

# Diagnostic Survey on Frescoes Paintings in Pompeii by Active IR-Thermography

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**Abstract** – This paper shows the first results of a diagnostic survey of the fresco paintings in two *domus* of the *Region V* in Pompeii, the *Domus* of *C. Iulius Polybius* and the *Domus* of *Casti Amanti*, which stand out for archaeological relevance and decorative asset. Especially, these cases of study were selected because pose special challenges for damage detection and conservation, due to the presence of large parts of not excavated soil behind walls and frescoes painting surfaces.

The survey has been realized within the framework of “*The Great Pompeii Project*” that aims to enhance the effectiveness of the actions and interventions for protecting the archaeological area of Pompeii by developing a special urgent programme of conservation, maintenance, and restoration. One of the main areas of intervention, where this survey is included, is the consolidation and restoration of decorated surfaces.

The diagnostic methodology applied in this work is the active thermography by means of an IR thermal camera that acquires the frescoes painting surface emission due to a thermal load applied to the frescoes itself. The measurement has been conducted in reflection mode, i.e. with the camera and the thermal load source located at the same side of the painted wall, the only mode of operation in thick walls as the ancient ones. The survey allowed identifying the main frescoes damages like detachments or delaminations, fissures and moist areas.

In this paper, the main problems related to the in-situ measurement by active thermography have been also illustrated and their influence on the diagnostic accuracy quantified. Specifically the issues of uniformity of the thermal load applied to the portion of the frescoes under measurement and the emissivity of its surface were deeply analyzed and their impact to the measurement quality identified.

**Keywords:** active IR thermography, fresco paintings delamination, detachments, Non Destructive Testing NDT, damage detection

## I. INTRODUCTION

Fresco paintings in archeological sites are subjected to seasonal climate variations and atmospheric and geological agents that may damage their integrity. In order to preserve them, it is thus necessary to monitor their health status on a regular basis.

Non Destructive Testing (NDT) is a good candidate for the monitoring of this kind of artworks because it does not require the removal of components of inspected pieces [1]. The most efficient NDT methodology for this kind of application is infrared thermography, which is based on the thermal inhomogeneities assessment on the frescoes that can be due to the presence of a defect, like detachments, cracks, flaking and moist areas. In infrared thermography, the painting is thermally stimulated (i.e. heated or cooled) to induce a temperature difference between undamaged areas, the so-called “sound” regions, and damaged ones. When the thermal emission of a specimen is monitored under natural conditions, i.e. the thermal stimulation is related to the environmental thermal oscillation, it is referred to as passive thermography. If the thermal stimulation is induced through the generation of a heat flow interacting with the thermos-physical properties of the test object, it is referred to as active thermography [2], [3].

Unfortunately infrared thermography, based on the thermal contrast between sound and damaged areas, are strongly affected by non-uniform heating at the surface and by the emissivity of the frescoes surface that is influenced by the chromatic distribution in the drawing. Hence, thermal contrast-based methods may identify false positive by confusing a defect with an area of low emissivity (which can be linked to a color variation) or

with an area weakly heated. In order to discern the presence of a defect from a chromatic variation or a non-uniform heating, advanced signal processing methods have been developed to be coupled with thermography inspection techniques [4], [5], [6].

In this paper active thermography was applied to detect damages on the frescoes of the *Domus of Casti Amanti* and a fresco of the 3C room at the *Domus of C. Iulius Polybius*. These large buildings are located along via dell'Abbondanza, the ancient main street in Pompeii, and were excavated during the 80s (*Domus of Casti Amanti*) and the 60s and 70s (*Domus of C. Iulius Polybius*), after the discovery of their facades occurred between 1910 and 1923 by Vittorio Spinazzola. In both cases the survey focused on some of the main preserved fresco paintings.

In the *Domus of Casti Amanti* the analysis concerned the paintings of late 3<sup>rd</sup> style (half of the 1<sup>st</sup> century A.D.) which adorn the *triclinium*, adjunct to the complex of the bakery. The room is characterized by the presence of framed images with banquet's scenes, set in different seasons. In the summer banquet the protagonists are represented passionately kissing, and from this detail derives the name of the house and related insula.

In the *Domus of C. Iulius Polybius*, the painted *lararium* near the kitchens was selected for the thermographic application. In this case, the fresco represents a sacrificial ritual, celebrated in the presence of two Lari. The sacrificial is due to a bearded man and a veiled woman, who is offering incense on an altar surrounded by a huge snake.

The testing and processing procedure will be described in Section II, where the measurement problems encountered and the solutions set up to solve them are highlighted and discussed. Section III describe the test set up and the results of the thermographic investigation.

## II. ACTIVE THERMOGRAPHY PROCEDURE AND SIGNAL PROCESSING

### A. Active thermography

Active thermography is applied to objects or systems that do not emit heat in their normal operation. In this case, the use of passive thermography would not lead to significant results since the systems considered are in thermal equilibrium with the surrounding environment without having significant temperature gradients. In active thermography, it is necessary to provide energy to the sample under observation in order to obtain a significant temperature gradient evidencing any anomalies and defects.

Active thermography involves different procedures depending on the methodology used for heating, acquisition and processing of data. In this paper, pulsed thermography (PT - Pulsed Termography) in reflection mode is exploited. Pulsed thermography is one of the most common thermal stimulation procedures because it

allows performing inspections very quickly. This technique consists on a brief pulsation from a few milliseconds for highly conductive materials (such as metals) up to a few seconds for non-conductive materials (such as plastics, epoxy graphite laminates, etc.) and then recording the temperature decay curve.

As a result of the thermal stimulation the temperature of the material changes rapidly after the initial pulse because the thermal front wave propagates under the surface and because radiation and convection phenomena drain heat from the surface. The presence of a defect under the surface alters the thermal diffusion through the material and changes the surface temperature in the region overcoming the defect itself once the thermal front emerges. The temperature gradient between the damaged region and the surrounding ones is the feature that allows identifying the defect.

Depending on the location of the thermal source, the active thermography may work in two modes:

1. in reflection mode: source and camera are positioned at the same side of the sample surface, see Fig. 1;
2. in transmission mode: source and camera are positioned on the opposite sides of the surface to be investigated.

Fig. 1 shows the test procedure:

- the thermal source, which in most cases is a series of halogen lamps or flash depending on the duration of the thermal pulse, produces an impulsive heating represented by the W-t time history;

- the damaged sample (e.g. with a surface-substrate detachment) warms up when the lamps are switched on and cool down when they are switched off according to an exponential function that will have different exponents depending on whether the camera frames the sound or damaged zone. The different exponential raising and decay is evident in the thermal time histories T-t. The red time history refers to the damaged area, the green one to the sound one.

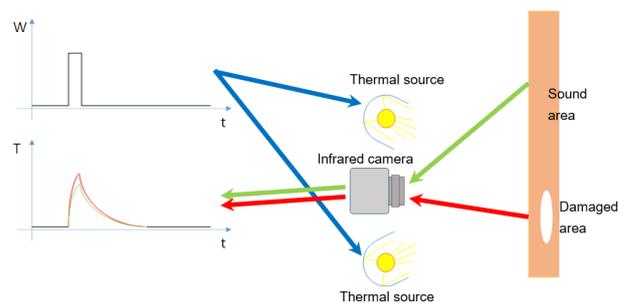


Fig. 1 Active thermography set-up

The thermal source exploited in the Pompei test case consists of three halogen lamps whose power does not emit a significant amount of energy. In addition, because some of the frescoes, like the ones of the *Domus of Casti Amanti*, have been recently restored their surface

exhibited a high level of reflection due to the presence of a protective layer applied during restoration. The high reflective layer further reduces the energy that, emitted by heating lamps, actually contributes to the wall heating. To cope with these problems, an extended heating time was required, preferring a Step Heating (SH) with respect to a Pulse Heating (PH). Therefore, the increase in surface temperature is observed during the application of a long-term thermal step (long pulse). In this way it is possible to enter into the wall a higher intensity thermal wave with a longer wavelength. It follows that the thermal wave may reach a greater depth of the wall, but also that it will be characterized by a worse spatial resolution. The lateral diffusion phenomena will be of greater magnitude, as well as the axial resolution of the analysis will be more coarse.

The infrared thermal camera used in the test is an Infratec – Variocam HD, with spatial resolution of 1024x768 pixel, spectral range of 7.5 to 14  $\mu\text{m}$ , temperature range of -40 to 1200  $^{\circ}\text{C}$ , accuracy of  $\pm 1.5$   $^{\circ}\text{C}$ , frame rate of 30 Hz.

### B. Signal processing

In the past, many signal processing methods have been developed to enhance the analysis of active thermography images with the aim of identifying defects in artworks. One of them is based in the Principal Component Analysis (PCA), [7]. PCA is a technique that reduces a set of dependent variables to one or more independent variables, with the aim of reducing the number of variables describing the phenomenon. The use of PCA aims at generating a compact and optimal description of a data set and reducing its size, trying to lose as little information as possible.

The main algorithm can be synthesized in the following phases:

1. normalization of data,
2. determination of the correlation matrix and its eigenvectors and eigenvalues,
3. sorting the eigenvalues in decreasing order and the corresponding eigenvectors).

The last step allows identifying the components in order of importance, since the  $j^{\text{th}}$  eigenvalue quantifies the influence of the  $j^{\text{th}}$  main component on the original data. The first major component is therefore a combination of variables that is responsible of the most variations; the second component is mostly responsible of the remaining variations and is independent to the first component and all the other components.

The information contained in the matrix of data captured with IR thermography is both spatial (which gives the geometry and defect position) and temporal (for each pixel of the thermal camera is recorded a time history). If the camera has a pixel number of 768x1024 and if 199 time samples have been acquired, the PCA input matrix has the size of 768x1024x199.

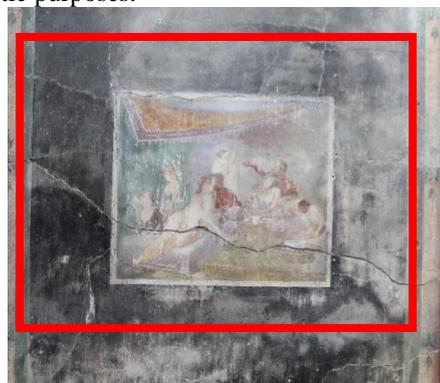
The Principal Components (PC) in output from the PCA have the same dimensions as the initial images (or thermogram), i.e. 768x1024 and they are called Space Components (SC). Each pixel of these SC concentrates all the information contained in the 199 time samples of the pixel itself in few components. Typically, in active thermography, the PCA identifies three or four main components, each of which contains independent information like heating inhomogeneities, surface shape variations, the emissivity variation due to the different color in the fresco and the defect information. Therefore, from 199 initial thermograms (one per time sample), all the information has been synthesized in no more than 4 images. These few images carry all the important information for identifying the defects.

## III. EXPERIMENTAL RESULTS

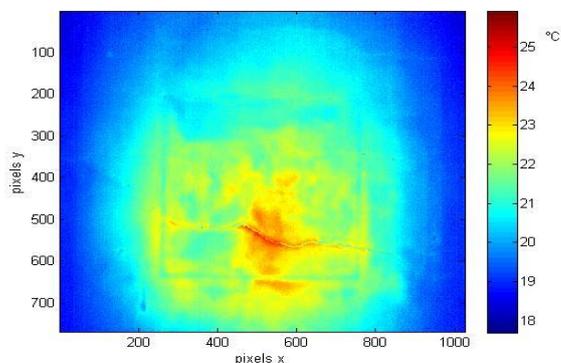
### A. The frescoes of the Domus of Casti Amanti

The tests have been carried out on three fresco paintings of the *Casti Amanti* room named P IX 12 9 m E, P IX 12 9 m N and P IX 12 9 m O.

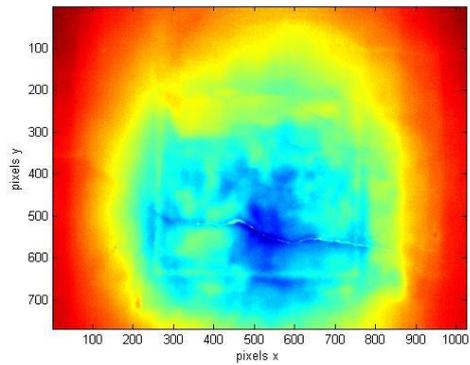
The PCA results are synthesized in Fig. 2, where the fresco P IX 12 9 m N picture is reported together with a thermogram at a specific time sample and the first two PCs, the only ones containing useful information for diagnostic purposes.



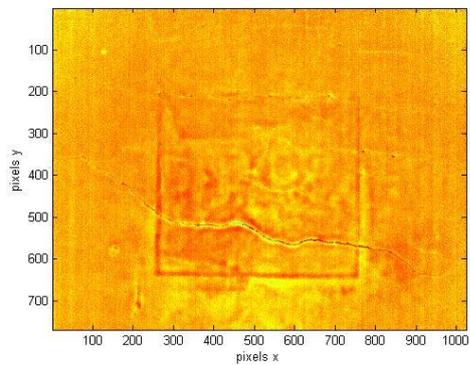
Fresco photograph (P IX 12 9 m N)



Thermogram at 90 s



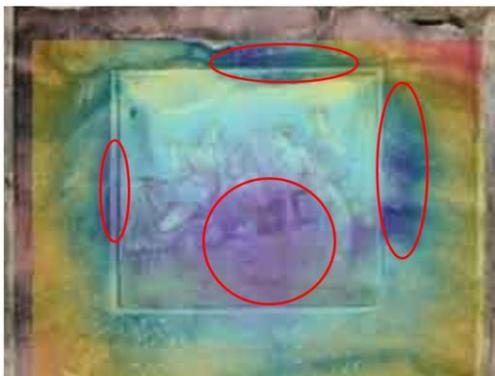
First PC



Second PC

Fig. 2 PCA results for fresco P IX 12 9 m N

As final result, the first PC has been superimposed to the visible picture of the three frescoes in order to evidence the eventual damaged regions highlighted in red in Fig. 3.



Fresco P IX 12 9 m E



Fresco P IX 12 9 m N



Fresco P IX 12 9 m O

Fig. 3 Diagnostic map of the three Casti Amanti frescoes

*B. The fresco of the Domus of C. Iulius Polybius*

Being the fresco of the *Domus of Iulius Polibius* rather big, it has been partitioned in nine portion in a 3x3 rectangles, as reported in Fig. 4.

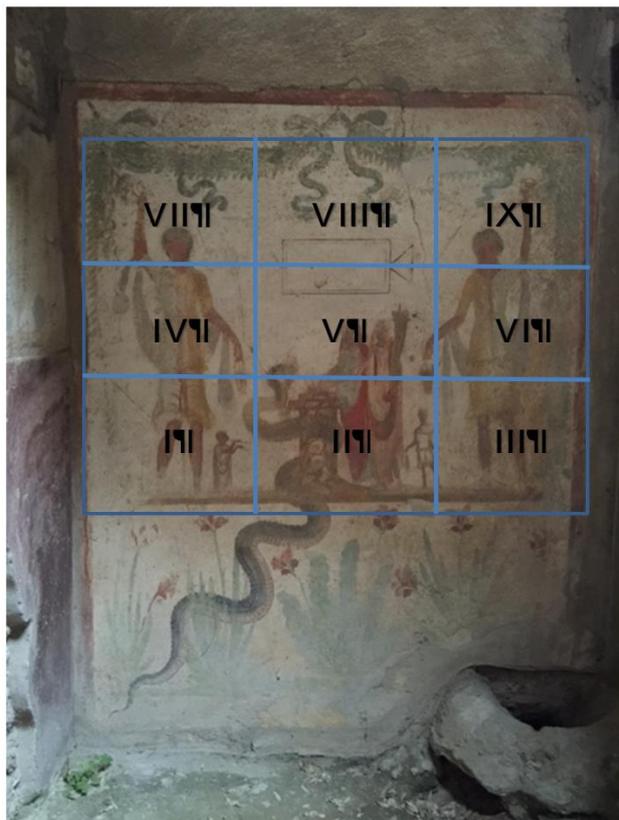


Fig. 4 Partition numbering of the Iulius Polibius fresco (P IX 13 3 3c O)

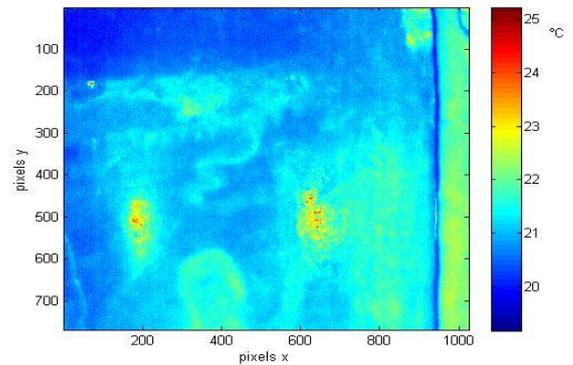
As in the previous section, the PCA results are synthesized in Fig. 5 only for the partition IX, where the partition picture is reported together with a thermogram at a specific time sample and the first two PCs.

In this case it is visible that the thermogram is influenced by both the heating inhomogeneities, i.e. the lamps light reflections are the two yellow spot in the thermogram at 59 s, and the surface colors, i.e. the woman head and the snake tail are easily distinguishable. The PCA is helpful in separating the different chromatic and reflective contributions, which are mostly concentrated in the second PC. The first PC instead is not influenced by those interfering inputs and can be used for more accurate diagnostic purposes.

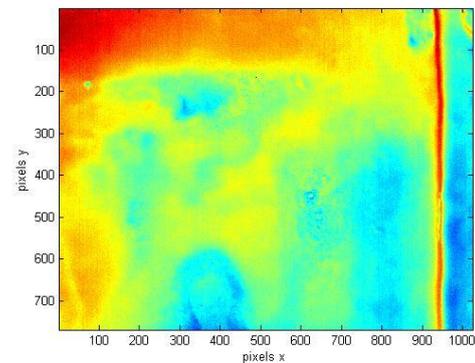
The first PC maps have been superimposed on the fresco visible image to allow an easier identification of the damaged areas, Fig. 6. The superimposition has been done using an on-site calibration procedure that made it possible to identify the match between the IR image and the visible one.



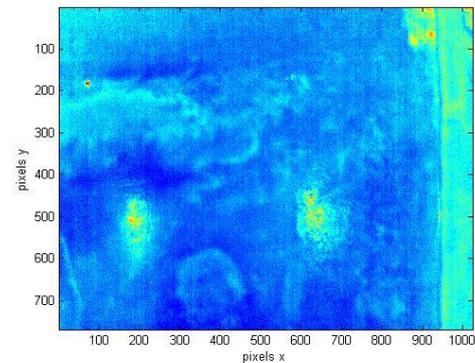
Fresco partition IX photograph



Thermogram at 59 s



First PC



Second PC

Fig. 5 PCA results for fresco P IX 13 3 3c O, partition IX



Fig. 6 PCA results for fresco P IX 13 3 3c O, partition IX

The peculiarities of the PCA do not allow having a map with fake consistent colors on all viewpoints: there are discontinuous colorations between the various viewpoints and the detachments appear with different colorations. In order to make the detached zones more intelligible, areas with a PC anomaly that may correspond to a detachment have been highlighted with red contour lines.

#### IV. CONCLUSIONS

The measurement campaign made it possible to identify some detached areas of the frescoes analyzed, the most interesting one being the fresco P IX 3 13 3c O of the *Domus of C. Iulius Polybius*.

Unfortunately, the conditions of the frescoes, mainly due to the protective layer added during a previous restoration, caused unexpected difficulties in the tests.

The protective surface layer indeed makes the fresco rather lucid in the visible spectrum and highly reflective in the infrared one. They therefore have a low or very low level of emissivity, which makes it very difficult the walls heating by irradiation and consequently the measurement by infrared thermography. Any object that is hotter than the fresco surface (e.g. even operators whose temperature is only +10°C over ambient temperature) are reflected by the surface, which also emits only a small part of the thermal energy it possesses. This situation has led to the need to operate at very high levels of thermal noise and the presence of false positives due to reflections.

Despite this, the results are interesting, and the defects are well recognized.

#### AKNOWLEDGEMENTS

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