REFLECTOGRAPHY, A NDT METHOD FOR IMAGES DIAGNOSIS

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Abstract: Infrared Reflectography (IR) is a non-destructive technique used for the analysis of artworks (paintings) to reveal hidden particularities under the pictorial layer.

The technique is based on an infrared radiation crossing the pictorial layer and reflected at the base or preparation of the artwork. Since they are generally transparent to radiation in the near IR , the results are a function of the absorption rates to the infrared radiation from the different pigments. A CCD camera, mounted by a sweeping device and equipped with appropriate filters, in the spectral band from ultraviolet to near infrared, detects the reflected radiation and transforms it into a visible image. A luminous source consisting in an halogen lamp is used to produce radiation in the near infrared.

The digitized images, denoted as REFLECTOGRAMS, are processed by an integration program to obtain a total image of the artwork called REFLECTOGRAPHY. Thus, the REFLECTOGRAPHY contains information located in the interior as well as on the surface of the artwork.

This inspection technique reveals lines, underlying drawings, author signs, inscriptions, restorations, or alterations suffered by the painting in addition to the artist's regrets. Furthermore, these details hidden to the direct sight, gives precious indications both on the realization technique and on the state of conservation of the artwork to restorers and art historians and, in some cases, it can help of the artwork authenticity.

This technique has been applied to the diagnostics of important paintings from the Buenos Aires National Museum (MNBA). This paper describes the operating principles of the technique and discusses the analysis of one artwork in which original outlines under the pictorial layer were found, and the artist's regrets were revealed.

Key words: Infrared Reflectography, Images Diagnosis, Paintings, Inspection and Application of NDT.

Introduction: In this paper we describe the application of special NDT techniques for the analysis and diagnosis of artwork images that allow to find information related with the original outline, conservation state or the restorations.

Reflectography is one of the non-destructive testing methods adopted in the analysis and diagnosis of paintings. The different techniques, (IR) Infrared Reflectography (UVR), Ultraviolet Reflectography, (VR) Visible Reflection and (VF) Visible Fluorescence, allow to carry out tests using different options of illumination and specific filters for each case. It is a very effective tool to discover invisible or hidden details in the pictorial layer. The first experiences in Reflectography were carried out with photographs on infrared sensitive film, but they had limited success due the low image quality and very long testing times. However, thanks to technological advances, such as the use of video cameras and more recently cameras CCD, images of better quality and resolution can be achieved.

The IR is an optic technique to obtain images operating in the spectral band of the near infrared. The wavelength of the useful electromagnetic spectrum ranges from 700nm to 3000nm.

In the spectral band of the near infrared (NIR), part of the electromagnetic radiation is transmitted through the painting superficial layers to be reflected by the base of the artwork or by its preparation or to be absorbed in the lines of the drawing, allowing to reveal hidden particularities under the pictorial layer. The reflected radiation interacts with the pigments, and thus the observed image is the integration of the whole phenomenon. The Reflectography image is the result of the contrast among the diffuse radiation that is obtained from the preparation base and that is absorbed by the materials that form the original drawing. The reflection is captured by the CCD camera mounted with appropriate filters. These filters transform the infrared radiation reflected by the object into visible image. The images are stored in digital format and then they are processed using an integration software program to obtain the final image of the artwork. This image is named Reflectography.

In this manner, an image is obtained that contains superficial as well as sub-superficial information of the artwork. The details that are observed with the naked eye, in addition to the hidden ones under the pictorial layer, related to the different techniques used, such as the original outlines, regrets and restorations in the painting contribute with information to historians and restorers to analyze and evaluate the particularities of the artwork. They also help with the historical location, origin and, in some cases, to confirm or to deny an attribution of the artwork.

This type of analysis can be applied to paintings, drawings and murals. Generally, it is a good tool for the restoration, conservation and cataloguing of artwork.

In this paper, the application of this method to renowned paintings of the MNBA is presented. Different techniques were used to analyze the artworks, which allowed finding details that were not visible with a naked eye. The results of the different studies allowed revealing the artist's regrets, details of the original drawing that had been modified, and outlines of the original design. To register the test’s results, the equipment was used in the four visualization modes.

The Reflectography Method: The technique is based on the characteristic that some elements have to be sensitive to electromagnetic waves of certain wavelengths (photosensitive probe sensor) and the behaviour of other materials in relation to this type of waves (chemical composition of the materials).

Within the electromagnetic spectrum, we can differentiate the visible light and the infrared radiation. The visible light is an electromagnetic wave with a wavelength between the 400 and the 700 nm, which can be perceived by the human eye, while the wavelengths of infrared radiation ranges between the 700 and the 3000nm and it is invisible to the human eye. The light has a constant behaviour but different wavelengths provide to our eyes different colour sensations.

The light is composed by energy particles (photons) that allow the acquisition of images in different type of bases. Thus, if chemical changes are occurring, the image is obtained by photosensitive films (Photographs) whereas and if electric reactions take place, the image is obtained by electronic means (Reflectogram).

The light is irradiated from a source (sun, lamp, flash, etc.). It moves in a vacuum at high speeds (almost 300.000 km/s), being able to traverse transparent substances, although loosing speed according to the density of the media. It propagates on a straight line in the form of waves perpendicular to the direction of displacement.

When an object is illuminated its behaviour varies according to the surface composition. The light (energy) that impacts on the object with different inclinations produces several physical phenomena: Absorption, Reflection, and Transmission.

Absorption: When visible light impacting on a black surface or an opaque surface, is absorbed almost totally, turning into heat.

Reflection: When the light impacts on a smooth and brilliant surface, and it is totally reflected at an angle equal to that of incidence (mirror image reflection) (Figure 1).

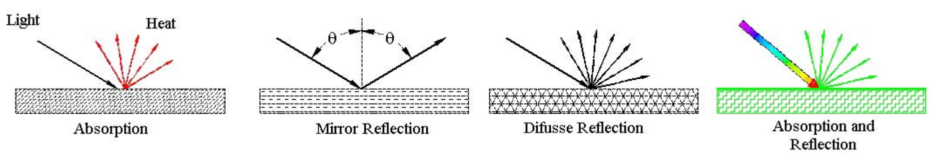


Figure 1: Mirror Image Reflection

If the surface is not completely smooth and brilliant, it reflects only part of the light that receives in all directions. This phenomenon is known as diffuse reflection, and is the base of the Colour’s Theory that says: “when a beam of waves of different length impacts on an object, it absorbs some, and reflects others. The reflected waves are the ones that determine the Colour of the Object.” The surfaces of objects always contain irregularities dispersing the light that they receive in all directions. For this reason, it is not necessary for the reflective surface to have obvious irregularities; the minuscule irregularities are enough to permit the surface to act as a diffuser, as it would be the surface layer of a perfectly smooth painting.

Transmission: it is the phenomenon for which the light can traverse non-opaque objects. When the light beam moves to a different media (Transparent) and in linear trajectory, the transmission is direct (Figure 2).

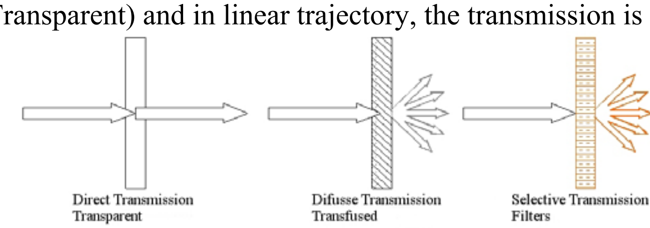


Figure 2: Transmission phenomenon

The selective transmission happens when certain materials such as glasses, plastics or coloured jells allow only certain wavelengths to pass and absorb others. The same applies to photographic filters, and thus the photographic importance of infrared radiations. Within the electromagnetic spectrum, the infrared radiation wavelength is between the visible spectrum and the radio waves (Figure 3).

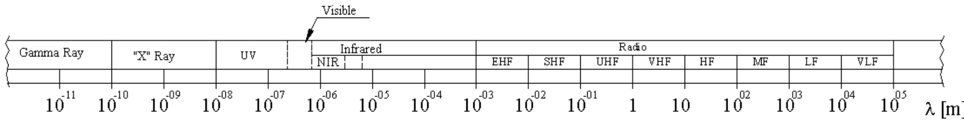


Figure 3: Electromagnetic spectrum band

The infrared spectrum can be divided in three bands: the near infrared, the half infrared and the distant infrared. The near infrared term (also denominated reflected infrared or photographic) refers to the part of the infrared spectrum that is closest to the visible light and it is the area of interest for the application of the technique.

Reflectography is a method that has the possibility to perform tests in field, obtaining the results in real time. It is used to obtain images of objects using radiation in the spectrum band from the ultraviolet to the near infrared. The usable spectrum region to obtain a reflectogram ranges from 320nm to 3000nm.

The camera for Reflectography available in our laboratory can operate in three bands of the spectrum, that is, the ultraviolet, the visible and the near infrared. When operating in the near infrared, it allows to subdivide in three small bands of different wavelengths that we will denominate here: IR1 (between 700 and 950 nm), IR2 (between 950 and 1150nm) and the IR3 (between 1150 and 1550nm). As other devices that are currently used to obtain images of good quality, this camera was designed specifically for the deployment on artworks.

Reflectography with CCD camera: This is a camera comprising an arrangement of sensors that transform the received electromagnetic signals into electric signals. The CCD cameras incorporate specially designed filters to establish the boundaries of the spectrum band required for each application.

The early CCD cameras (with Silicon) used for Reflectography operated within a wavelength near the 1100nm. These cameras provided good resolution, because a wide range of greys could be visualized, but the contrast was low since the wavelength (similar to the one used in infrared photographs) impeded a good visualization of the design and hidden particularities behind the pictorial layer. One of the most important advantages of this type of camera consist in obtaining a Reflectography image in real time, allowing the adjustment of the test parameters to the optimum values. The use of this type of devices requires the storage of a large amount of data to reproduce a picture and to obtain the complete image of the artwork with good resolution. However, the visibility has been improved with the uses of special CCD devices.

Operation principle: The paintings are constituted by the support that can be cloth, wood, cardboard, etc; the bases or preparation that use to be plaster, and the pictorial layer that has different chemical compositions, according to the pigments used by the artist (Figure 4)

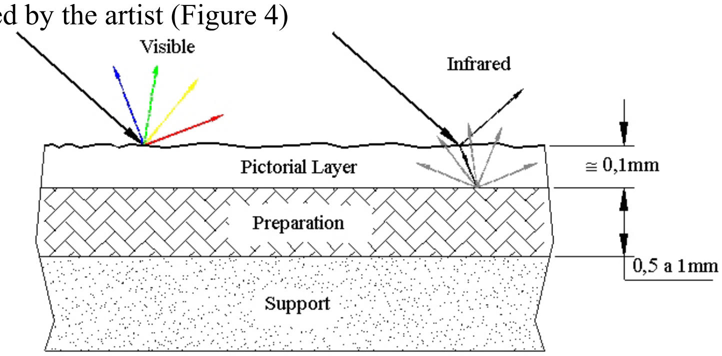


Figure 4: Behaviour of the reflections.

The examples described in this paper are applications to oil paintings on plaster base and canvas support. To obtain a VR and IR, the artwork is illuminated with a light source. The simplest source consists on a couple of halogen lamps located symmetrically and oriented at such an angle to obtain uniform illumination. To obtain an image in the VF mode or for UVR, the illumination source is provided by mercury lamps.

The luminous beam is reflected from the pictorial layer and it is manifested as the visualization of the real image of the artwork when operating in the spectrum band of the visible light.

In the (NIR), the electromagnetic radiation can cross the superficial layers through the transmission phenomenon. This transmitted intensity radiation that is always smaller than the incident, experiences reflection and absorption. In consequence, the observed image is the conjunction of the reflection, absorption and transmission phenomena in the superficial layer and the one that is returned by the base.

To obtain the Reflectography in the NIR appropriate filters must be used that allow to observe the phenomenon. Similarly, for the spectrum band of the UV, proper filters must be selected for this visualization mode. If the illumination conditions are not uniform or the precision of the mechanical system of displacement is not appropriate, the assembly of images is very time-consuming due to the distortion at the edges of the image caused by uneven illumination. Also, it is necessary to take into account that the artwork can have defects like cracks, lack of pictorial layer, restorations, or distortions of the support or the frame.

Equipment Used: The techniques of images analysis have demonstrated to be a powerful tool in the scientific analysis and the documentation of paintings in the field of investigation and conservation of artwork. The Reflectography stands out within the methods of diagnosis by images. This technique requires obtaining images in the spectrum range between the UV and the IR. The existent technology, It was explained earlier, had multiple limitations, requiring long testing times, and hence the integral reporting of an artwork was inefficient and had poor repeatability. The technological challenge was then the implementation of an effective, especially developed for the study of artworks. (Figure 5).

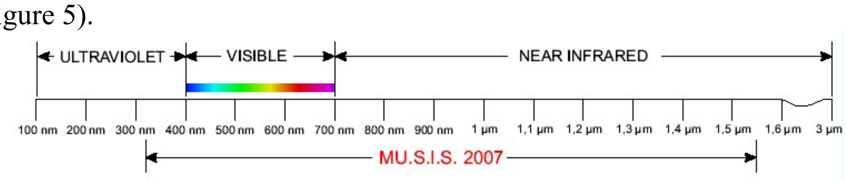
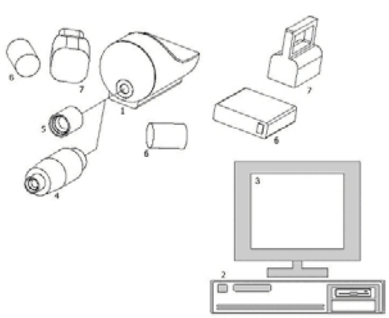


Figure 5: Equipment's Spectrum work band

The equipment comprises a mechanism for the selection of the image's band, an optic detector and a cooling device for the detection elements. The selector of spectrum band and the sensibility detector are computer controlled. The output of the camera is connected to the video acquisition card and the images are stored in the computer hard drive (Figure 6).



Camera Specifications

1. MUSIS 2007 Camera Module
2. Computer and Video Digitizer
3. Monitor
4. Infrared to Visible Imaging Converter
5. Lens
6. Halogen Lamps
7. Hg Lamps
8. Spectral Response: 320-1550 nm
9. Number of pixels: 795(H) x 596 (V)
10. External Dimensions: 14cm x 15cm x 19cm (HVD)

Figure 6: Elements that conform the Reflectography equipment

Figure 7: Assembly and displacement system of equipment   Figure 8: Reflectography test in the MNBA

The system incorporates two illumination sources; two halogen lamps utilized in the VR mode and the IR mode and mercury lamps for UVR and VF. The system has an orthogonal scanning manual device with graduate movements. It has articulated arms for the camera and assembly for the sources of illumination (Figures 7, 8).

Analysis: The information offered by the test for the visualization of the outline is a function of two parameters: Contrast and Transparency of the pictorial layer. The contrast depends on the material used to make the drawing and on the reflectivity of the preparation. The Transparency in a function of the painting layers and depends of the pigment's composition used by the artist. These are not presupposed parameters, because they depend on the selection of the materials that were used for the design and the painting.

The Contrast is the difference of reflectivity between the preparation and the line of the drawing. When the sketching tool is charcoal, the infrared absorption is high and the contrast improves. In these cases, the drawing could be very visible even when the pictorial layer is not very transparent. When the material used for of the drawing doesn't absorb enough infrared radiation or the reflectivity of the preparation is low, the original design might be invisible. The transparency to the infrared radiation depends on the chemical composition of the pictorial layer. It is also important to keep in mind the spectrum band used to perform the tests.

Furthermore, if the wavelength used is lower than 1000nm, the visualization might not be acceptable since it does not traverse the pictorial layer easily. It allows seeing transparency through clear pigments (red and white) but for wavelengths higher than 2000nm, improvements in the visualization are not achieved.

Diagnosis: The analysis of the images of tested paintings, registered in the different modes, allows to understand the obtained data and to contribute information to historians and restorers to analyze and evaluate the particularities of an artwork and perform the diagnose.

Results: The test is performed by placing the artwork in an easel. The scanning device is located in such a way that the surface of the artwork is halfway of the movement plane of the camera. The camera and the sources of illumination are selected to work in the desired spectrum band.

The test of the artwork is carried out acquiring partial images with some overlapping. These images are later integrated to obtain a total reproduction of the artwork with the best quality of information. The images that are observed next represent an example of two reflectograms obtained by line scanning (Figure 9) using the reflection mode IR1, integrated to obtain the Reflectography of a row (Figure 10).

Figure 9 Acquired partial Images.   Figure 10: Result of the processing

Next we present the analysis of artworks in which original designs were found under the pictorial layer that cannot be registered in the visual image, where the artist's regrets are revealed.

In the images acquired in the two infrared modes (IR1 and IR2), could be observed as the clear colours turned transparent. It can be noticed at the left of the horse's head, a silhouette that reveals the figure of two horses that composed the originally artwork. In these modes can be better visualized the drafts or outlines, the original outline of the artwork or the artist's regrets. In the VF mode it is distinguished the intervened area, for an artist's regret that appears of different colour due to the chemical composition of the pigments used in the repair is different to those that were used in the original work (Figures 11,12,13,14).



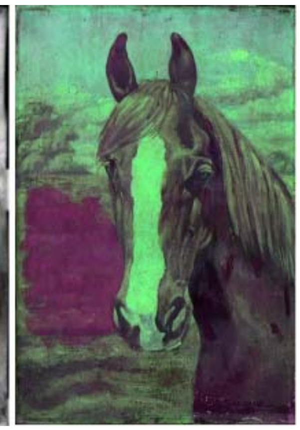



Figure 11 Figure 12 Figure. 13 Figure 14

Reflectography in VR, IR1, IR2 and VF modes. Oil Painting on canvas "Horse of Grenadier"(Argentina 1950)

Curupayti Trench. Painting of the XIX century

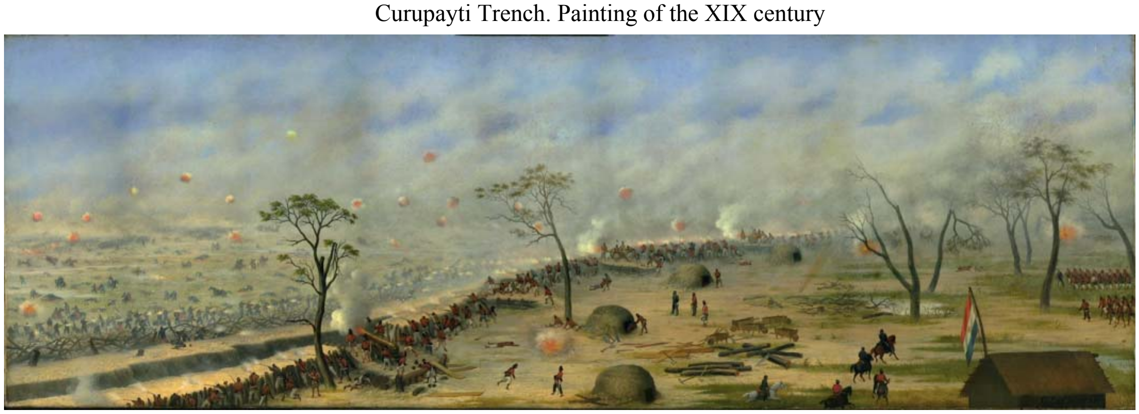
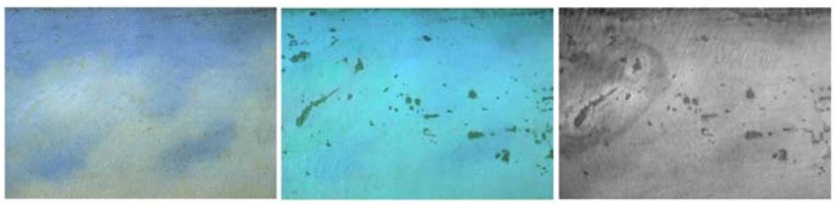


Figure 15 VR mode

Figure 16 IR2 mode

Figure 15 is the Integral artwork in VR mode and the Figure 16 shows some details hidden under the pictorial layer (IR2 mode)



VR VF UV R

Figure 17

The restores panting section , where can be seen the interventions in the VF and UV modes (Figure 17)

VR IR1

Figure 18

The IR1 mode shows a hidden horseman under the pictorial layer that is not observed with a naked eye (Figure 18).

In the artwork (XVI Century) "Virgin with boy and San Juan" (Figure 23), it is distinguished with the mode IR1 that some lines of the original drawing have changed: the position of the virgin's hand (Figure 22), the cross was longer (Figure 21), the boy has more locks on his head and in the right section (Figure 19), and the outline of the branches of a tree can be seen (Figure 20).

Figure 19

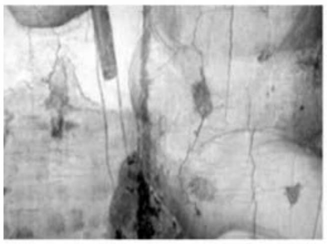


Figure 21

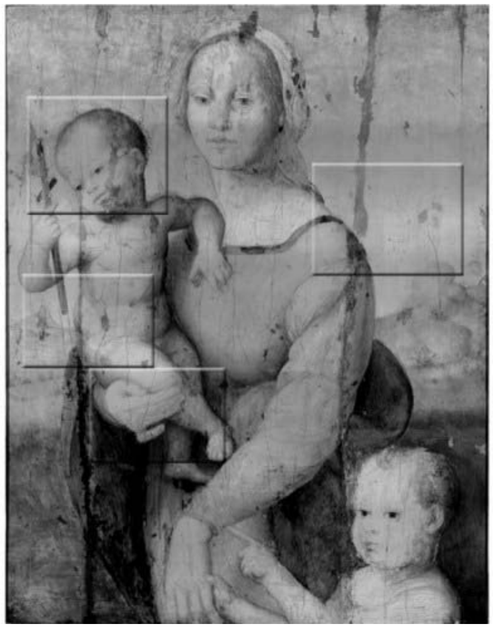


Figure 20

Figure 22

Figure 23: IR1

Conclusions: The study of the artworks examined in this paper is presented as an example of the scope of the Reflectography methods.

It allows finding drawings that are part of sketches used by the artist. Some details are observed at first sight, (VR), other, hidden under the pictorial layer, tested in the NIR spectrum band.

These hidden data can turn into a very valuable tool when certifying an artwork, since the knowledge of other artist’s distinctive characteristics can accessed and determine the age of a painting.

This is a very significant piece of information for the experts in the task of the analysis of an artwork piece. When surveying an artwork, it is important to use all the tools to visualize the most quantity of details, working with the IR1, IR2 and IR3 spectrum bands and, and thus compare with the VR colour image of the artwork. The analysis of the results allows perceiving original outlines, to check the artist's regrets, to verify restorations and to confirm modalities of the artist's way of work, with the observation of different bands in the near infrared and also using the VF and the UVR.

By means of the digitising, processing, and storage of the images, this test permits to collect the information and compare it later with the result of other non-destructive tests. To perform a diagnosis, the investigation is completed verifying the discovered information with other non-destructive methods of image processing such as digital x-rays and colour Reflectography. These tools help to the historical location, origin, and in some cases to confirm or to deny an attribution of the artwork.

This type of analysis can be applied in paintings, drawings and murals and it serves like a diagnosis for the restoration, conservation and cataloguing of the artworks.

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Acknowledgments: To MNBA that allowed working in their facility with the Reflectography equipment gaining practice and experience. Recognition for the persistent support and collaboration efforts from the museum’s Restoration Manager: Mrs. Marta I. Fernández.