Multispectral imaging of photographs

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Summary: Anna Seweryn, *Multispectral imaging of photographs*

The article discusses the meaning and examples of how multispectral imaging techniques can be used to study photographic collections. This non-invasive research technique allows to compile additional information about works of art, of historical value, complex technological structure or in bad condition. The text focuses on the process of multispectral imaging, but it also relates to previous research on imaging of different archival materials. It discusses examples of multispectral imaging various types of photographic prints as well as related problems – from fading of the picture through degradation resulting from fire. The selected examples made it possible to present basic possibilities of using MSI in the context of photographic archive.

Introduction

Multispectral imaging (MSI) is increasingly appearing in the literature on the study of historic archival materials. This minimally invasive and fairly inexpensive research method allows additional information about the object to be obtained. It is particularly applicable to documents of high historical value, technically complex or affected by degradation. Performing imaging using a multispectral camera and variable, narrow-band illumination is a natural continuation of earlier methods of analytical photography of works of art, assisted by ultraviolet or infrared radiation. The process of multispectral imaging goes beyond the standard tasks of an art conservator or digitiser, but a specialised studio dedicated to this process can provide a place where the needs and tasks of both disciplines intersect and complement each other.

Multispectral imaging process

Multispectral imaging is now used in a wide range of appliances, from industry and agriculture to historic preservation. Imaging systems are being used to analyse waste in the rubbish sorting process,[1] detect biological contaminants in food,[2] or identify microorganisms.[3] The process is increasingly entering museums, archives and libraries, where its use allows the capture of features of a historic object that are not visible to the unaided eye or when taking a standard

1 K. Tutak, M. Pieszko, *The use of spectra imaging for material identification in waste* sorting, "Archives of Waste Management and Environmental Protection" 2015, vol. 17, no. 4, pp. 67–78.

2 A. Soni, Y. Dixit, M. M. Reis, G. Brightwell, *Hyperspectral imaging and machine learning in food microbiology: Developments and challenges in detection of bacterial, fungal, and viral contaminants,* "Comprehensive Reviews in Food Science and Food Safety" 2022, 21(4), pp. 3717–3745.

3 J. Le Galudec, M. Dupoy, V. Rebuffel, P. R. Marcoux, *Microbial identification through multispectral infrared imaging of colonies: combining chemical and morphotype analysis,* "Research Square" 2023.

photograph or scan. This type of examination and simultaneous reproduction of the object is gaining popularity, mainly due to the low cost and minimally invasive nature of the examination process for the artwork. Currently, the greatest risk associated with the multispectral imaging process is the exposure of the object to damage caused by exposure to ultraviolet radiation. Exposure of the artwork to ultraviolet wavelanght during imaging for a period of 30 seconds generates damage comparable to a day's exposure of an object to daylight.[4] The process of multispectral imaging is a complex task and involves the selection of archival material, the adaptation of equipment to the size and type of object, the registration of image sequences and the processing of the resulting digital data. The system allows the registration of images recorded on a monochrome digital matrix using illumination emitting a narrow electromagnetic band. The set enabling imaging consists of a multispectral camera equipped with an objective and filter wheel, a set of lamps generating illumination of various electromagnetic wavelengths – from ultraviolet to infrared – and a computer with software.[5] Various types of detectors are used for multispectral imaging, including silicon matrix (modified digital cameras recording radiation in the 360–1100 nm range) and specialised InGaAS cameras recording images in the 900–1700 nm wavelength.[6] The effect of the system is to generate from a dozen to several dozen images, which can then be analysed by creating multi-layered files – data cubes.[7]

4 C. Jones, Ch. Duffy, A. Gibson, M. Terras, *Understanding multispectral imaging of cultural heritage: Determining best practice in MSI analysis of historical artefacts*, "Journal of Cultural Heritage" 2020, no. 45, p. 342.

5 The MSI imaging set-up used for the research described in this article consists of a ZWO ASI6200MM Pro camera, a ZWO Electronic Filter Wheel 5×50 mm/2" with BAADER Planetarium filters, a JENOPTIK UV-VIS-IR 60 mm APO lens, lamps generating electromagnetic radiation in 12 electromagnetic wavelengths in the 375–940 nm range, and a computer with software for image registration and post-processing of the data.

6 A. Cosentino, *Identification of pigments by multispectral imaging; a flowchart method*, "Heritage Science" 2014, no. 2 (8), p. 1.

7 Multispectral images can be described as data cubes or collections of files recorded using different wavelengths, every 50 nm or so (as opposed to hyperspectral imaging, where the

The visual inspection of photographs taken in the light of a narrow range of electromagnetic waves can help in the search for additional content, but the most significant result of the research is visible as a result of computer processing of the data performed with the help of specialised algorithms. The type of digital processing and its effects depend on the software used, the algorithm chosen, and the files selected for analysis. Data cubes can be processed using *Principal Component Analysis (PCA*), which allows certain elements of the recorded object to be enhanced. With this technique, the digital image data is compressed, and the features are made visible. Images are also processed using *Independent Component* Analysis *(ICA*), where data are transformed into a new independent set.[8] *Linear Discriminant Analysis (LDA*) is used to produce false-colour images. Digital images can also be analysed using the *Spectral Angle Mapper (SAM)* option, which measures the similarity between two files (spectra) and identifies components with similar characteristics, including revealing areas of identical chemical structure. MSI images are also analysed by false colouring, where three suitable images (layers) are selected from a set and overlaid as coloured layers. The most common combination making up the file are photographs taken in infrared, red and green (IrRG) or infrared, green and blue (IrGB).[9]

In the MSI imaging process, it is particularly important to create a suitable testing facility for the objects. This includes, first and foremost, performing examinations in a darkened room with a controlled climate, ensuring that the object can be manipulated safely, and the stability of the camera and lamp mounting in a defined and fixed position. In the context of photographic materials, both

difference is 10–20 nm). In the simplest version of the study, four images are taken: in the blue, green, red and infrared spectra, after: A. Tonazzini, E. Salerno, A. A-S. Zienab et al, *Analytical and mathematical methods for revealing hidden details in ancient manuscripts and paintings. A review,* "Journal of Advanced Research" 2019, no. 17, https://www.sciencedirect.com/science/article/pii/S2090123219300037 [accessed 04.02.2024]

8 ICA is mainly used to authenticate the text layer of manuscripts (separating it from the background).

9 A. Tonazzini, E. Salerno, A. A-S. Zienab et al, *Analytical and mathematical methods…*, cited.

negatives and positives, made on transparent substrates, it is also necessary to identify an additional light source (backlighting).

The production of the digital files themselves using a multispectral camera is relatively quick and simple. Problems can arise, however, at the stage of computer processing of the digital data cubes. The huge number of files generated and the countless possible combinations of individual layers require lengthy and meticulously documented analysis. Free, sometimes imperfect data processing software and the large volume of files can lead to frequent software errors and loss of work results. In addition, in the case of files generated during the imaging of historic photography, there is a lack of precise instructions on recommended and proven methods for analysing the data with specific algorithms. Their use, therefore, becomes experimental and often does not yield the expected results. The description and documentation of the research performed are also a problem, especially in the context of digital data processing. When publishing a photograph generated using a specialised program for processing multispectral files, it would be necessary to provide all the information that would make it possible to reconstruct the path leading to a given research result, including the type of computer program and algorithm used, the exact type and order of the images (layers) used, along with a description of the lighting used during the taking of the photograph, the filter and the type of additional options modifying the data entered (e.g. inversion).

Application of multispectral imaging

Multispectral imaging is used by researchers on many occasions in the field of art. Research using a multispectral camera is used to gain the best possible understanding of an artwork, including the determination of its technological structure or history, which translates into the state of preservation of the artwork as well as documenting the state of preservation before and after conservation. The generation of digital spectral images makes it possible to authenticate documents on degraded basis, read filigrees, distinguish inks and writing media, and reach content covered by microbial infection or dirt. Imaging can also be helpful as a tool for meticulous visual documentation of the conservation work carried out and for estimating the condition of the object before and after the treatments,[10] as well as assisting the process of reading documents intently damaged or destroyed during a fire or as a result of flooding.[11] In the history of the examination and imaging of documents and other works of art, we have already encountered the use of ultraviolet[12] or near-infrared[13] since the beginning of the 20th century. Researchers operating multispectral imaging systems usually focus on the analysis of single, unique writing or painting artwork. Some of the most famous document studies include the reading of a palimpsest from Archimedes' Codex C[14] or the discovery of the nuances of Thomas Jefferson's Declaration of Independence.[15] The study of manuscripts is usually efficient and allows additional information to be obtained, as document substrates and writing media interact differently with different electromagnetic wavelengths, e.g. iron-gallic

10 K. D. Chlebda, T. Łojewski, *Obrazowanie hiperspektralne w analizie dokumentów i konserwacji sztuki*, "Notes Konserwatorski" 2016, no. 18, p. 63.

11 T. Łojewski, M. Maciaszczyk, W. Płosa, *Uczytelnienie zapisków Marcela Nadjary'ego, więźnia obozu Auschwitz-Birkenau, metodą obrazowania multispektralnego*, "Notes Konserwatorski" 2022, no. 24, pp. 59–74.

12 In the case of photographic collections, ultraviolet radiation was used to identify coatings, locate the occurrence of *foxing* or identify areas of retouching and colouring, and identify surface corrosion, after: L. A. Daffner, D. Kushel, J. M. Messinger, *Investigation of surface tarnishing found on 19th-century daguerreotypes*, "JAIC online, Journal of the American Institute for Conservation" 1996, vol. 35, no. 1, pp. 9–21.

13 A. D. Kushel, *Transmitted Infrared Radiation to the Examination of Artifacts,* "Studies in Conservation" 1985, vol. 30, no. 1, pp. 1–10.

14 R. L. Easton Jr., W. Noel, *The multispectral imaging of the Archimedes palimpsest*, "Gazette du livre médiéval" 2004 , no. 45, pp. 39–49, https://www.persee.fr/doc/galim_0753-5015_2004_num_45_1_1646 [accessed 04.02.2024].

15 F. G. France, T. B. Toth, *Spectral imaging for revealing and preserving world cultural heritige,* conference proceedings "19th European Signal Processing Conference (EUSIPCO 2011)", 2011, pp. 1452–1453, https://www.researchgate.net/publication/267995180_Spectral_imaging_for_revealing_and_preserving_world_cultural_heritage [accessed 04.02.2024].

ink reflects infrared light, and carbon-based writing materials absorb it, which significantly alters the legibility of the original object in the digital image.[16] The system also allows the registration of discolouration and changes in the optical properties of writing materials.[17]

The making of digital copies of archival material and works of art, or the visual inspection of them using multispectral imaging systems, are also used to establish the authenticity of a document or to obtain evidence by forensic laboratories.[18] Imaging is also combined with other research methods, such as RTI, which makes it possible to relate the texture of an object to its colour information.[19]

16 C. Jones, Ch. Duffy, A. Gibson, M. Terras, *Understanding multispectral imaging of cultural heritage: Determining best practice in MSI analysis of historical artefacts,* "Journal of Cultural Heritage" 2020, no. 45, p. 340.

17 MSI was chosen for the study as a method that does not require sampling of historic objects, and manuscripts (17th–20th century) made with iron-gallic ink were studied. Thanks to the study, the researchers can estimate the date of the object's creation, and they propose to extend the research by modelling and simulating the degradation of the inks over time. Through mathematical analysis of the files obtained, they were able to obtain correlations between historical objects and their date of creation (and so the technique can be used to determine the date of creation of an object), per: A. Rahiche, R. Hedjam, S. Al-maadeed, M. Cheriet, *Historical document dating using multispectral imaging and ordinal classification*, "Journal of Cultural Heritage" 2020, no. 45.

18 A. Rahiche, R. Hedjam, S. Al-maadeed, M. Cheriet, *Historical document dating using multispectral imaging and ordinal classification,* "Journal of Cultural Heritage" 2020, no. 45, p. 30.

19 An important issue in the documentation of works of art is to know the definition of colour as the need for objective identification of colour in terms of its reproduction and the definition of reproduction, i.e. the visualisation of colour in a given structure (the texture of an object's surface). There is a need to develop research and programmes that link the real world with the virtual world, where the shapes and material properties of the model plane are reflected. During the colour analysis of a work of art, the authors recommend taking into account the colour of the object, the gloss of the surface, its roughness, the size and shape of the artwork, as well as the contrast of the individual elements, after: M. Gaiani, I. A. Fabrizio, A. Ballabeni, *Cultural and architectural heritage conservation and restoration: which colour?,* "Coloration Technology" 2020, no. 137.

Multispectral imaging of historic photographs

To date, there is a lack of publications treating the topic of multispectral imaging in the context of antique photographs in a cross-sectional manner.[20] Among the few works devoted to the subject, one can mention a modest imaging study devoted to the daguerreotype[21] and a recent study on an assemblage of retouched photographic prints,[22] as well as photography-related postcards.[23] While imaging manuscripts, including palimpsests, yields good results in many situations, with originally unseen content becoming legible, it is difficult to predict the possibilities of photographic image registration and processing. The advantage of manuscripts for this type of process is the contrast, technological and spectral, between the writing medium and the substrate. The trace left by the writing

20 There are descriptions of applying multispectral and hyperspectral imaging to photographic collection projects. Still, these are usually limited to a description of the equipment used and a sparse conclusion of the research, e.g.: M. Picollo, C. Cucci, A. Casini, L. Stefani, *Hyperspectral imaging applied to the study of negative and positive films*, conference proceedings "Colour Photography and Film: Sharing knowledge of analysis, preservation, conservation, migration of analogue and digital materials", 2021, pp. 217–219.

21 D. Goltz, G. Hill, *Hyperspectral Imaging of Daguerreotypes,* "Topics in Photographic Preservation" 2011, no. 14, p. 194 and https://chsopensource.org/photographic-materials/ and https://iconphmgblog.wordpress.com/2021/01/28/using-multimodal-imaging-and-machine-learning-to-understand-hand-coloured-photographs/ [accessed 04.02.2024].

22 R. Sharma, *Daubing Titipu, Colourants in Japanes Albumen Prints,* University of Amsterdam, 2020. Master's thesis on the study of a photographic album of coloured albumen prints from Japan.

23 The subject of the study was postcards produced in Greece in the early 20th century. The study compared a collection of cards (without dating) from the collections of institutions with material from private collections marked with a specific date. The study was carried out on a microscopic scale, to find commonalities and differences between the collections that can help in the process of dating specific objects, after: V. Kokla, *Assessing historical printed materials using the combination of historical information and imaging techniques. Case study: Greek postcards of the early 20th century*, "International Circular of Graphic Education and Research" 2021, no. 13.

tool also produces spectral differences that are readable by the camera and software. How the photograph is produced, where the image particles are sunk deep into a smooth and uniform binder layer, can be a certain complication during the registration process. Hypothetically, we should be able to achieve greater readability of the created files when applying imaging photographic techniques characterised by surface differences of light and shadow batches, as in daguerreotype or techniques based on dichromate salts.[24] Due to the technological diversity, each of the photographic techniques should await a separate study, as should each of the various research problems associated with it – from image fading, discolouration, and traces of microbial infection, to degradation associated with damage caused by catastrophic events. The work carried out on photographic imaging should result in a library of data that allows us to determine the use of the most effective method of illuminating an object, as well as the most appropriate combination of algorithms to obtain the information we are looking for. The data in the library could facilitate identification of the technology used to take a photograph, get to the content or record a particular type of damage. When deciding to perform multispectral imaging, we must be aware that the restoration of illegible content will not go hand in hand with the preservation of the original colour of the object, which can, unfortunately, interfere with the perception of the whole. At the same time, computer software allows us to combine the recorded image components and create a data cube reproducing the image in RGB colour scale (Photo 1).

The way the files are produced in the study allows them to be analysed before the data cubes are processed. Just looking at the individual raw images can provide us with new information about the object under study. One of the

24 In the case of daguerreotypes, an image layer made of mercury-silver amalgam deposited on the surface of a silver-plated substrate will reflect radiation in a contrasting manner and thus most likely allow image details to be recorded and read. The same should be true of photographs made on the basis of dichromate salts and pigments, where the image layer will have a structure analogous to the painting layer.

Photo 1.
Chromogenic colour print subjected to multispectral imaging. Clockwise description: reproduction of the original print made with a Canon EOS 5D Mark III digital camera; photograph taken with the MSI system at 375 nm electromagnetic wavelength with the use of a red filter – visible increase in the readability of the detail, especially in the parts affected by microbiological infection; photograph taken with the MSI system at 375 nm electromagnetic wavelength with the use of a UV filter – visible authentication of the extent of microbiological infection; photograph taken with the MSI system and with the use of the HOKU programme – reconstruction of the original colours of the object by combining the three components responsible for the RGB colour channels (photo A. Seweryn)

aims of imaging may be to make invisible content, a faded or impurity-covered image, more legible in the case of a photograph made of silver, iron compounds, dyes or pigments. Good results in image enhancement can be obtained in the case of damaged photographs made using the cyanotype technique. A significant increase in image contrast is obtained when photographs are registered using illumination with an electromagnetic wavelength of 410 nm and a red filter (Photo 2). We gain a positive result when attempting to register the contrast between background and image due to the individual characteristics

Photo 2.
Attempts to authenticate a degraded photographic image made using the cyanotype technique (contemporary photography). On the left, a reproduction of the original print made with a Canon EOS 5D Mark III digital camera (the right half treated with alkali to degrade the image). On the right, the image obtained with MSI imaging using 410 nm illumination and a red filter (photo A. Seweryn)

of the paper substrate of photographic prints, including luminescence caused by the addition of optical brighteners to the paper pulp or baryta layer. Its observation can also help us to date the object, and to distinguish originals from later replicas or duplicates.

Working with silver photography is less predictable, and the effect of contrast enhancement in an image is more difficult to see. To observe it, it is best to perform tests on photographs that contain lettering in the image content (e.g. shop signs, posters), and image content usually occurs when photographs are taken with illumination in the 375–480 nm wavelength range.

Multispectral imaging can be used to attempt to read photographs that are not only faded but also covered up by dirt, microbial infection or physical and chemical degradation products. One of the typical degradations occurring on gelatine-silver materials is the silver mirroring effect. *Silver mirroring* is the result of the migration of silver ions that occurs in the object due to the presence of chemical contaminants, inappropriate temperature and increased relative humidity. The presence of metallic silver on the surface of an image layer disturbs the free perception of its content: on photographic prints, in intensely darkened parts, it produces a blue sheen, and on negatives seen in transmitted light, it reveals itself as yellowing. Taking photographs with a multispectral camera at 375 nm, 410 nm, and 940 nm illumination allows the covered content to be read. Similarly, the use of computerised analysis helped to read the blurred figures and background details originally captured in the photograph (photo 3). For the analysis, the PCA option in the HOKU software was used, along with images taken at 375 nm (with blue filter) and 525 nm (with green filter and as input) and 525 nm and 632 nm (as ROI) along with inversion of all layers.

Photo 3.
Gelatine-silver photograph with visible silver image degradation (*silver mirroring*), locally mechanically removed. Top: reproduction of the original print taken with a Canon EOS 5D Mark III digital camera. Below, the image obtained with MSI imaging (processing in HOKU software) (photo A. Seweryn)

One of the common types of damage present in photographs on paper basis is *foxing* – a localised discolouration of a rusty colour. *Foxing* is the result of microorganisms and/or iron compounds in the paper structure, which migrate to the face of the object over time and become visible. This type of damage can distort the perception of a photograph and render its original content unreadable. The registration of UV-induced fluorescence images makes it possible to identify areas of yet undisclosed discolouration. In images recorded in the infrared wavelength range, the degradation products are no longer visible, and the image's legibility is enhanced (Photo 4).

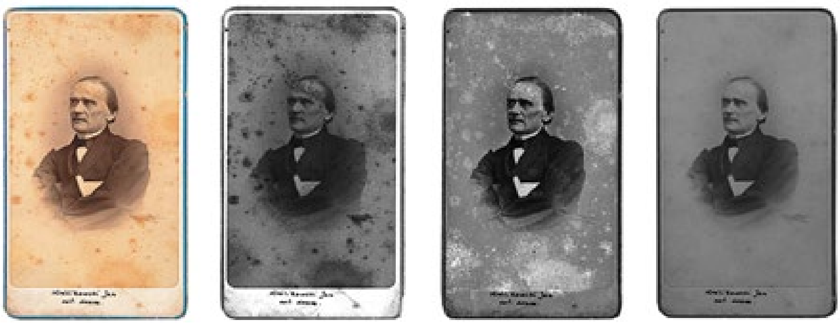

Photo 4.
Effect of multispectral imaging for a photograph produced using the albumen technique, with visible damage to parts of the image, known as *foxing*. Sequentially visible: reproduction made under VIS light, using 375 nm wavelanght with a UV filter, 375 nm wavelanght with a red filter and 850 nm wavelanght (photo A. Seweryn)

In the case of albumen prints, characterised by the small thickness of the paper basis, the possibility of reaching the contents found on the cardboard substrate was observed during the multispectral imaging process – the text was revealed in infrared light (850 nm) and then enhanced during digital data processing using the ICA method (Photo 6). The legibility of the notations underneath the paper backing of the photographs offers the hope of reading the information contained on the currently inaccessible backs of objects, such as those mounted into photo albums.

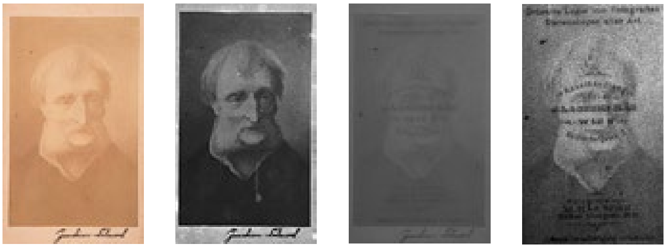

Photo 5.
Effect of multispectral imaging for a photograph produced using the albumen technique (graphic reproduction). Sequentially visible: reproduction made under VIS light, using 375 nm wavelanght with a red filter, and 850 nm wavelanght, as well as the authentication of the notations on the cardboard thanks to computer processing of the files (photo A. Seweryn)

Another important issue in the reading of photographs is the restoration of the content of objects damaged in the event of a disaster. Reaching archival material that has been damaged by water, in the case of the gelatine-silver photographs, which are the most numerous in the collection, will require reading the small amount of content preserved in the often-dissolved layer of the photographic image. In the case of burnt objects, the image may be browned, deformed or covered with soot residue, which can be partially remedied using infrared radiation and digital file processing (Photo 6).

Fig. 6.
Readability of a gelatine-silver photograph affected by fire damage. Sequentially visible: reproduction made under VIS light, using radiation at 740 nm, and two results of digital file analysis – *a pseudo-colour* version and *PCA* (photo A. Seweryn)

By imaging with the pseudo-colour and normalisation options, it was possible to obtain more legible parts of the previously hidden image, although the image generated (especially with the latter option) lacks the tonal continuity typical of photography, and the edges of the figures and illegible parts are covered by 'digital noise'.

Summary

Multispectral imaging has a wide range of applications, and projects based on the collected data often present interdisciplinary challenges, combining knowledge of object technology, content and degradation processes. The use of a multispectral imaging system is invaluable in deciphering the content of damaged and unreadable objects, while also fitting in with the idea of slow digitisation,[25] a process that places more emphasis on fully understanding the document being analysed rather than simply reproducing and making its contents accessible. Slow digitisation also allows for an additional evaluation of the existing schemes and recommendations used in cultural institutions for creating and making digital content available.[26] Although the digitisation methodology is already well developed and widely used in Poland, multispectral imaging still needs further development to become a widely accepted practice in institutions storing archival collections. It is important to recognise the applicability of multispectral imaging while critiquing and rationally looking at the balance of gains and losses that accompany carrying out this process on historical objects. One of the unspoken sides of the process is still the analysis of errors, which, as with

25 D. Jutrzenka-Supryn, J. Czuczko, *Digitalizacja zabytkowych książek – nowe spojrzenie, nowe możliwości*, "Notes Konserwatorski" 2023, no. 25, p. 83.

26 A. Prescott, L. Hughes, *Why do we digitize? The case for slow digitization,* "Archive Journal", September 2018, https://www.archivejournal.net/essays/why-do-we-digitize-the-case-for-slow-digitization/ [accessed 04.02.2024]. The authors of the text point out that any archival, unitary objects should be subjected to specialised imaging methods, unlike contemporary library collections where digital mass reproduction of text is a sufficient process.

any analytical study, do after all occur, and the detection of which, due to working in a digital environment, we may have limited influence over.

In the context of historic photography, the field of application of multispectral imaging remains wide and still not fully explored. To assess the usefulness of the MSI system in the reprography of historic photographs, detailed and well-documented research is needed, as well as an examination of the available hardware and software, of which more and more are appearing on the market. The potential of this technology in the preservation and restoration of cultural heritage is promising, and further research and development are likely to bring many more benefits to the field of conservation and digitisation of historic photographic collections.

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