms of brightness, NN restores best the film, it seems that the red is replaced by an unrealistic pink.

Conclusion

In this work, we proposed a film-to-painting transformation, where the colors of reversal are corrected using methodologies from the color management field.

More precisely, we scanned a dataset of multiple film types that captured two reference color targets, and we compared the capabilities of the film types in rendering the same object. Thus, our first finding is that the color gamut varies significantly with the film types. Afterwards, we attempted to compensate for these film-specific differences by correcting the colors based on a mapping to the known, reference colors of the target. We applied and compared four methods, out of which the neural network model outputs the best result. Lastly, we used the same methodology for a film record of Paul Klee's *Junger Proletarier* painting, dating from 1995 and shot on Kodak Ektachrome film. We noticed that by correcting the film, we manage to get closer to the colors of the painting. However, it is difficult to validate the final result without complementary evidence on the painting's evolution, the stability of the materials in its composition and a log of its display and storage conditions. In the future, we plan to conduct such analysis and inform our transformation with additional anchor points taken from the painting itself, i.e. those areas in the painting that haven't changed.

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***Giorgio Trumpy** has been an associate professor at the Norwegian University of Science and Technology since 2021. He studied Conservation Science in Florence and received his PhD in Scientific Photography from the University of Basel (2013). For two years (2014-2016), he was Postdoc fellow at National Gallery of Art in Washington DC and for 5 years (2016-2021) at the University of Zurich. His work focuses on Spectroscopy and Imaging Science for conservation of cultural heritage.*