# UNVEILING THE ART-SCIENCE TAPESTRY: OPTICAL METHODS IN CULTURAL HERITAGE CONSERVATION AND RESTORATION

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ARTWORKS
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THERMOGRAPHY

Optical methods are a formidable tool in the conservation of cultural heritage; a large number of techniques are currently available, and the search for new methods is flourishing. In this paper, we will discuss some of these techniques, which, in addition to making a significant diagnostic contribution, have profoundly changed the way we engage with and imagine art. The selected techniques are primarily visual, thus their results are presented as images. The visual nature of these methods is crucial, as it allows an easy comparison with the artwork under study and enables their use by researchers from different backgrounds. These images may also be appreciated by the general public. In particular, the paper proposes a reflection on the relationship between the artwork and its representation through a scientific method.

## INTRODUCTION

It is a matter of fact that Western thought is *oculocentric* and that the visual approach permeates our society (Luigini & Menchetelli, 2022). Technologically speaking, the ever-increasing capability to record and process images will further enhance the pervasive importance of the visual approach: we live in an age of images. Just to give an example, with more than 5 billion mobile devices in use in 2021 (covering around 67% of the world's population) and more than 7,5 billion smartphone connections by 2025 (GSMA, 2022), images can be produced virtually anywhere and in any time.

A similar (r)evolution has happened in science. Scientists have always used images and graphs, even if the use of non-representational pictures to display data is relatively recent: statical graphics was invented around 1750-1800. It requires a diversity of skills, the visual-artistic, the empirical-statistical and the mathematical, as Edward Tufte pointed out (Tufte, 2001). According to him:

> Modern data graphics can do much more than simply substitute for small statistical table. At their best, graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore, and summarize a set of numbers –even a very large set– is to look at pictures of those numbers. Furthermore, of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful. (Tufte, 2001, p. 9)

The attention to data graphics lead to a theory of visual display of quantitative information (Tufte, 1990; Tufte, 1997; Tufte, 2001; Bertin, 2011). However, this was only a part of the (r)evolution. John D. Barrow wrote:

> In just a few years, the presentation of science at all levels, from technical seminars for fellow experts to popular expositions for the general public, has become extremely visual. The ubiquity of PowerPoint,

> web-streamed video, digital photography, and artificial computer simulation has meant that images dominate science in a way that would have been technically and financially impossible just 20 years ago. There is a visual culture in science and it is rapidly changing.
>
> Visuality penetrated the practice of science just as deeply as it fashioned its presentation.
>
> The future of science will be increasingly dominated by artificial images and simulations. (Barrow, 2008, pp. xiii-xiv)

There is a field in which images are usually the result of measurement that has also developed tremendously since 1960: optical methods (Prenel & Ambrosini, 2012; Ambrosini & Ferraro, 2018). This extraordinary development has been driven by two revolutionary changes: the invention of the laser light source and the invention (and great development) of digital recording and processing.

We can now add the last thread to our tapestry and talk about cultural heritage.

Conserving and restoring cultural heritage is a crucial task that requires the integrated use of different scientific and technological approaches (Borg et al., 2020). Among these approaches, optical techniques have emerged as a powerful non-destructive and non-invasive tool for the analysis of cultural artefacts (Alfeld et al., 2013).

Optical methods, including holography (Amadesi et al., 1974; Paoletti & Schirripa Spagnolo, 1996), electron speckle pattern interferometry (ESPI) (Paoletti & Schirripa Spagnolo, 1996; Ambrosini & Paoletti, 2004), reflectography (Ambrosini et al., 2010), and optical coherence tomography (OCT) (Targowski et al., 2012), have transformed the field of cultural heritage with their ability to provide insights, for instance, about surface conditions, structural defects, hidden layers and pigment identification.

Although the contribution of optical methods to the conservation and restoration of cultural heritage cannot be underestimated at all, this article highlights the cultural importance of their use in the field of art. In fact, this intersection (this *tapestry*, as we wrote in the title) between art, science, technology, and a visual approach has proved to be vital and instrumental to a better understanding of the past, providing us with a window to see things in a different and deeper way.

In the following, we will discuss some of the many optical methods available today that, by providing results in the form of an image, are best suited for comparison with the artwork itself and, at least in part, are easily understood by the general public.

## THE BEGINNING: PHOTOGRAPHY AND X-RAYS

Photography was the first revolutionary application of optical methods in the field of cultural heritage; it finally made possible the accurate reproduction of works of art. For many of them, which had been destroyed, photographic reproduction is now the only way of appreciation.

But optical methods were soon to go even further, making possible to see the hidden side of masterpieces; with X-rays, at the beginning of the 20th century, it became possible to ‘see the invisible’, i.e. what was hidden behind or inside works of art. X-rays could also be used for diagnosing the cultural heritage, for example to find galleries of woodworms in panel paintings or to reveal buried structures such as nails or other materials, but they could also open a window to another world, a world in which the artist made mistakes and changed his mind, erasing and moving arms and hands, faces, expressions and clothes.

The world of artworks revealed through X-rays is full of *pentimenti*, the emotive word employed by restorers to describe these works of art *in fieri* that have remained concealed for centuries. Decades ahead of its time, X-ray diagnostics functions much like a modern text editor, enabling you to trace the mistakes and corrections that guided the artist to

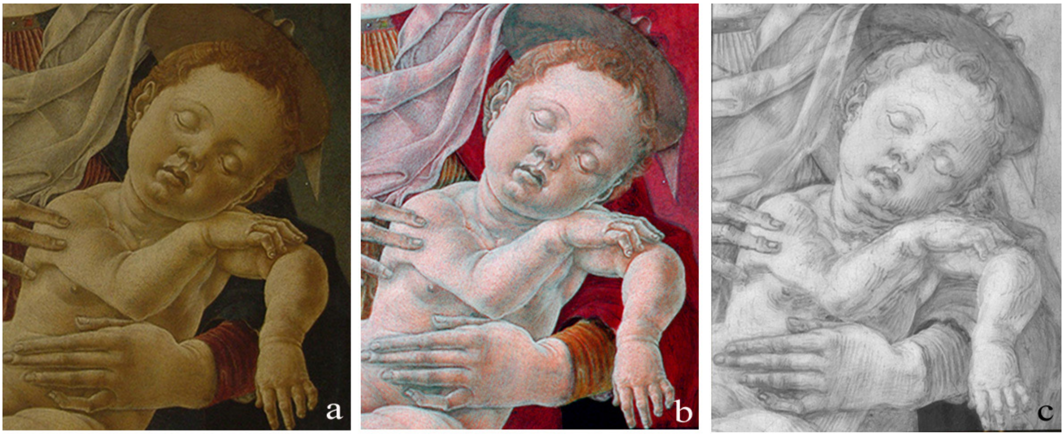


**Figure 1** Cosmè Tura, *Madonna dello Zodiaco* (detail), painting on wood, 15th century, Accademia Galleries (Venice, Italy): a) visible; b) false-color image with IR information mapped as red; c) infrared image. (Ambrosini et. al, 2011).

the final result. In some fortunate cases, shifts in taste or the necessity to reuse materials have led to the discovery of entirely different works hidden beneath the surface.

## UNVEILING THE HIDDEN ART: IR REFLECTOGRAPHY

Another major contribution to the study of cultural heritage has come from infrared radiation. Initially, traditional cameras, when equipped with infrared film, could record radiation up to approximately 1,1 microns. From the late 1960s onward, electronic devices were developed to record infrared radiation at even longer wavelengths, extending up to approximately 2,5 microns. The technique of infrared reflectography (De Boer, 1968; Daffara et al., 2010) is now widely employed, enabling the visualization of what lies beneath the paint layer. In fact, various color pigments exhibit more or less transparency to different infrared wavelengths, depending on their material and thickness. In numerous instances, preparatory drawings become visible beneath the paint, unveiling an entire artistic world. This hidden art, now accessible for study, provides insights into how artists worked, prepared their compositions, and whether they made changes (i.e., had *pentimenti*) during

**Figure 2** Cosmè Tura, *Madonna dello Zodiaco* (detail), painting on wood, 15th century, Accademia Galleries (Venice, Italy): a) visible; b) false-color image with IR information mapped as red; c) infrared image. (Ambrosini et. al, 2011).

execution. Moreover, it serves as an effective method for unveiling copies that typically do not reveal *pentimenti*.

Figures 1-3 show examples of reflectography enhanced by multispectral colour mapping. In particular, in Figure 1, a detail of the *Madonna dello Zodiaco* by Cosmè Tura, the false-colour image shows more information in the dark areas as well as a good differentiation of the pigment under the Virgin's left hand (compare Figure 1a with Figure 1b); the preparatory drawing is clearly visible in Figure 1c.

In Figure 2, the same colour mapping is applied to a different detail of the painting. The goldfinch beaking grapes turns out very dark in the visible range (Figure 2a); the image recorded in IR shows much more details of the drawing (Figure 2c).

A third example is the masterpiece *Madonna con Bambino* (Fig. 3a) housed in the Santa Verdiana Museum in Castelfiorentino (Florence, Italy). Despite the controversy surrounding its attribution, it is generally accepted to be the work of Cimabue from the second half of the 13th century. Moreover, a very young Giotto could be the author of the Child. Extensive restorations are clearly visible in red and purple, especially the horizontal imitative reintegration that filled the gap corresponding to the junction of the two panels (around the centre of the painting).

## HOLOGRAPHY AND BEYOND

It was almost by chance that Dennis Gabor invented holography in 1948. For several years, it remained little more

**Figure 3** Cimabue, *Madonna con Bambino*, painting on wood, 13th century, Santa Verdiana Museum, Castelfiorentino (Florence, Italy). a) visible; b) false-color image with IR information mapped as red. (Ambrosini et. al, 2011).

than a laboratory curiosity until the advent of the laser in the 1960s, when it exploded and revolutionised the production of images in both science and art.

Unlike photography, holography can record not only the intensity but also the phase of the light wave. This means, for example, that it is possible to create three-dimensional images that are virtually indistinguishable from the original.

The classic holographic technique, which was developed in the mid-1960s and had its heyday in the 1980s and 1990s, requires a laser source for both recording and viewing images.

It is a purely analogue process in which the image is recorded on a glass plate, coated with photographic emulsion, developed and viewed again.

The process was lengthy, expensive and technically complex, requiring dark rooms for recording and examining the image and adherence to strict stability requirements, including the use of anti-vibration tables. The ultimate reward for those overcoming these difficulties was a three-dimensional image of unprecedented quality, never equaled again.

Holography sparked the interest of many artists, and soon museums devoted solely to holograms collection appeared.

From a scientific perspective, holography's most significant contribution was the development of a new diagnostic technique called holographic interferometry. By recording two holograms at different times and superimposing them, one obtains an image of the object under examination covered by black and white lines; these interference fringes provide information about the deformations it has undergone.

Holographic interferometry, originating in mechanical engineering, spread rapidly. In the early 1970s, at the newly founded Faculty of Engineering in L'Aquila, the group led by Prof. Franco Gori began to experiment with holographic interferometry for the diagnosis of panel paintings (Amadesi et al., 1974). This marked another small revolution in the larger revolution of holography, initiating the development of many optical methods currently used for cultural heritage, such as speckle photography, electronic speckle pattern interferometry, shearography, digital holography and correlation methods (Ambrosini & Paoletti, 2004).

The development of these techniques coincided with the decline of traditional holographic methods: too slow, expensive and difficult for our times.

The same decline happened to holography museums, which closed one after another. Today, the largest collection of holograms open to the public can be found at the MIT Museum, where many of the first techniques were developed.

Superimposing two holograms on the same plate produces two reconstructions of the object, at different times and under different conditions. Visually, only one object appears, covered in black and white lines. The availability of a fully three-dimensional copy radically changed the way we look at objects, even artistic ones, but it was the presence of fringes the real revolution. From their pattern it was possible to obtain information about the deformations they had undergone and the presence of sub-surface defects that were not visible.

Photographing an interferogram does not reproduce the experience of observing it in real life, precisely because the three-dimensionality is lost.

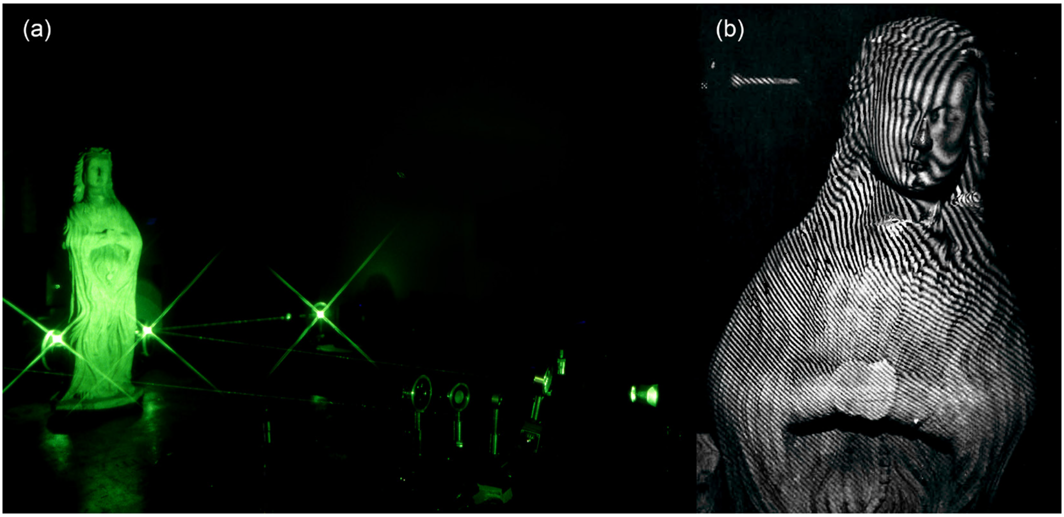
A real interferogram, i.e. one observed with a laser source, will appear as an exact three-dimensional copy of the object, furrowed by a series of black and white lines related to the displacements and deformations it has undergone, with a sensitivity of the order of a fraction of a micron.

From an aesthetic point of view, this is a beautiful object in which a technical map is superimposed on the iconographic details.

In the case of art diagnostics, the fringes represent iso-displacement lines. Since surface movements are also linked to any invisible (sub-surface) inhomogeneities, it is as if a topographical map were superimposed on a photograph of a known landscape (the artwork), so sensitive as to show the effects of what lies beneath that known surface.

And, as we have said, they can be graphically striking: cracks are identified by lines reminiscent of swallows drawn by children, resembling large Vs; detachments, the great enemy of pictorial surfaces, are identified by vaguely concentric fringes, hinting at an underlying bubble-like structure. An example on a stone statue is illustrated in Figure 4. Figure 5b shows holographic interferometry on a painting of wood. Between the two exposures, the painting was heated with a flow of moderately warm air; some hidden faults are detected (yellow arrows).

**Figure 4** *Maddalena*, stone statue 13th-14th century, Santa Maria di Collemaggio Basilica (L'Aquila, Italy). a) Laboratory setup; b) holographic interferogram revealing cracks. (Paoletti et al., 1989).



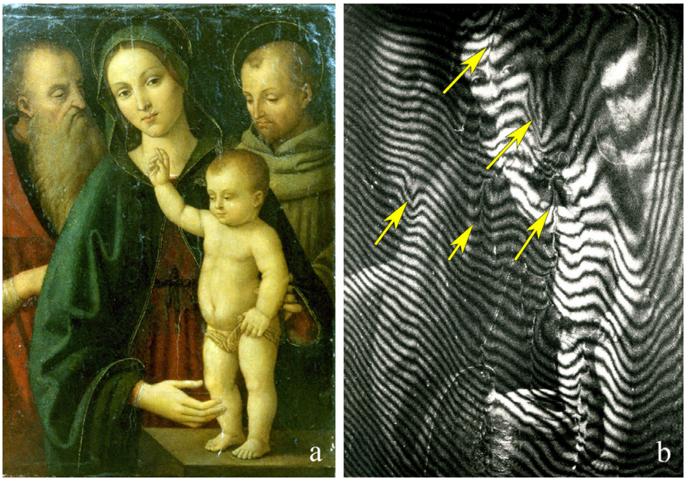


**Figure 5** Perugino's school, *Madonna con Bambino*, painting on wood, 15th century, House Museum Signorini Corsi (L'Aquila, Italy). a) visible; b) holographic interferogram revealing defects. (Paoletti & Schirripa Spagnolo, 1996).

## IR THERMOGRAPHY

The advent of thermography has added a new dimension to optical methods. With thermography, which has become increasingly efficient thanks to technological developments and is now available, at least for basic applications, on smartphones, it is possible to capture a temperature map and translate it into a false-colour or greyscale image. Once again, a visual image provides information of a different nature: in fact, temperature differences can be used to detect the presence of moisture, assess differences in materials, identify buried structures (such as windows and doors embedded in walls or support frames), and recognize defects below the surface (Ibarra-Castanedo et al., 2008; Ambrosini et al., 2010; Paoletti et al., 2013; Gavrilov et al., 2014). In the architectural field, the identification of buried structures (masonry, arches, etc.) can greatly aid in reconstructing the changes undergone by the artifact.

Figure 6 shows an application of infrared thermography. Specifically, Figure 6b presents the result obtained by applying a quantitative processing called Differential Absolute Contrast (DAC) (Maldague, 2001) to the thermal map. This enhances the visibility of defects, revealing structural features such as the three dark areas –two under the neck of the

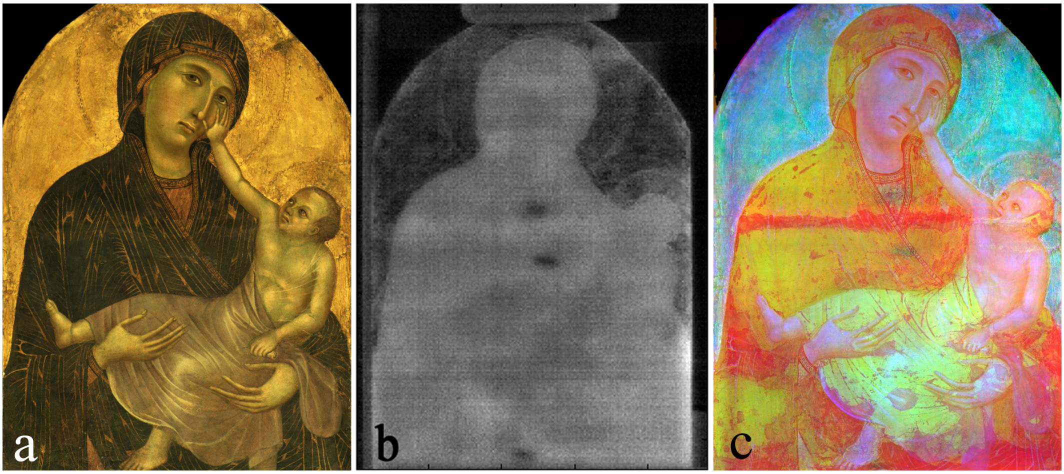


**Figure 6** Cimabue, *Madonna con Bambino*, painting on wood, 13th century, Santa Verdiana Museum, Castelfiorentino (Florence, Italy). a) visible; b) thermogram obtained by applying the DAC algorithm (Ambrosini et al., 2010); c) false-color image with IR information from thermocamera mapped as red and IR information at about 1.82 μm mapped as green. (Ambrosini et. al, 2011).

Virgin and one under the left foot of the Child– corresponding to the nails in the wooden panel (Ambrosini et al., 2010).

Figure 6c was created by assigning the thermal map to the red channel, the IR image to the green channel, and the visible green channel to the blue channel. This is an interesting result as it conveys information on both the pictorial layer (restoration and repainting are clearly identified) and the wooden support (the two nails and the horizontal junction of the wooden panels).

## CONCLUSIONS

Optical methods have revolutionised the way we study, restore and appreciate works of art. These techniques provide valuable insights into the physical and chemical properties of artworks, offering a glimpse into their historical context and artistic techniques. By employing optical methods, we can explore new avenues in art conservation, enabling restorers to identify and address problems that would otherwise remain undetectable. Furthermore, these methods enhance our appreciation of artworks by revealing hidden details beyond what is visible to the naked eye, shedding light on the creative process. With the aid of optical methods, we can continue to unlock the secrets of our cultural heritage, ensuring its preservation for future generations to enjoy.

These images are the result of a scientific measurement and are often very beautiful. They convey information about the measured quantities (i.e. temperature, deformation, etc.) while retaining the iconographic features of the artwork. To quote Paul Klee, “art does not reproduce the visible; rather, it makes it visible” (Klee, 1961, p. 76). In this sense, optical methods can be seen as a form of art themselves, as they make the invisible visible.

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