DIGITAL HERITAGE (2025)
S. Campana, D. Ferdani, H. Graf, G. Guidi, Z. Hegarty, S. Pescarin, and F. Remondino (Editors)

What can a historic black and white photograph tell us about the original colours of a painting? A case study on Edvard Munch's *The Scream (1910?)*

P. Siozos[1], I. C. A.Sandu[2], P. I. Stavroulakis[1] and S. Sotiropoulou[1,3]

[1]Institute of Electronic Structure and Laser (IESL), Foundation for Research and Technology – Hellas (FORTH), Heraklion, Crete, Greece.
[2]Munch Museum,Conservation Section, Edvard Munchs Plass, 1, 0194 Oslo, Norway.
[3]School of Applied Arts and Sustainable Design, Hellenic Open University, Parodos Aristotelous 18, 26335, Patras, Greece.

Abstract

We present a computational method that uses historical black-and-white photographs combined with recent multi/hyperspectral imaging to detect colour changes in artworks caused by exposure to environmental conditions or other factors over time. The method is based on the comparative study of a historical black and white photograph with a corresponding image derived computationally from the spectral data cube of the most recent acquisition with a spectral camera, by simulating the capture mode based on the sensitivity curves of the film. The proposed method is completed with the necessary calibrations and refinements of the simulation. In this paper, we present the application of the method to the painting of Edvard Munch's The Scream (1910?) located in the MUNCH Museum in Oslo, of which a historic black and white photograph was taken with orthochromatic film in 1938. The comparison revealed significant differences in lightness, indicative of colour changes, such as fading in the yellow areas and unexpected brightening in the blue areas, a phenomenon not previously reported. The results provide new insights into the material ageing of The Scream and offer a valuable opportunity to study a historical photographic document that captured the painting only a few decades after its creation, preserving evidence of its original appearance that is no longer accessible through direct visual observation. Furthermore, the methodological approach demonstrated here broadly applies to other cultural heritage objects for which historical photographic records and modern spectral imaging are available, providing a non-invasive, data-driven framework for tracking colour and material changes over time.

CCS Concepts

• ***Applied computing*** → ***Digital libraries and archives;*** • ***Computing methodologies*** → ***Image processing;***

1. Introduction

From the moment a work of art is created, the passage of time and exposure to environmental conditions begin to affect its material integrity and conservation state. Movable heritage, in particular, is more susceptible to such changes due to its frequent relocation, which often results in variable and potentially more aggressive ageing conditions when exposed to risk factors. Understanding the stability or sensitivity of an artwork's materials to these factors is crucial not only for the long-term preservation of cultural heritage but also for identifying potential deviations between the current and original appearance of the object. Historical black-and-white photographs provide valuable visual records that may capture artworks in a state closer to their original condition; however, their meaningful interpretation requires careful calibration and comparison.

Since its earliest days, photography, has been adopted and widely used in museums, as a technique that provides visual documentation and supports archival and conservation practices. From the 19th century onwards, museums have embraced photography as a precise and efficient means for documenting objects and interventions recording exhibitions and preserving visual evidence of artworks and cultural artefacts. These monochrome photographs are valuable historical records, that can provide otherwise lost information about the condition and appearance of artworks in the past [Edw19].

In this study, we investigate whether historical monochrome photographs can be systematically used to detect changes in artworks, with a particular focus on identifying colour changes.

The approach is applied to a case of exceptional cultural significance: Edvard Munch's *The Scream (1910?)*. This iconic painting, renowned worldwide as a symbol of modern anxiety and dispair, represents a unique piece of art both artistically and historically. Understanding its material evolution over time is critical not only for its preservation but also for ensuring that future generations experience the artwork, knowing and understanding as closely as possible how it was in its original appearance.

Recent advances in spectral imaging and computational modelling now enable accurate reconstructions of historical photographic processes, offering new opportunities for non-invasive comparative study of the past and present condition of artworks through comparison of historical photographs and equivalent contemporary simulations. By combining these technologies, we aim to explore material changes in The Scream and assess the broader potential of this methodology for cultural heritage studies.

2. Methods

2.1. Orthochromatic photograph of Munch's paintings

For the analysis, we used a copy of a digitized photograph taken on monochrome film by Edvard Munch in his studio in 1938, which captures several of his famous paintings (Figure 1). The film used was an Agfa Chromo-Isolar-Platte with an orthochromatic emulsion. Orthochromatic film is primarily sensitive to the blue and green regions of the visible spectrum, while being largely insensitive to red light. As a result, red areas in the original paintings appear black or very dark in the photograph. The digital image of the historic photograph was cropped, resized, and geometrically registered to the sRGB image reconstructed from the multispectral data recently acquired on *The Scream (1910?)* (Figure 2).

Figure 1: *"The Gates of Hell" in Munch's winter studio at Ekely. Photograph of Edvard Munch's artworks taken in 1938. "The Scream" (1910?) is visible in the left side of the door, above two other paintings, "Anxiety" and "Despair" (Photo: R Væring, MM.D.02386 ©Munchmuseet, 1938?).*

To make a meaningful comparison between the images, it was first necessary to compensate for the non-linear response of the film used in the 1938 photograph. Photographic films, such as the orthochromatic one used in this study, exhibit a nonlinear response characterized by the Hurter–Driffield (H-D) curve [JM77]. To correct for this nonlinearity, an H-D correction was applied to the scanned photograph. The normalized pixel intensity, E, representing film density, was mapped to the relative normalized exposure, y, using:

$$E = -\frac{1}{a}\ln\left(\frac{1}{y+\varepsilon}-1\right)+b$$

where is a small constant to avoid division by zero, with *a = 12* and *b = 0.45*. This correction linearizes the pixel response, enabling direct comparison with the simulated orthochromatic images. The H-D correction curve and the corrected image are presented in Figure 3.

Figure 2: *Magnified view of the photograph shown in Figure 1, presenting The Scream (1910?) painting (left) and the corresponding sRGB image generated from the multispectral dataset (right).*

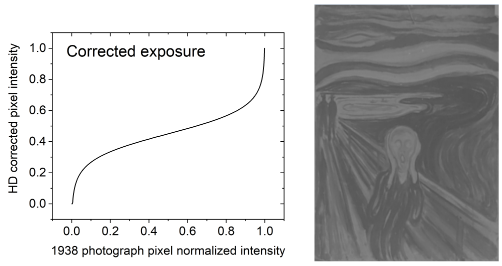

Figure 3: *The corrected digitised image of the 1938 photograph of the Scream (right) after application of the Hurter–Driffield (HD) correction represented in the plot (left).*

2.2. Multispectral imaging of the Scream (1910?)

Multispectral analysis of the Scream was carried out using a prototype scanner developed by CNR-INO, based on a point-scanning approach [SRB*18]. A single photodiode per wavelength captures the radiation reflected from the surface during a vertical boustrophedon scan, producing high-quality reflectograms. The system simultaneously acquires 32 narrow-band images (16 VIS: 390–780 nm, 16 NIR: 750–2500 nm). The scanner includes an XY(Z) scanning unit with high-precision stages and an optical head uses a 45°/0° illumination/observation geometry with halogen lamps and high-power LEDs. Collected radiation is focused onto a 6×6 optical fiber bundle leading to an array of Si and InGaAs photodiodes, each with narrow-band filters. Calibration uses certified color standards and an in-scene white reference. The 16 channels in the visible (390 to 780 nm) were used to generate the simulated orthochromatic image. In the Figure 2 the sRGB image of the painting created from the multispectral data is presented.

2.3. Methodology for generation of simulated orthochromatic image from multispectral data

Ideally, the orthochromatic photograph would be replicated today using analog film to support the validation of the simulation. However, this is not feasible due to strict conservation protocols and the practical difficulties of reproducing historical photographic conditions, such as the original film stock, camera settings, and development processes. As an alternative, multispectral imaging provides a flexible, accurate, and non-invasive method for simulating various black-and-white photographic responses. This makes it particularly well-suited for sensitive cultural heritage objects, where direct analog reproduction is not possible. The relative spectral sensitivity of the orthochromatic emulsion was obtained from literature data [WD13]. A sensitivity coefficient was assigned to each multispectral channel in the visible range (Figure 4). The simulated orthochromatic pixel intensity was calculated as:

$$I_{pixel} = \sum_{ichannel} I_{pixel}(i)\, S(i)$$

where $I_{pixel(i)}$ is the pixel intensity in channel i, and $S(i)$ is the corresponding sensitivity coefficient from Figure 4. Pixel intensities were subsequently normalized across the full dynamic range. The resulting simulated orthochromatic image is shown in Figure 4.

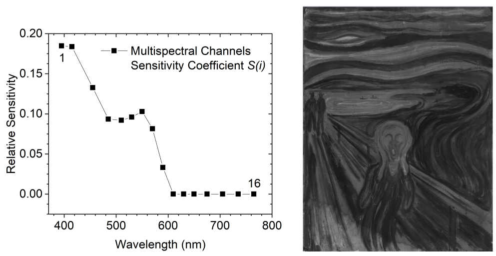

Figure 4: *Graph showing the relative sensitivity of the orthochromatic film at the wavelengths corresponding to the multispectral channels (left). Simulated orthochromatic image of the Scream (1910?) created from multispectral data (right).*

2.4. Intensity calibration of the 1938 image

To enable a more accurate comparison between the simulated orthochromatic image and the corrected orthochromatic image from 1938, a calibration of pixel intensities was performed. To do this, pixels within a green region to the right of the image were selected to construct a calibration curve. The green area has been chosen because it composed mainly of the chrome based green pigments (Viridian or chrome oxide) [SSF*22], which are known for its chemical stability [EWCS07]. As a result, any color changes over the years are expected to be insignificant .

However, it is important to consider that the complete paint system, which includes the binding medium, may still have experienced aging-related changes over time. Environmental exposure may have led to yellowing or other physical or chemical alterations in the binder, potentially affecting the appearance of the green area. Although this region was selected based on the presumed stability of its pigments and the absence of visible degradation, we acknowledge that possible changes in the binder or surface condition could introduce uncertainties into the calibration process. This limitation should be considered when interpreting the results.

The calibration curve was generated by plotting the pixel intensities from the green area of the 1938 image against the corresponding pixel intensities from the simulated image (Figure 5). A linear regression was then applied, and the resulting equation was used to adjust the pixel intensities of the 1938 image accordingly.

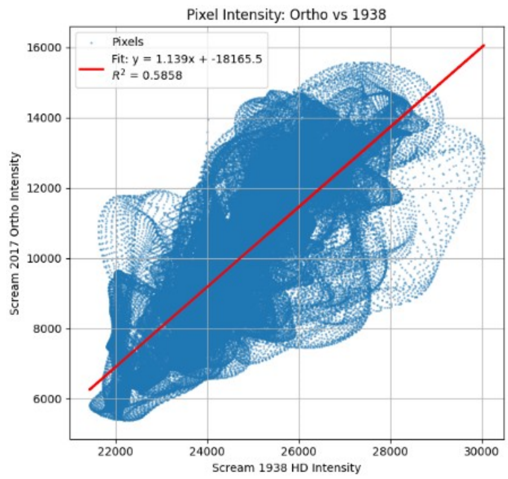

Figure 5: *Linear calibration curve based on pixel intensities from green-coloured areas of the corrected 1938 photograph and the simulated orthochromatic multispectral image.*

3. Results

A methodical visual comparison of the two images was conducted. This examination revealed prominent differences in specific areas of the painting, in particular within three distinct colour ranges corresponding to shades associated with specific pigments. These differences suggest possible colour changes in areas where these pigments are predominant (Figure 6).

The first and most striking change was observed in the blue areas (Figure 6a), where the originally dark blue shades appear to have brightened over time.

While changes in blue pigments have been previously reported in other paintings by Edvard Munch, they have primarily involved a darkening phenomenon associated with ultramarine and cobalt blue [BFG*24], [BFG*25]. In contrast, the present study on The Scream (1910?) identifies a distinctly different alteration characterized by a brightening of the blue areas, which to our knowledge has not been documented before.

Macro X-ray fluorescence (MA-XRF) mapping of the artwork, as part of a MOLAB campaign carried out in 2017 [CSR*19] indicates that the primary pigment used in the vivid blue regions exhibiting this brightening effect is ultramarine, a complex sodium aluminosilicate containing sulfur. Cobalt blue, also known as Thenard's blue, was also identified in the painting, but appears to have been used only in specific regions details.

One possible explanation for the observed colour change is what has been reported in the literature as dissociation of the oil binder in the oil paints, resulting in colour desaturation and a visual appearance closer to that of the unbound pigment [DLRMN*17], [MDLR24]. However, we acknowledge that this remains a working hypothesis, and further research is ongoing to fully understand the mechanisms underlying this phenomenon.

Finally, changes in the yellow areas are noted, particularly a decrease in lightness (Figure 6b). These changes are likely related to degradation of the cadmium yellow pigment, a phenomenon that has been previously documented in various paintings [VDSJD*12]. Cd yellow investigation performed by Monico et al [MCR*20] showed that specific types of this pigment can fade under exposure to high relative humidity and light [CAG*22, SGL*19, SFM*18, CSR*19, MCR*22].

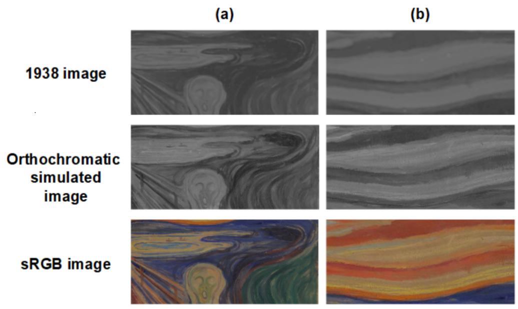

Figure 6: *A side-by-side comparison between the corrected 1938 photograph and the simulated orthochromatic image, allowing to observe differences in the dark blue areas (a) and yellow areas (b).*

4. Conclusion

This study demonstrated that the combined use of historical black-and-white photographs and modern spectral imaging provides a powerful, non-invasive approach for detecting material and colour changes in artworks over time. By simulating the spectral sensitivity of the orthochromatic film used in a 1938 photograph of Edvard Munch's The Scream (1910?) and reproducing a corresponding image from recent multispectral data on the painting, the comparative study identified significant colour changes.

Specifically, a brightening of the dark blue regions and a fading of the yellow areas were observed. These findings highlight the potential of historical photographic records, when properly calibrated and compared with modern imaging data, to uncover previously ignored aspects of an artwork's material history.

This approach can be broadly applied to other cultural heritage objects, offering a robust, non-invasive, and data-driven methodology for tracking the evolution of artworks over time.

Ongoing work focuses on the in-depth analysis of imaging, scanning, and spectroscopic data mainly from the MOLAB campaign, with the aim of validating the observed colour changes and investigating the specific chemical reactions responsible for the underlying degradation processes.

5. Acknowledgement

This research was carried out as part of the PERCEIVE project (GA. 693529), which aims to develop integrated imaging, modeling, and analytical methodologies for the conservation and understanding of cultural heritage materials. The authors gratefully acknowledge financial support from the Transnational Access to Research Infrastructures activity of the European Union's Horizon 2020 Programme (IPERION CH, GA. 654028), which supported the analyses on The Scream conducted in 2017.

References

[BFG*24] Boracchi G., Ferrer B. S. E.-J., Gnemmi M., Falchi L., Izzo C., Sandu I. C. A.: Ultramarine Blue in Edvard Munch's Collection: A Multi-Analytical Study of Early 20th Century Commercial Oil Paints. *Heritage 7*, 8 (July 2024), 4027–4044. Number: 8. URL: https://www.mdpi.com/2571-9408/7/8/190, doi:10.3390/heritage7080190. 3

[BFG*25] Boracchi G., Ferrer E.-J. B. S., Gnemmi M., Falchi L., Izzo C., Sandu I. C. A.: A multi-analytical study of early twentieth-century industrially produced cobalt blue paints from Edvard Munch's studio. *The European Physical Journal Plus 140*, 3 (Mar. 2025), 188. Number: 3. URL: https://link.springer.com/10.1140/epjp/s13360-025-06062-0, doi:10.1140/epjp/s13360-025-06062-0. 3

[CAG*22] Chan E., Aambø M., Godzimirska M., Grimstad T., T. Lojewski I., I.C.A. Sandu: Light-induced color changes on "The Scream" versions in the Munch museum collection. vol. 13, pp. 1623–1634. 4

[CSR*19] Cartechini L., Sandu I., Rosi F., C. Grazia, L. Monico, A. Romani, R. Pereira de Freitas, M. Godzimirska, E. Chan, G. Landro, E. S. Tveit, P. Pettersen, C. Miliani: The "Scream" by Edvard Munch (1910): non invasive integrated spectroscopic investigations of the painting materials. In *MA-XRF Scanning in Conservation, Art and Archeology* (Catania, 2019). 3, 4

[DLRMN*17] De La Rie R. E., Michelin A., Ngako M., Del Federico E., Del Grosso C.: Photo-catalytic degradation of binding media of ultramarine blue containing paint layers: A new perspective on the phenomenon of "ultramarine disease" in paintings. *Polymer Degradation and Stability 144* (Oct. 2017), 43–52. URL: https://linkinghub.elsevier.com/retrieve/pii/S0141391017302343, doi:10.1016/j.polymdegradstab.2017.08.002. 4

[Edw19] Edwards E.: What are photographs doing in museums?, Mar. 2019. URL: https://www.vam.ac.uk/blog/museum-life/what-are-photographs-doing-in-museums. 1

[EWCS07] Eastaugh N., Walsh V., Chaplin T., Siddall R.: *Pigment Compendium: A Dictionary of Historical Pigments*, 0 ed. Routledge, Mar. 2007. URL: https://www.taylorfrancis.com/books/9781136373862, doi:10.4324/9780080473765. 3

[JM77] James T. H., Mees C. E. K. (Eds.): *The Theory of the photographic process*, 4th ed ed. Macmillan, New York, 1977. URL: https://archive.org/details/TheTheoryOfThePhotographicProcess/page/n201/mode/2up?view=theater. 2

[MCR*20] Monico L., Cartechini L., Rosi F., Chieli A., Grazia C., De Meyer S., Nuyts G., Vanmeert F., Janssens K., Cotte M., De Nolf W., Falkenberg G., Sandu I. C. A., Tveit E. S., Mass J., De Freitas R. P., Romani A., Miliani C.: Probing the chemistry of CdS paints in *The Scream* by in situ noninvasive spectroscopies and synchrotron radiation x-ray techniques. *Science Advances 6*, 20 (May 2020), eaay3514. Number: 20. URL: https://www.science.org/doi/10.1126/sciadv.aay3514, doi:10.1126/sciadv.aay3514. 4

[MCR*22] MONICO L., CARTECHINI L., ROSI F., LUCIANO G., VIVANI R., COTTE M., M. GHIRARDELLO, D. COMELLI, C. MILIANI, I.C.A SANDU, E. TVEIT, K. JANSSEN, A. ROMANI: Study of properties and chemical stability of cadmium yellow paints by a multi-technique approach at multiple scale lenghts. 4

[MDLR24] MICHELIN A., DE LA RIE R. E.: Ultramarine blue containing paint layers: Further study of the photo-catalytic degradation of binding media. *Journal of Cultural Heritage 70* (Nov. 2024), 163–172. URL: https://linkinghub.elsevier.com/retrieve/pii/S1296207424001936, doi:10.1016/j.culher.2024.09.002. 4

[SFM*18] SANDU I., FORD T., MILIANI C., JANSSENS K., VAN DER SNICKT G., J. STRIOVA, M. RAFFAELLI, R. FONTANA, LAURA CARTECHINI, F. ROSI, A. ROMANI, L. MONICO, C. GRAZIA, R. PEREIRA DE FREITAS, A. TOURNIE, C. ANDRAUD, V. DETALLE, E. BOURGUIGNON, K. LACLAVETINE, F. MIRAMBET, S. GEORGE, J.-Y. HARDEBERG, M. UFNALEWSKA-GODZIMIRSKA, G. LANDRO, E. STOREVIK TVEIT, P. PETTERSEN: The “Scream” by Edvard Munch - same motif, different colours, different techniques and approaches – a novel non-invasive comparative study of two of its versions. 4

[SGL*19] SANDU I., GODZIMIRSKA M., LANDRO G., STOREVIK TVEIT E., PETTERSEN P., MILIANI C., STRIOVA J., RAFFAELLI M., FONTANA R., CARTECHINI L., ROSI F., ROMANI A., MONICO L., GRAZIA C., PEREIRA DE FREITAS R., A. TOURNIE, C. ANDRAUD, V. DETALLE, E. BOURGUIGNON, K. LACLAVETINE, F. MIRAMBET, T. FORD: TECHnical Study of CoRE Art Materials & TECHniques of SCREAM versions, IPERION. 4

[SRB*18] STRIOVA J., RUBERTO C., BARUCCI M., BLAŽEK J., KUNZELMAN D., DAL FOVO A., PAMPALONI E., FONTANA R.: Spectral Imaging and Archival Data in Analysing *Madonna of the Rabbit* Paintings by Manet and Titian. *Angewandte Chemie International Edition 57*, 25 (June 2018), 7408–7412. Number: 25. URL: https://onlinelibrary.wiley.com/doi/10.1002/anie.201800624, doi:10.1002/anie.201800624. 2

[SSF*22] SANDU I. C. A., SANDBAKKEN E. G., FERRER J. S., SYVERSEN T., HULL A.: The Art Historical Materials Collection at Munch: Colours, Brands, Labels. *International Journal of Conservation Science 13*, 1 (Dec. 2022), 1653–1664. Number: 1. URL: https://ijcs.ro/public/IJCS-22-122_Sandu.pdf. 3

[VDSJD*12] VAN DER SNICKT G., JANSSENS K., DIK J., DE NOLF W., VANMEERT F., JAROSZEWICZ J., COTTE M., FALKENBERG G., VAN DER LOEFF L.: Combined use of Synchrotron Radiation Based Micro-X-ray Fluorescence, Micro-X-ray Diffraction, Micro-X-ray Absorption Near-Edge, and Micro-Fourier Transform Infrared Spectroscopies for Revealing an Alternative Degradation Pathway of the Pigment Cadmium Yellow in a Painting by Van Gogh. *Analytical Chemistry 84*, 23 (Dec. 2012), 10221–10228. Number: 23. URL: https://pubs.acs.org/doi/10.1021/ac3015627, doi:10.1021/ac3015627. 4

[WD13] WHAITES E., DRAGE N.: *Essentials of dental radiography and radiology*, fifth edition ed. Churchill Livingstone, Elsevier, Edinburgh London New York, 2013. 3