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NON-INVASIVE COLOR RESTORATION OF FADED PAINTINGS USING LIGHT FROM A DIGITAL PROJECTOR

ABSTRACT

A group of five paintings on canvas known as Mark Rothko's Harvard Murals (1963) has changed color due to the presence of a fugitive red pigment (Lithol Red) in the paint and excessive exposure of the works to natural light in a room with large windows. This project explores the possibility of recreating the original color appearance of the paintings by illuminating them with a digital projector. A camera-projector system controlled by a computer is implemented. With a calibrated camera the painted surface and the projector's non-linear response are characterized. By comparison with a target image a corrective color image is calculated and projected onto the original paintings. Using this augmented reality approach (Bimber 2005) it is possible to recreate the original color appearance without altering the paintings physically.

RÉSUMÉ

Un groupe de cinq peintures sur toile de Mark Rothko connues sous le nom de *Harvard Murals* (1963) ont changé de couleur en raison de la présence d'un pigment rouge fugitif (rouge lithol) dans la peinture et d'une exposition excessive des œuvres à la lumière naturelle, dans une salle dotées de grandes fenêtres. Ce projet explore la possibilité de reconstituer l'apparence de la couleur d'origine des tableaux en les éclairant avec un projecteur numérique. Un système caméra/projecteur commandé par un ordinateur est mis en place. Avec une caméra calibrée, la surface peinte et la réaction non linéaire du projecteur sont caractérisées. Par comparaison avec une image cible, une image corrective de la couleur est calculée et projetée sur les tableaux originaux. En utilisant cette approche par la réalité augmentée (Bimber

INTRODUCTION

Mark Rothko donated five large canvas paintings to Harvard University in 1963, now known as his Harvard Murals (Cohn 1988). The paintings were displayed in a dining room in the then newly built Holyoke Center (Figure 1), where they were subjected to high levels of natural light. Due to the high light exposure and the presence of the fugitive red pigment Lithol Red, the color of the Murals changed dramatically. In 1979, as a result of this alteration, the canvases were removed and kept in dark storage. Since then the paintings have rarely been on view.

Figure 1

Mark Rothko's Harvard Murals, Panels One, Two, and Three, Holyoke Center, 1963. Photo: James K. Ufford and Michael Nedzweski. © President and Fellows of Harvard College (Harvard Art Museums)

The paintings are referred to as Murals only because of their monumental size. In fact, they are executed on stretched canvas supports and not on an architectural support. All five works are unframed and 267 cm in height with varying widths. The first three panels form a triptych. On each canvas one abstract form floats in front of a crimson background. This background was painted with animal skin glue as a paint medium into which the artist had mixed the dry pigments Lithol Red and Ultramarine Blue (Cohn 1988, Stenger 2010) creating a color that has sometimes been described as red wine. The paintings were exposed to bright daylight through the windows of Holyoke Center for 15 years and although fading was noticed early on little action was taken for a long time. This was

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2005), il est possible de recréer l'apparence originelle de la couleur sans altérer physiquement les tableaux.

RESUMEN

Un grupo de cinco pinturas sobre lienzo conocido como *Harvard Murals* (1963), de Mark Rothko, ha cambiado de color debido a la presencia de un pigmento fugaz rojo en la pintura (rojo litol) y a la excesiva exposición de las obras a la luz natural en una sala con grandes ventanales. Este proyecto explora la posibilidad de recrear el aspecto original del color de las pinturas iluminándolas con un proyector digital. Se utiliza un sistema de proyector con cámara controlado por ordenador. Con una cámara calibrada, se caracterizan la superficie pintada y la respuesta no lineal del proyector. Comparando con una imagen de referencia, se calcula una imagen de color corrector, y ésta se proyecta sobre los cuadros originales. Utilizando este acercamiento de realidad aumentada (Bimber 2005) es posible recrear el aspecto del color original sin alterar físicamente los cuadros.

due to a complicated stewardship and ownership situation. The works were under the care of the staff from the Fogg Art Museum at Harvard University, but installed outside the Museum and owned by the Harvard Cooperation. Consequently, the original crimson background color has moved towards a light blue. This color change occurred on different paintings to different degrees depending on their position within the room and their respective positions to the windows. In some cases the extent of the fading varies within a single painting.

Today the paintings have become overlooked. Although the Harvard Murals are one of three important commissions in which Rothko aimed for the creation of a room, they are rarely part of current scholarly discussions about Rothko's oeuvre and retrospectives. This paper describes an attempt to recreate the original color appearance of the original works by inpainting with light. Based on color-restored photographs of the Murals in their original condition in 1964, and reference colors from an unused sixth panel in the series, a camera projector system is used to illuminate the paintings with light whose corrective color is calculated pixel by pixel.

The discourse in the Western world on color loss at the surface of art objects and attempts of reconstruction go back to the early 19th century. Evidence that ancient marble sculpture was once painted was first discussed by Antoine-Chrysostome Quatremère de Quincy in 1815 (Quatremère 1815). At that time color reconstructions started as drawings and later plaster casts of ancient sculptures were painted in an attempt to recreate the original appearance. This approach to aged polychrome sculpture is still used and discussed today (Ebbinghaus 2008, Panzanelli 2008).

The process of altering the color appearance of a work of art using an illumination system was first demonstrated in 1986 by Lafontaine (1986). In his work, a combination of blue and white light was used to compensate for the yellowness of the existing varnish on a painting by J.M.W. Turner. More recently, light from digital projectors has been used in similar ways. Law and coworkers have restored the appearance of a Native American ceramic vessel which has losses and stains (Law 2009). Janke and Riedl have restored a large loss in a 16th-century secco painting on the ceiling at the Brömserhof Museum in Rüdesheim am Rhein (Janke 2010). The digital light replacement fill onto the white loss is based on a watercolor copy of the missing sequence. Further, at Hampton Court Palace, a faded large 16th-century tapestry was brought back to its original color with digital light technology based on unfaded threads in the unexposed back of the piece (Carr 2009).

The color reconstruction of Mark Rothko's Harvard Murals differs from these works in several ways. On the one hand, one does not have to deal with the three dimensional aspects of a curved paint surface in a vault or on a vessel. On the other hand, one is not filling in complete losses onto a white surface. The projector compensates for varying color change

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while additional ambient light ensures that the viewer experiences the paintings with their full physicality. A key aspect in the appearance of works by Rothko is the subtle difference in color and gloss, the latter achieved by the use of different binding media within single paintings. The preservation of these characteristics, high color accuracy and correct registration are all crucial for a successful restoration.

To develop and test color reconstruction a small scale mock-up was created with the same painting materials as the Murals. This allows us to implement the procedure described below and refine the software without experimenting on the original art work.

TARGET IMAGE

Restored Kodak Ektachrome photographs from 1964 of Rothko's Harvard Murals in their original state served as a color reference in the compensation process. However, these transparencies had also changed color over the last 50 years because the cyan photographic dye in the emulsion for Ektachrome slides at the time was not stable. The images were therefore digitally restored to extract the original color of the paintings. The Ektachrome slides were scanned on a custom made scanner at the Imaging and Media Lab at Basel University. Red, green, and blue Light Emitting Diodes (LEDs), which have a spectrally narrow bandwidth, were used. This property of the light sources ensures that the recorded optical densities are proportional to the photographic dye concentrations. The slide was imaged onto a Sinar camera back 54 FW (22 Mpixel, Kodak CCD sensor KAF 22000) with a 100 mm Sinar lens. The recorded Sinar 4shot image was converted to a TIFF (Tagged Image File Format) file using the raw photo decoder "dcraw" (Coffin 2010). Subsequently, the original color of the Ektachromes was then reconstructed using a chemical fading model based on the recorded dye concentrations (Frey 1994).

Uneven illumination of the paintings in the 1964 photographs can be corrected assuming a homogeneous background color of the wall behind the paintings. Further digital processing was required to compensate for the overemphasis of red in the Ektachrome film. This unfaithful color reproduction was an esthetic choice of the developers of the Ektachrome film material, as it resulted in healthier skin tones often desired by portrait photographers. In an attempt to compensate for this, the authors tried to match the Kodak Color Checker and Kodak Gray Scale in the original Ektachrome photographs with vintage references. The latter should be very similar to those used in the 1964 photography. These reference cards were photographed together with an X-Rite Color Checker and calibrated the image with a commercial color profile maker (inCamera 4.5 by PictoColor). ProPhoto RGB was then chosen as a processing color space as the Kodak Color Card contains colors outside the sRGB and even Adobe RGB 1998 gamuts. To work in a linear color space, an encoding gamma of 1.8 was applied. The samples from the

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gray patches in the Ektachrome and the reference image were compared and fitted to a polynomial of 3rd degree. After applying this calibration curve to the whole image the color patches were matched by determining the channel mixing matrix with a nonlinear least square fit.

Final color adjustments were made by using the sixth, never displayed, painting of the series as a reference. This painting is part of the group, but was not installed together with the other five paintings. Color measurements with an i1 spectrometer from X-Rite enabled the crucial last fine adjustment since all the paintings had originally the same background color.

GEOMETRIC MAPPING

With a camera-projector system (Figure 2) similar to the set-up used by Grossberg (2004) and Law (2009) the correct geometric mapping and the radiometric compensation was calculated using the software programming package MATLAB®. The digital camera was calibrated with an X-Rite ColorChecker® under standard D50 light. The resulting IIC (International Color Consortium) profile was then applied to all images acquired in the following procedures.
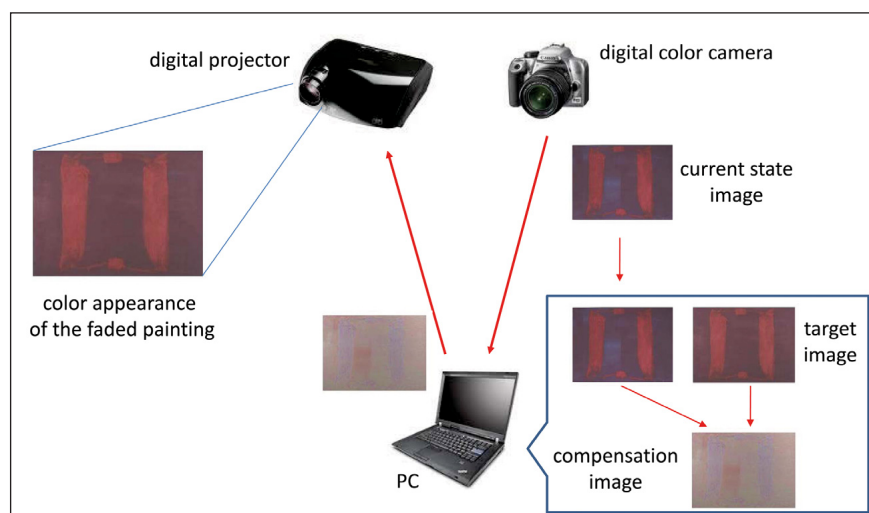

Figure 2
Camera-projector system and workflow for the color restoration of a mock-up painting

The geometric mapping yields the coordinate transformations, sometimes called homographies, between the projector, the camera and the target image. In addition to the target image, only one other image is acquired. The full painted surface and projector field are captured in a single shot. Corresponding features in the images can be selected using the Control Point Selection Tool (cpselect) in MATLAB's Imaging Processing Toolbox. The geometric transformation is then calculated based on the control points with another supplied function (cp2tform) from the Toolbox. The result is generally a projective transformation written as a 3 x 3 matrix, the homography matrix. This procedure ensures the correct registration of the projected corrective image

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and the painted surface. It is robust even when camera, projector and the painting are aligned off-axis. A more detailed description of geometric transformations and image registration in MATLAB® is given by Gonzales (2009).

RADIOMETRIC COMPENSATION

The radiometric compensation is performed for every pixel. The subsequent procedure and explanation follows the description of Grossberg and coworkers (Grossberg 2004). The camera response in the red, green, and blue (RGB) channels $\mathbf{C} = (C_R, C_G, C_B)$ can be described as

$$\mathbf{C} = \mathbf{VP} + \mathbf{F}$$

$\mathbf{V}$ is the 3×3 color mixing matrix that describes the couplings between the projector and camera channels as well as their interaction with the reflectance of the painting. $\mathbf{P}$ is the projector brightness and depends in a nonlinear fashion on the scalar input brightness value I, $\mathbf{P} = (P_R(I_R), P_G(I_G), P_B(I_B))$. Since the projector illumination serves only a color corrective function additional ambient light has to be part of the model. This is described by the additive term $\mathbf{F} = (F_R, F_G, F_B)$.

The desired color correction of the painting occurs when the camera response matches the RGB values of the target images for every pixel. To determine the projector input values I_R, I_G, and I_B that will achieve this, the parameters of the model first have to be calculated.

To decouple the color channels and arrive at one independent equation for each channel, a diagonal matrix $\mathbf{D}$ is defined with diagonal entries V_{RR}, V_{GG}, V_{BB}. Further, a matrix $\widetilde{\mathbf{V}} = \mathbf{VD^{-1}}$ is defined with the diagonal elements of $\widetilde{\mathbf{V}}$ normalized to 1. This conveniently separates the recovery of the diagonal elements of $\mathbf{V}$ and the mixing of the color channels described by $\widetilde{\mathbf{V}}$.

To recover the matrix $\widetilde{\mathbf{V}}$ four images are acquired with the camera. For the first image, neutral light is projected from the projector by choosing $\mathbf{I^{(1)}} = (I^{(1)}_R, I^{(1)}_G, I^{(1)}_B)$ with $I^{(1)}_R = I^{(1)}_G = I^{(1)}_B$. In the other three images only one of the channels is increased and the other two are left unchanged. For example $\mathbf{I^{(2)}} = (I^{(2)}_R, I^{(1)}_G, I^{(1)}_B)$ with only the red channel enhanced. In this case the camera responses for the two images can be described by

$$\begin{pmatrix} C_R^{(1)} \\ C_G^{(1)} \\ C_B^{(1)} \end{pmatrix} = \widetilde{\mathbf{V}}\mathbf{D} \begin{pmatrix} P_R^{(1)} \\ P_G^{(1)} \\ P_B^{(1)} \end{pmatrix} + \mathbf{F}$$

$$\begin{pmatrix} C_R^{(2)} \\ C_G^{(2)} \\ C_B^{(2)} \end{pmatrix} = \widetilde{\mathbf{V}}\mathbf{D} \begin{pmatrix} P_R^{(2)} \\ P_G^{(1)} \\ P_B^{(1)} \end{pmatrix} + \mathbf{F}$$

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With the projector brightness unchanged for the green and blue channel, the camera detects the following changes in its response:

$$\Delta C_R = \widetilde{V}_{RR} V_{RR} \Delta P_R$$

$$\Delta C_G = \widetilde{V}_{GR} V_{RR} \Delta P_R$$

$$\Delta C_B = \widetilde{V}_{BR} V_{RR} \Delta P_R$$

Since $\widetilde{V}_{RR} = 1$ the following two matrix elements can be calculated

$$\widetilde{V}_{RG} = \frac{\Delta C_G}{\Delta C_R} \quad \text{and} \quad \widetilde{V}_{RB} = \frac{\Delta C_B}{\Delta C_R}$$

Subsequently, the other off-diagonal elements of $\widetilde{\mathbf{V}}$ are calculated by comparing the gray image to two images with the green or blue channel respectively enhanced. Once all elements of $\widetilde{\mathbf{V}}$ are known, three decoupled equations are obtained

$$\widetilde{\mathbf{C}} = \mathbf{D}\, \mathbf{P(I)} + \widetilde{\mathbf{F}}$$

With $\widetilde{\mathbf{C}} = \widetilde{\mathbf{V}}^{-1}\mathbf{C}$ and $\widetilde{\mathbf{F}} = \widetilde{\mathbf{V}}^{-1}\mathbf{F}$. The red channel equation then reads

$$\widetilde{C}_R = V_{RR}\, P_R(I_R) + \widetilde{F}_R$$

The responses of the green and blue channel equations have the same form. Seven measurements are used, each to characterize the non-linear response curves for the three channels. For a given $\mathbf{C}$ from the target image the projector values $\mathbf{I}$ can then be calculated pixel by pixel for the entire compensation image.

EXPERIMENTAL AND RESULTS

For the realization of the camera projector system off-the-shelf instruments were purchased. The digital camera used is a Canon EOS Rebel XS 18-55IS, single-lens reflex with a 10 megapixel CMOS sensor. The color correction is projected with an Optoma TX1080 projector. It is a High Definition (HD 1920 × 1080), DLP® instrument with a maximum brightness of 3600 lumens and a 2200:1 contrast ratio. The MATLAB® software package (Version 7.11.0.584, R2010b) runs on an IBM Thinkpad with an Intel Core2 Duo central processing unit at 2.53 GHz with 3 GB RAM. The digital photographs are taken remotely and in RAW format with the EOS Utility software provided by Canon. Subsequently, the RAW images are processed by calling from within the MATLAB code the dcraw software (Coffin 2010) with switches set to -4 (for 16 bit linear instead of 8 bit with gamma correction) and –o 0 (no color management). The use of dcraw as a raw converter ensures that the camera sensor data is not processed in any unknown or unwanted way.

To test the equipment and develop the software a smaller scale mock-up was created with the same pigments, binding media, and canvas support as the Rothko paintings. After taking reference images the painting was exposed in selected areas with a 250 Watt halogen tungsten lamp for several weeks. The total light exposure accumulated to approximately
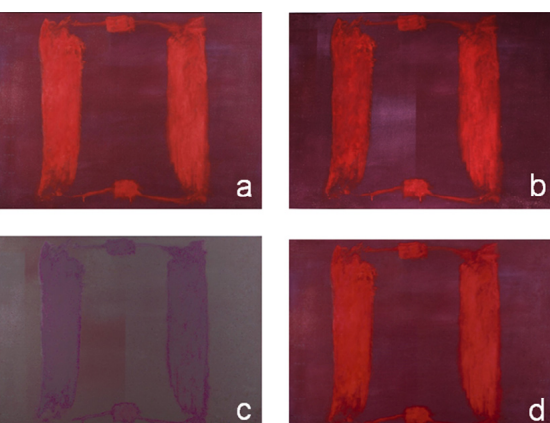
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8 mega lux hours. This resulted in faded areas with soft and sharp edges. The software development and its extensive testing could be achieved with this mock-up painting. Figure 3 demonstrates how the mock-up painting was 'unfaded' and made to appear in its original state with the camera-projector system described above.

Figure 3a and 3b show two photographs of the painting before and after fading in selected areas. The former one serves as a target image in the calculations. By comparing the two images in the software, it is possible to calculate a corrective image (Figure 3c) based on the recovery of all the parameters of the projector, cameras and paint surface. Figure 3d is a photograph of the faded painting (b) with the corrective image projected onto its surface with the correct registration. The result is very close to the target image (a). The sharp edges of the faded areas in (b) can be completely eliminated and the correction is seamless.

A second test of the procedure was performed on the original severely faded Panel Five of Rothko's Harvard Murals. In close agreement with the test on the mock-up painting, Panel Five with the corrective image illuminating was very close in color appearance to the target image. Different ratios of color corrective light and ambient light were assessed. It was found that a situation with no ambient light at all makes the painting appear as a glowing rectangle in the dark and was rejected as inappropriate. A ratio of 1:1 with 25 lux from the projector and 25 lux from the additional halogen tungsten lamps at 45 degrees was found to be the optimal display conditions. The maximum of 50 lux was set as a standard (Thomson 1994) until the light sensitivity of the remaining red pigment is quantified with a microfadometer.

The test runs have shown that it is crucial to take into account that objects have different color appearance under different lighting conditions. When the target image shows the painting in daylight illumination, for example CIE Standard Illuminant D65 with a color temperature of 6500 K, the color corrected painting will look too cool in a tungsten lit environment with a color temperature of about 3000 K. Therefore it is crucial to choose an appropriate chromatic-adaption transform to arrive at the correct color appearance under a reference illuminant (Westland 2004).

CONCLUSIONS

A novel restoration technique that uses colored light from a digital projector to compensate for color alteration is being used. To the author's knowledge, this approach has not been used previously for the restoration of paintings. It recreates the original color appearance without changing the paint surface physically and is therefore completely reversible. In fact, one can easily compare the unrestored and color-corrected object by switching the projector on and off. The camera projector system is a tool that has many parallels to conventional conservation practices, such as inpainting and cleaning (Hedley 1985). As in traditional art conservation reversibility is a key objective, some decisions are subjective and based on informed

Figure 3
a: Mock-up painting before fading
   (target image)
b: Partially faded painting
c: Compensation image
d: New appearance
   (image c projected onto b)

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compromises to preserve the overall integrity of the piece and the relationship within a series. A balance between respect for the history of the painting and the artist's intent is one of the central aims of the project.

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REFERENCES

BIMBER, O., and R. RASKAR. 2005. *Spatial augmented reality: merging real and virtual worlds*. Wellesley, Massachusetts: AK Peters.

CARR, C., H. OWENS, and R. PERKINS. 2009. Scientists 'virtually restore' 16th century tapestry at Hampton Court Palace. The University of Manchester News Archive. http://www.manchester.ac.uk/aboutus/news/archive/list/item/?id=4568&year=2009&month=04 (accessed 10 November 2010).

COHN, M.B., ed. 1988. *Mark Rothko's Harvard Murals*. Cambridge, Massachusetts: Center for Conservation and Technical Studies, Harvard University Art Museums.

COFFIN, D. 2010. http://www.cybercom.net/~dcoffin/dcraw/ (accessed 10 November 2010).

EBBINGHAUS, S. 2008. Gods in color: painted sculpture of classical antiquity. Cambridge, Massachusetts: Harvard University Art Museums.

FREY, F., and R. GSCHWIND. 1994. Mathematical bleaching models for photographic 3-color materials. *Journal of Imaging Science and Technology* 38(6): 513–519.

GONZALES, R.C., R.E. WOODS, and S.L. EDDINS. 2009. *Digital Images Processing using MATLAB®*. Gatesmark Publishing.

GROSSBERG, M.D., H. PERI, S.K. NAYAR, and P.N. BELHUMEUR. 2004. Making one object look like another: Controlling appearance using a projector-camera system. In *Proceddings of the 2004 IEEE Computer Society Conference "Computer Vision and Pattern Recognition (CVPR)", 27 June–2July 2004*, 1: 452–459.

HEDLEY, G. 1985. *On humanism, aesthetics and the cleaning of paintings*. London: Courtauld Institute of Art.

JANKE, M., and N. RIEDL. 2010. Missing piece of 16th-century mural recreated virtually. *The Art Newspaper,* http://www.theartnewspaper.com/articles/Missing-piece-of-16th-century-mural-recreated-virtually/21757.

LAFONTAINE, R.H. 1986. Seeing through a yellow varnish: a compensating illumination system. *Studies in Conservation* 31(3): 97–102.

LAW, A.J., D. ALIAGA, Y.H. YEUNG, R. MCCOY, A. MCKUNE, and L. ZIMMERMAN. 2009. Projecting restorations in real-time for real-world objects. In *Museums and the Web 2009: Proceedings,* eds. J. Trant and D. Bearman, published 31 March

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2009. Toronto: Archives & Museum Informatics. http://www.archimuse.com/mw2009/papers/law/law.html (accessed 10 November 2010).

NAYER, S.K., H. PERI, M.D. GROSBERG, and P.N. BELHUMEUR. 2003. A projection system with radiometric compensation for screen imperfections. In *ICVV International Workshop on Projector-Camera Systems (PROCAMS)*, 2003.

PANZANELLI, R., E. SCHMIDT, and K. LAPATIN. 2008. *The color of life: polychromy in sculpture from antiquity to the present*. Los Angeles: J. Paul Getty Museum.

QUATREMÈRE DE QUINCY, A.-C. 1815. *Le Jupiter olympien, ou, l'art de la sculpture antique considéré sous un nouveau point de vue*. Paris.

STENGER, J., E.E. KWAN, K. EREMIN, S. SPEAKMAN, D. KIRBY, H. STEWART, S.G. HUANG, A.R. KENNEDY, R. NEWMAN, and N. KHANDEKAR. 2010. Lithol Red salts: characterization and deterioration. *e-Preservation Science* 7:145–157. http://www.morana-rtd.com/e-preservationscience/.

THOMPSON, G. 1994. *The museum environment*. 2nd edition. Butterworth-Heinemann Series in Conservation and Museology. London: Butterworth & Co. Ltd.

WESTLAND, S., and C. RIPAMONTI. 2004. *Computational color science using MATLAB*. West Sussex: John Wiley & Sons Ltd.