INTERNATIONAL JOURNAL OF ARTS SCIENCE HUMANITIES RESEARCH STUDIES (IJASHRS)

(Open Access, Double-Blind Peer Reviewed Journal)

ISSN Online:

EDUSCHOOL ACADEMIC RESEARCH & PUBLISHERS

Imaging the Painted Surface: Analytical Science in Art Conservation

Shripathi Kalluraya

Research Professor, Institute of Social Science and Humanities,Srinivas UniversityMangalore, Karnataka, India

Article information

Received: 5th May 2026
Received in revised form:10th June 2026
Accepted:13th July 2026
Available online:10th August 2026

Volume: 2
Issue: 3
DOI: https://doi.org/10.5281/zenodo.21867618

Abstract

The examination of paintings has been transformed by a family of imaging and analytical methods that recover information from beneath the visible surface without removing material. This paper reviews those methods, the questions they answer, and the interpretive problems they create. It begins with the conservation ethics that made non-invasive examination a priority, then follows the stratigraphy of a painted object from varnish to support, identifying which technique interrogates which layer and on what physical principle. Reflectance imaging spectroscopy, infrared reflectography, optical coherence tomography, X-radiography, scanning macro X-ray fluorescence and X-ray powder diffraction tomography are each assessed for spatial resolution, depth reach and the class of information returned. Two well documented cases illustrate what the methods have delivered: the recovery of a hidden composition beneath a later painting, and the identification of a degradation product that explains the fading of a pigment. The paper then examines computational analysis of brushwork and its use in attribution, where the statistical evidence has proved more useful as a constraint on connoisseurship than as a replacement for it. The concluding argument is that these methods have shifted the epistemic basis of the discipline from expert judgement towards material evidence, without eliminating the interpretive step, and that the principal risk now is confident over reading of maps whose relation to the painter's intention remains indirect.

Keywords: Technical Art History, Conservation Science, Macro X-Ray Fluorescence, Reflectance Imaging Spectroscopy, Non-Invasive Analysis, Attribution.

INTRODUCTION

A painting is a stratified object. What the viewer sees is the uppermost of several layers, each deposited at a different moment and each carrying evidence of decisions that the finished surface conceals. Beneath the varnish lie paint layers and glazes, beneath those an underdrawing, beneath that a ground applied to prepare the support, and beneath everything a canvas or panel with its own history of construction, repair and reuse. Every stage of that sequence is potentially informative, and until recently almost none of it could be examined without taking the object apart.

The change has come from instrumentation. Over roughly three decades, a set of techniques originally developed for medicine, materials science and remote sensing has been adapted to the examination of works of art, and the resulting field, generally known as technical art history when it addresses historical questions and conservation science when it addresses treatment, now produces evidence that neither connoisseurship nor archival research can supply. This paper reviews the principal methods, examines what they have established, and considers the interpretive difficulties that follow from evidence of this kind.

WHY NON-INVASIVE METHODS

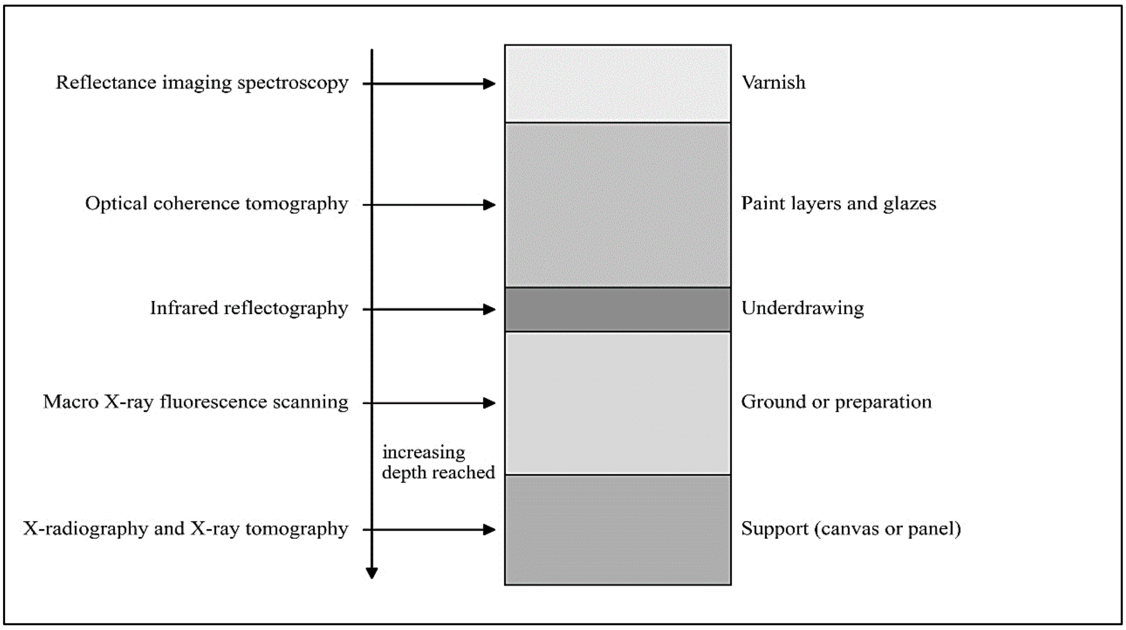
The preference for non-invasive examination is not merely practical. It follows from a shift in conservation theory that took place across the second half of the twentieth century.The classical position held that restoration should reveal the work of art without committing a historical or aesthetic forgery, and that it should be recognisable as intervention and reversible in principle.[1] Later theory moved further, treating conservation as a negotiation among the several communities that hold a stake in an object rather than as the recovery of an authentic original state, on the argument that no single true condition of the object exists to be recovered.[2] Both positions converge on the same operational rule. Whatever is done to an object should minimise irreversible change, and taking a sample is irreversible by definition.

Sampling has not disappeared. Cross sections examined under the microscope remain the reference method for establishing layer sequence, and a sample of a few tenths of a millimetre from an area of existing loss remains defensible. What has changed is the burden of justification. A sample must now be shown to answer a question that non-invasive examination cannot, and the range of questions that qualify has narrowed steadily as instrumentation has improved.

THE STRATIGRAPHY AND THE METHODS THAT REACH IT

Figure 1 sets the principal methods against the layer each interrogates. The organising physical principle is penetration: longer wavelengths and more energetic particles reach deeper, at a cost in spatial resolution and in specificity about what has been detected.

Figure 1. The layer structure of a typical easel painting and the depth routinely reached by each family of non-invasive examination methods. Thicknesses are schematic and not to scale



The surface

Reflectance imaging spectroscopy records a full reflectance spectrum at every pixel across the visible and near infrared range. Because many pigments have characteristic absorption features, the resulting data cube supports pigment identification and mapping over the whole surface rather than at selected points, and it distinguishes materials that appear identical to the eye and to conventional colour photography.[3] Applied to Old Master paintings and to illuminated manuscripts, the method has proved capable of separating pigments within a single passage of colour and of mapping the distribution of a binder or a degradation product across a composition.[4] The limitation is depth. Reflectance methods interrogate the uppermost layers only, and a strongly absorbing upper paint layer conceals whatever lies beneath it.

The near surface

Infrared reflectography exploits the transparency of many pigments in the near infrared and the strong absorption of carbon black. Where the underdrawing was executed in a carbon containing medium, it appears through the paint, and the difference between drawing and finished painting records the artist's changes of mind. The technique is old, is inexpensive, and remains among the most productive available.[5]

Optical coherence tomography, adapted from ophthalmic imaging, produces cross sectional images of translucent layers by low coherence interferometry. It resolves varnish thickness, the sequence of glazes and the presence of earlier coatings at micrometre scale, without contact and without sampling, and it has become the standard method for monitoring varnish removal in progress rather than assessing it afterwards.[6]

Through the object

X-radiography records differences in the attenuation of X-rays, which depends strongly on atomic number, so that lead containing pigments in particular appear with high contrast. It reveals the construction of the support, losses and repairs, and compositions painted over.

Scanning macro X-ray fluorescence is the most consequential recent addition. A focused X-ray beam is rastered across the surface and the fluorescence spectrum recorded at each point, producing a separate distribution map for each chemical element present. Because the fluorescence originates from the whole irradiated thickness, elements in buried layers appear, and the maps can be combined to reconstruct concealed compositions.[7] The decisive practical development was the construction of transportable instruments, which allowed the method to be applied in galleries and studios rather than requiring the object to travel to a synchrotron.[8]

X-ray powder diffraction imaging goes further, identifying crystalline compounds rather than elements. Since it is the compound and not the element that determines colour and degradation behaviour, this distinction matters, and diffraction based mapping resolves questions that elemental mapping leaves open.[9] Related X-ray methods, including laminography and computed tomography, extend the same principles to three dimensional reconstruction of layer structure.[10]

Table 1. Principal non-invasive imaging and analytical methods for paintings, with the information each returns and its main limitation

Method	Physical basis	Information returned	Principal limitation
Reflectance imaging spectroscopy[3,4]	Reflectance spectrum recorded at every pixel	Pigment identification and mapping at the surface	Little depth penetration
Infrared reflectography[5]	Pigment transparency and carbon absorption in the near infrared	Underdrawing, changes of composition	Fails where the drawing medium lacks carbon
Optical coherence tomography[6]	Low coherence interferometry in translucent layers	Varnish and glaze thickness, layer sequence	Restricted to translucent upper layers
X-radiography[10]	Attenuation of X-rays with atomic number	Support construction, losses, overpainted compositions	Superimposes all layers in one image
Scanning macro X-ray fluorescence[7,8]	Element specific X-ray fluorescence, point by point	Elemental distribution maps including buried layers	Identifies elements, not compounds
X-ray powder diffraction imaging[9]	Diffraction from crystalline phases	Compound specific maps, including degradation products	Slow acquisition, limited access to instruments
Portable multitechnique campaigns[11]	Several complementary methods applied in situ	Combined molecular and elemental evidence on site	Coordination cost, restricted analytical depth

TWO DEMONSTRATIONS

The value of these methods is best shown by cases in which they settled a question that could not otherwise be settled.The first is the recovery of concealed compositions. Synchrotron based X-ray fluorescence mapping of a Van Gogh painting recovered the image of a woman's head hidden beneath a later composition, reconstructing it in colour from the distribution of antimony and mercury associated with specific pigments.[12] Earlier X-radiographs had shown that something lay beneath, but they could not resolve what. The elemental maps could, because they separate the buried layer by its chemistry rather than by its density alone. Subsequent work using the same principle over whole canvases established the reworking of compositions as a routine object of study rather than an occasional discovery.[13]

The second is degradation chemistry. The fading and discolouration of red lead in a Van Gogh painting was traced by X-ray powder diffraction tomography to the formation of plumbonacrite, a lead carbonate phase that had not previously been identified in this context and that supplied the missing step in the reaction pathway.[9] This is a result with immediate conservation consequences, since knowing the mechanism indicates the environmental conditions that accelerate it, and it could not have been obtained by elemental mapping, which sees only lead.

Both cases illustrate a general point. The methods do not merely confirm what expert observation already suspected. They answer questions that observation had no means of addressing, and in doing so they change what counts as a settled matter in the discipline.

THE SUPPORT AS DOCUMENT

The layers above the support have received most analytical attention, but the support itself carries evidence of a different kind, concerning when and where an object was made rather than how it was painted.Panel paintings on oak can be dated by dendrochronology. The ring sequence of a panel is matched against regional reference chronologies to establish the felling date range of the tree, from which a plausible earliest date for the painting follows once allowance is made for seasoning and for the removal of sapwood. European practice rests on extensive reference chronologies, and the method also indicates timber provenance, since the near exclusive use of Baltic oak in Netherlandish panels during certain periods is itself a datable characteristic.[14] The evidence is a terminus after which the painting must have been made, not a date of execution, and the distinction is often blurred in secondary accounts.

Canvas supports carry a comparable signature. The density and spacing of warp and weft threads vary along a roll of canvas in a way that is effectively individual, and these variations are visible in X-radiographs because the threads attenuate differently from the ground between them. Automated analysis of radiographs can measure thread density across a whole painting and produce weave maps, and cross correlation of these maps identifies pairs of paintings cut from the same bolt.[15] Where such a match is found, it constrains chronology and workshop association independently of style, which is exactly the kind of evidence connoisseurship has historically lacked. The method has limits, since it requires plain weave canvas, good radiographs and a sufficient corpus for comparison, and a shared bolt establishes proximity in the studio rather than identity of hand.

What these support based methods share with the layer based methods described earlier is the recovery of evidence that is physical, reproducible and independent of aesthetic judgement. What they also share is that the inference from that evidence to a historical conclusion remains a matter of argument.

COMPUTATION AND ATTRIBUTION

A parallel development applies statistical analysis to high resolution images rather than to spectra. Brushwork carries an individual signature in stroke length, curvature, pressure and directional consistency, and these properties can be quantified. Early collaborative work between image processing researchers and museum specialists demonstrated that computational measures could distinguish authentic works from close contemporary copies within a controlled corpus.[16] Later work extended the approach with learned rather than hand designed features, improving performance on style and artist recognition tasks.[17]

The limits of this work should be stated plainly, and the researchers themselves have generally stated them. Performance depends on the corpus, and a classifier trained on securely attributed works of one period will not transfer to another. Digitisation conditions introduce artefacts that the classifier may learn instead of the brushwork. Most fundamentally, an attribution question is rarely a two class problem with a clean training set, since the contested cases are contested precisely because the boundary between workshop, follower and hand of the master is not sharp. The realistic role of computational analysis is as one constraint among several, capable of showing that a proposed attribution is inconsistent with measurable properties of the surface, and much less capable of establishing one.

INTERPRETIVE PROBLEMS

Three difficulties recur across the methods described here.The first is the gap between a map and a meaning. An elemental distribution map is a physical measurement. Reading it as evidence of an artist's decision requires assumptions about pigment availability, workshop practice and the sequence of application, and those assumptions are historical rather than analytical. A change visible in a fluorescence map may record an alteration by the painter, a later restorer, or a workshop assistant, and the map alone does not distinguish them.

The second is the seduction of the image. Reconstructions of hidden compositions are visually compelling and circulate widely, which creates pressure to present a reconstruction as a recovered painting rather than as an inference from a set of element maps with stated uncertainty. Careful practice presents the maps alongside the reconstruction. Publicity rarely does.

The third is access. Synchrotron beam time is scarce, instruments are expensive, and the collections that receive detailed technical examination are those with research funding and institutional connections. The consequence is a documented corpus skewed towards a small number of celebrated European painters, and a technical literature that describes the practice of those painters in great detail while leaving most of the world's painted heritage unexamined. Portable multitechnique campaigns partially address this, since they bring the instruments to the object and can be deployed in institutions that could never host a fixed facility.[11] They do not remove the underlying inequality in analytical attention.

CONCLUSION

Non-invasive imaging and analysis have altered the evidential basis of the study of paintings. Questions about layer sequence, pigment identity, concealed composition and degradation mechanism that once depended on expert inference or on destructive sampling can now be addressed by measurement, and the results have repeatedly proved both more specific and less flattering to received opinion than expected.[9,12]

Two qualifications follow the achievement. The measurements are physical and the conclusions drawn from them are historical, so the interpretive step remains and should be made visible rather than absorbed into the authority of the instrument. And the distribution of analytical attention is uneven in a way that shapes what the discipline knows, concentrating detailed technical knowledge on a small and already well studied canon. Extending portable instrumentation to collections outside that canon is the most productive available use of the methods, and it is a question of funding and priority rather than of physics.

REFERENCES

1. Brandi, C. (2005). *Theory of restoration* (C. Rockwell, Trans.). Nardini Editore. (Original work published 1963)
2. Munoz Vinas, S. (2005). *Contemporary theory of conservation*. Elsevier Butterworth-Heinemann.
3. Liang, H. (2012). Advances in multispectral and hyperspectral imaging for archaeology and art conservation. *Applied Physics A, 106*(2), 309–323. https://doi.org/10.1007/s00339-011-6689-1
4. Cucci, C., Delaney, J. K., & Picollo, M. (2016). Reflectance hyperspectral imaging for investigation of works of art: Old master paintings and illuminated manuscripts. *Accounts of Chemical Research, 49*(10), 2070–2079. https://doi.org/10.1021/acs.accounts.6b00048
5. Delaney, J. K., Zeibel, J. G., Thoury, M., Littleton, R., Palmer, M., Morales, K. M., de la Rie, E. R., & Hoenigswald, A. (2010). Visible and infrared imaging spectroscopy of Picasso's *Harlequin musician*: Mapping and identification of artist materials *in situ*. *Applied Spectroscopy, 64*(6), 584–594.

6. Targowski, P., & Iwanicka, M. (2012). Optical coherence tomography: Its role in the non-invasive structural examination and conservation of cultural heritage objects, a review. *Applied Physics A, 106*(2), 265–277. https://doi.org/10.1007/s00339-011-6687-3
7. Alfeld, M., & Broekaert, J. A. C. (2013). Mobile depth profiling and sub-surface imaging techniques for historical paintings: A review. *Spectrochimica Acta Part B: Atomic Spectroscopy, 88*, 211–230.
8. Alfeld, M., Vaz Pedroso, J., van Eikema Hommes, M., Van der Snickt, G., Tauber, G., Blaas, J., Haschke, M., Erler, K., Dik, J., & Janssens, K. (2013). A mobile instrument for *in situ* scanning macro-XRF investigation of historical paintings. *Journal of Analytical Atomic Spectrometry, 28*(5), 760–767. https://doi.org/10.1039/c3ja30341a
9. Vanmeert, F., Van der Snickt, G., & Janssens, K. (2015). Plumbonacrite identified by X-ray powder diffraction tomography as a missing link during degradation of red lead in a Van Gogh painting. *Angewandte Chemie International Edition, 54*(12), 3607–3610. https://doi.org/10.1002/anie.201411691
10. Janssens, K., Van der Snickt, G., Vanmeert, F., Legrand, S., Nuyts, G., Alfeld, M., Monico, L., Anaf, W., De Nolf, W., Vermeulen, M., Verbeeck, J., & De Wael, K. (2016). Non-invasive and non-destructive examination of artistic pigments, paints, and paintings by means of X-ray methods. *Topics in Current Chemistry, 374,* 81. https://doi.org/10.1007/s41061-016-0079-2
11. Miliani, C., Rosi, F., Brunetti, B. G., & Sgamellotti, A. (2010). *In situ* noninvasive study of artworks: The MOLAB multitechnique approach. *Accounts of Chemical Research, 43*(6), 728–738. https://doi.org/10.1021/ar100010t
12. Dik, J., Janssens, K., Van der Snickt, G., van der Loeff, L., Rickers, K., & Cotte, M. (2008). Visualization of a lost painting by Vincent van Gogh using synchrotron radiation based X-ray fluorescence elemental mapping. *Analytical Chemistry, 80*(16), 6436–6442. https://doi.org/10.1021/ac800965g
13. Legrand, S., Vanmeert, F., Van der Snickt, G., Alfeld, M., De Nolf, W., Dik, J., & Janssens, K. (2014). Examination of historical paintings by state-of-the-art hyperspectral imaging methods: From scanning infra-red spectroscopy to computed X-ray laminography. *Heritage Science, 2*, 13. https://doi.org/10.1186/2050-7445-2-13
14. Haneca, K., Cufar, K., & Beeckman, H. (2009). Oaks, tree-rings and wooden cultural heritage: A review of the main characteristics and applications of oak dendrochronology in Europe. *Journal of Archaeological Science, 36*(1), 1–11.
15. Johnson, D. H., Johnson, C. R., & Erdmann, R. G. (2013). Weave analysis of paintings on canvas from radiographs. *Signal Processing, 93*(3), 527–540.
16. Johnson, C. R., Hendriks, E., Berezhnoy, I. J., Brevdo, E., Hughes, S. M., Daubechies, I., Li, J., Postma, E., & Wang, J. Z. (2008). Image processing for artist identification. *IEEE Signal Processing Magazine, 25*(4), 37–48. https://doi.org/10.1109/MSP.2008.923513
17. Van Noord, N., Hendriks, E., & Postma, E. (2015). Toward discovery of the artist's style: Learning to recognize artists by their artworks. *IEEE Signal Processing Magazine, 32*(4), 46–54. https://doi.org/10.1109/MSP.2015.2406955