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# INFRARED METHODS IN NONINVASIVE INSPECTION OF ARTWORK

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## ABSTRACT

*The problem of attribution and forgery in artwork is quickly becoming more acute with the advance of both the technology and experience of painting forgers. Sometimes even an experienced expert is not able to detect counterfeits that have been made with almost the same materials and technique as the original. Further, even the substitution of the signature of a famous artist on a painting can dramatically increase its value.*

*Another problem of interest is the examination process of a painting preceding its restoration. This procedure can show the restorer the most affected regions of a canvas and/or its delimitations, separating particular regions by the extent of their damage.*

*For these reasons, the role of professional scientific examination is of great importance. Thus, scientific procedures based on modern high-technological devices and methods must be developed to enable both restoration pre-examination and complex forgery-detection.*

*In this article the three infrared methods suitable for the inspection of art inspection are discussed. These include near infrared vision, thermography, and pulse phase thermography, a method never before used in art field.*

*Through the use of several original masterpieces, these techniques are shown to be effective instruments for art inspection and restoration alike. They permit the detection of hidden underdrawings that were done before the painting was finished, concealed and altered signatures, and restored regions of pictures. These methods may also be used to locate delaminations between the paint layers and areas of varying paint thickness.*

## INTRODUCTION

Preserving the cultural heritage is an important problem for both art specialists and scientists alike. As the age of a masterpiece increases, it requires increasingly meticulous handling. For this reason it is necessary that the restoration process be extremely gentle – unprofessional treatment can have irreversibly adverse consequences. To treat a painting, a restorer needs complete information regarding its condition: degraded regions, type of pigments used, and the strength of the support and ground layers.

Another concern is the possibility of both unintentional and intentional alterations, particularly forgeries. During the restoration process some parts of painting can be painted or even added. Related cases included altering or forging original signatures. Naturally, the addition of a famous painter's signature onto any painting increases its price several times and is a common example of art fraud.

Information regarding both these alterations and the condition of the paint can be extracted by using special scientific techniques. Among different imaging techniques, the first ones are obviously optical techniques, including 2D and 3D optical methods are widely used for imaging color acquisition, optical fluorescence imaging, etc. In addition to well developed optical methods, there are also such technologies as neutron illumination, X-ray scalpel beams, sonic tomography, vibro-acoustics, laser ultrasound, ultrasonic air-coupled microscopy as well as advanced developments in infrared technology (see reviews of advanced methods for art objects [1, 2, 3]).

Among these methods the infrared techniques appear to hold the most promise. Due to longer wavelengths and better penetrability into the structure of the material, infrared radiation can be successfully utilized for the purposes of alterations detection, condition inspection and for the recognition of art forgery.

Here we describe several methods of infrared examination of paintings—near-infrared, pulse and pulse phase thermography—as reliable instruments that may prove to be great resources art restorers and museum attribution committees.

**NEAR INFRARED INSPECTION**

In late 1960s the applicability of near-infrared (NIR) inspection to art study was proposed by J.R.J. van Asperen de Boer [4]. It is at this time that the history of near-infrared techniques began. It was shown that most pigments are transparent in 0.7-2.5 μm band and, thus, underpaintings can be viewed by using an NIR camera such as vidicon, or CCD-based cameras introduced in 1990s [5].

In our experiments we use a digital forensics-designed Fujifilm Finepix S3 Pro UVIR camera with sensitivity up to 1100 nm.

The first example is an intentionally altered model painting. In particular, it is an early 20$^{th}$ century canvas-based oil painting with several customized artifacts which we were used as a test range for our techniques.

In this work a transmission scheme was used: a filament lamp was placed behind the painting and the camera was used to register the transmitted light. This method was selected so as to eliminate possible reflections from the surface of the painting, which held the possibility of reducing the quality of snapshots.

In Figure 1, one can see the results of the transmission experiment. The hidden artifacts are clearly visible. The hidden chapel roof was detected, as well as the replaced pipe and painted attic windows. These alterations were intentionally close to those which can typically happen during the restoration processes or due to forger's activity.

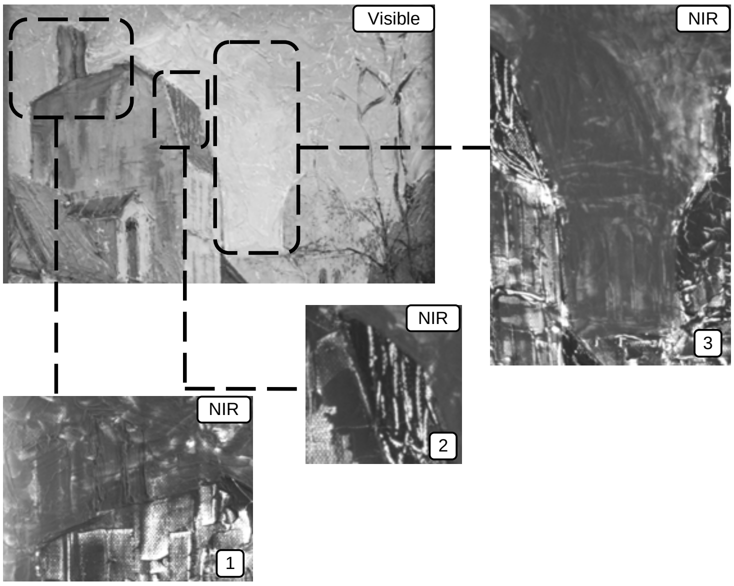



*Fig.1. The altered parts of test painting revealed with NIR method.*
*1 – The pipe on the roof was moved to a new position,*
*2 – Triangle attic windows covered,*
*3 – The conceaded chapel in the middle of the scene.*

One of the most interesting artifacts on this painting was the altered signature. The original one was painted, covered with thin paper and then painted again in effort to make the detection more difficult. The "faked" signature was subsequently inserted.

Such an artifact can represent the possibility of intentionally concealing original features on a painting, which can be done during the reparation of a canvas or as a result of other circumstances.

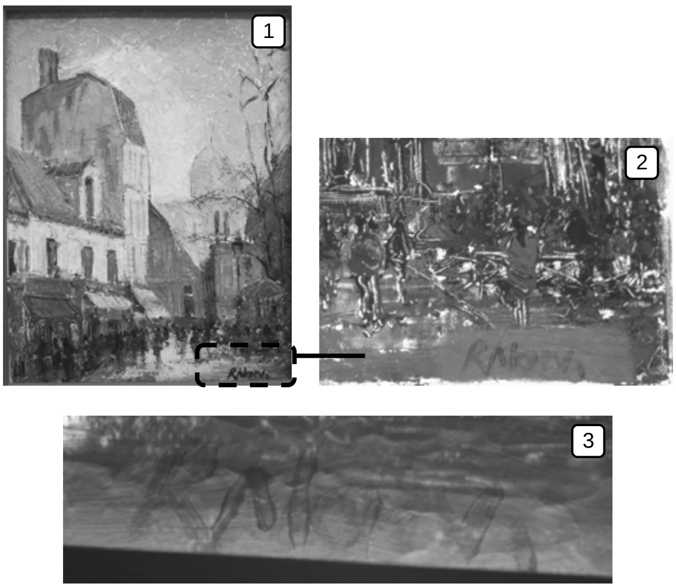



*Fig.2. The signature artifact region:*
*1 – Total image in visible light, 2 – the signature region in NIR,*
*3 – NIR image of the signature in higher resolution*

In Figure 2, a blurred rectangular region of the paper layer under the surface of the paint is observable. In most of cases this is enough to say that the signature is different from the original, however, the genuine signature is still concealed. The method by which it is revealed will be shown later.

## THERMOGRAPHIC INSPECTION

Thermographic inspection is closely related to the previously discussed near-infrared analysis, save for the fact that it uses larger wavelengths (3-14 μm, in contrast to 0.7-2.5 μm), corresponding to "heat pulses" rather than "light" in usual meaning. In principle, thermal waves, having longer wavelengths, should be able to propagate deeper than NIR waves, providing new possibilities for art inspection.

Usual pulse thermography applies heat pulses to the sample while monitoring the cooling process. Due to heat penetration into the bulk of the sample, uniformly heated surfaces tend to cool down at the same rate over the entire surface due. If there are artifacts present under the surface that have low thermal conductivity (such as cleavages or other kinds of paint), the cooling rate in this region decreases. Hence, the region becomes a little warmer than its surroundings and can be detected with a thermal imager up until thermal equilibrium is reached, whereup the defects once again become invisible.

This method, being a very effective method for finding hollows in plexiglas, metals and other materials, can be applied to artwork analysis as well. Wooden- or metal-based paintings can be heated for a relatively prolonged period while the cooling dynamics are be studied. Due to the small thickness of canvas-based paintings, the heat supplied dissipates very quickly and the defects, if present, rapidly become invisible. One possible solution is to reduce the application time of heat to the canvas by means of a powerful flash lamp or fan heater, etc. The heating duration must be shorter than time required for heat penetration from the surface into an estimated defect. Naturally, this time depends on the paints used, thicknesses of layers, in most cases being very short (down to ~0.1-0.5 s).

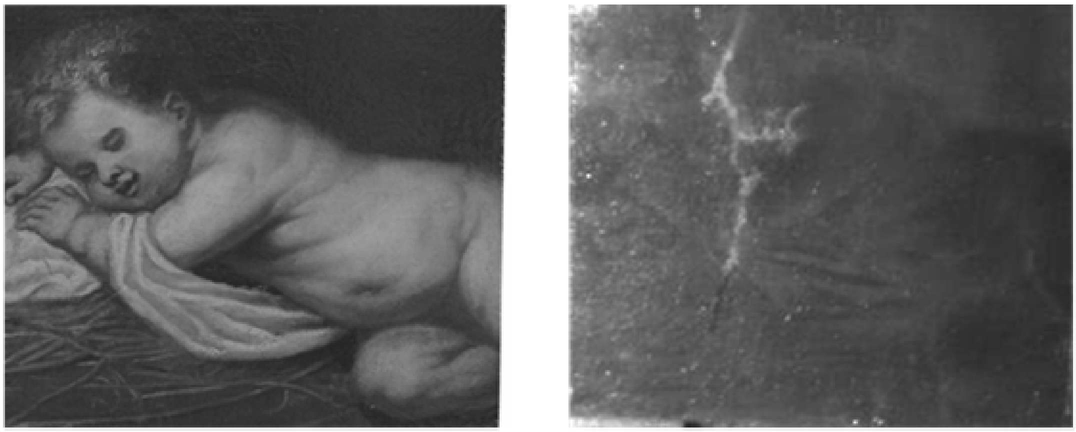
The first promising application of the method is in discovering delimitations in paintings. In cooperation with air-coupled scanning microscopy [6, 7, 8] it provides exhaustive information on the location of disbonds, which is of great importance for art restorers.

The secondary effect given by pulse thermography is, once again, the detection of underdrawings and sketches.  For example, those made with charcoal and graphite strongly adsorb infrared light well and, thus, can be easily detected.

Figure 3 provides an example of finding delaminations.  Here one can see the results of thermographic testing. The sample represented a canvas-based, varnish-covered oil painting from the $18^{th}$ century that was suspected to be "Cimon and Pero" ("Roman Charity") by Rubens.

Under blacklight illumination (soft ultraviolet, ~350 nm) it was obvious that the painting had been restored at least three times. While some of the restorations were obviously related to canvas breakage, the others resulted from damaged varnish or paint. In Figure 3(b), the moment after flash firing is presented. As can be seen, the restored region remains several degrees warmer than the surrounding regions. This is caused by bad heat sink under the restored region (i.e., a delamination containing air). The rapid appearance of the defect contour suggests it is relatively shallow. As mentioned above, several seconds after the surface layers become uniformly heated the defect disappears.

The heat was applied to the sample with a sudden light pulse (time ~1/175 s) and subsequently observed by a thermal imager FLIR SC4000 (sensitivity band: 3-5 μm).



(a) (b)

*Fig.3. Results of thermographic painting testing: (a) snapshot in visible light,*
*(b) snapshot in thermal infrared (3-5 μm).*
*The region of revious restoration is clearly visible.*

**PULSED PHASE THERMOGRAPHY**

More complex techniques include the mathematical processing of thermographic data. One of these methods is Pulsed Phase Thermography (PPT) which, first announced in 1990s by X.Maldague [9], has been widely utilized for the examination of metals, plastics, composite structures and other materials and structures [10, 11, 12].

The PPT method uses mostly the same equipment as regular thermography: a short-pulse heater or a flashlamp and a computer-based thermal imager to store and analyze thermal data.

The short heat pulse that is applied can be mathematically represented as a superposition of harmonic heat waves with different frequencies by fast Fourier transformation (FFT). The temperature response can be transformed as well, and the amplitudes and phases of the transformed signal can be subsequently studied separately as separate signals.

According to the one-dimensional solution of Fourier's Law, a heat wave with wavelength $\lambda$ propagates according to the following equation [13]:

$$T(z,t) = T_0 \exp\left(-\frac{z}{\mu}\right)\cos\left(\frac{2\pi z}{\lambda} - \omega t\right),$$

where T is temperature, z is the depth in the media, $\lambda$ is wavelength, and $\omega=2\pi f$ is the modulation frequency. $\mu$ is a decay rate, which is expressed as

$$\mu = \sqrt{\frac{\alpha}{\pi f}},$$

with $\alpha$ the thermal diffusivity. This diffuse depth can be treated as an effective penetration depth for the heat wave modulated with frequency *f*. As can be seen, the lower the modulation frequency of the heat harmonic, the deeper the layer that can be reached.

A wave of frequency *f* can reach depth $\mu$ and, thus, is affected by defects at that level. For this reason, in the case that the thermal diffusivity of the material is known, one can perform quantitative measurements at the depth of the defect.

Due to Fourier transformation, all the frequencies can be studied using only one pulse. During the test the sample is heated with a short heat pulse. The thermal imager detects and stores the temperature dynamics for each point of the sample surface. After completing the experiment, a 3D array of thermal data is collected for the temperature-vs-time dependency for all points in the field of view of the imager. The temperature-time dependency for each point is processed using an FFT algorithm and the phase part of the transform is selected. In fact, it has been shown [13] that the phase part of the transformation is more suitable for discerning between defective and sound areas, especially in the case of deep defects. This is because the sensitive region for the phase reaches 2 $\mu$ [14], as compared to $\mu$ for that of amplitude.

By performing these computations on the collected 3D array it is possible to construct another 3D array containing Fourier transformations. Each 2D "layer" of this array corresponds to a particular frequency. This information can be connected to depth in that lower Fourier frequencies tend to include deeper defects and higher frequencies give images of shallower features.

It should be noted that PPT enables the detection of the hidden signature on the sample painting described in the NIR section (Figure 4).

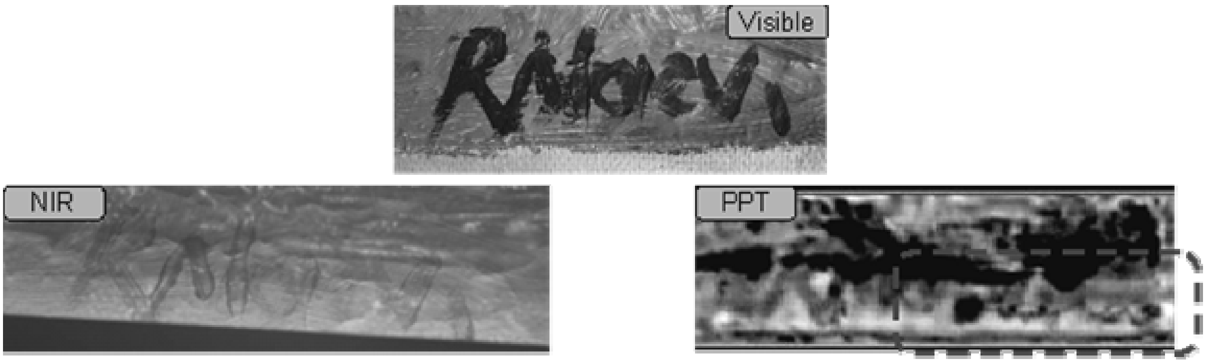



*Fig.4. Results of PPT testing of faked signature and comparison to NIR.*

Another example of PPT is presented in Figure 5. Performing the PPT testing with a part of the "Cimon and Pero" painting, a severe defect was observed in the region of Pero's face and Cimon's forehead (restored regions). This defect is located relatively close to the surface and can also be partly detected with NIR examination. Blacklight illumination also shows evidence of restorations in that area. Some changes within the scene are also visible.

(a) (b)

*Fig.5. Results of PPT testing on real painting.*

## CONCLUSION

Advanced infrared inspection is an efficient, powerful and reliable way to retrieve valuable information pertaining to the condition of paintings. The results presented show that such critical information as the presence and location of underdrawings, regions of previous restorations, thickness of paint layers, and the presence of delaminations can be obtained by using NIR or thermographic examination without performing complex testing procedures.

The results of this research demonstrate that a combination of various advanced infrared techniques provides a very powerful and efficient experimental tool for the noninvasive inspection of artwork. In particular, the infrared methods allow one to perform general diagnostics of paintings, detect damaged regions, the nature of defects, areas of previous restorations, and possible forgeries. In addition, these methods have great potential for finding alterations to the subject as well as author sketches and signatures.

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