

Active Thermography Analysis of Wall Paintings in the Early Christian Basilica Complex of Cimitile (Italy)

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Abstract – This study investigates the use of active thermography (AT) in the mid-wave infrared (MWIR) range to assess the conservation state of wall paintings within the Early Christian basilica complex of Cimitile (Italy). The research focused on paintings in the Basilicas of San Felice and San Giovanni, affected by issues such as pigment loss, detachment, and moisture-related degradation. Controlled thermal stimulation was applied to generate differential thermal maps (ΔT), enabling the identification of subsurface anomalies, weakened adhesion zones, and potential moisture accumulation. Conducted as a pre-restoration diagnostic survey, the analysis provided essential, non-invasive insights into fragile mural surfaces without physical contact. The results confirmed the diagnostic value of AT in detecting hidden defects and guiding the planning of targeted conservation strategies. This thermographic approach delivers critical data to support preservation efforts of Cimitile’s mural heritage and facilitates the early detection of deterioration processes in comparable historic contexts.

I. INTRODUCTION

The conservation of mural paintings in historic and archaeological contexts represents a complex challenge that requires the use of advanced non-invasive diagnostic techniques to support effective and sustainable preservation strategies [1, 2]. Wall paintings are highly sensitive to environmental conditions and structural instabilities, which can lead to deterioration phenomena such as detachments, salt efflorescence, pigment loss, biological colonization, and moisture-related damage. Within this framework, Active thermography (AT) has emerged as a reliable and powerful technique for the non-contact analysis of artworks and architectural surfaces, allowing the detection of subsurface anomalies by monitoring thermal behavior in a rapid and non-destructive manner [3-14].

AT operates by capturing the infrared radiation emitted from surfaces after controlled thermal stimulation, enabling the detection of subsurface defects that are often invisible to the naked eye. It is particularly effective for delicate surfaces such as wall paintings, where physical contact and invasive sampling are not permitted [15-18].

This study focuses on the application of AT to wall paintings within the Early Christian basilica complex of Cimitile, one of the most significant and stratified heritage sites in southern Italy [19-21]. Dating back to the 3rd century AD, the complex comprises several interconnected basilicas richly adorned with frescoes portraying religious iconography and narrative biblical scenes. Despite their historical and artistic value, these artworks have undergone considerable deterioration over time due to prolonged exposure to environmental fluctuations, structural instability, seismic events, and degradation processes linked to humidity and biological colonization.

In this context, thermographic surveys were conducted in the Basilicas of San Felice and San Giovanni to assess the conservation state of selected mural paintings. The diagnostic campaign employed active MWIR thermography to detect deeper or less evident defects through induced thermal contrasts. By analyzing temperature variations over time and space, it was possible to identify areas affected by moisture, voids behind the plaster, and compromised adhesion of pictorial layers, conditions that, if left unaddressed, may lead to irreversible loss.

These pre-restoration analyses were designed to provide valuable information for guiding targeted conservation interventions. The findings contribute to the development of informed and site-specific restoration strategies, promoting the protection, monitoring, and valorization of mural heritage within the complex.

II. MATERIALS AND METHODS

A. Wall Paintings of the Cimitile Basilica Complex

The research focused on paintings ed surfaces located within two key structures of the Cimitile complex: the Basilica of San Felice and the Basilica of San Giovanni. These churches house a significant series of wall paintings dating back to the 3rd century AD to the early Middle Ages, including biblical narratives, iconographic portraits of saints, symbolic elements, and ornamental motifs. The paintings were executed using traditional lime-based fresco techniques applied to architectural plaster, often composed of multiple preparatory layers. Many of these artworks are currently affected by various forms of degradation, including fading pigments, microcracks, surface efflorescence, and partial detachment of both the plaster and pictorial layers. In several cases, damage is exacerbated by prolonged exposure to moisture and temperature fluctuations within the buildings. The complexity of stratigraphy, combined with heterogeneous material compositions and aging processes, make these mural surfaces particularly suitable for thermographic investigation aimed at identifying subsurface anomalies, mapping decay phenomena, and informing tailored conservation strategies.

B. Thermographic Technique and Equipment

Active thermography was chosen for this study due to its capability to enhance subsurface contrast through external thermal stimulation. A cooled MWIR camera (FLIR X6580 sc), equipped with an InSb detector (FPA 640×512 pixels, NETD ~ 20 mK at 25°C), was employed. The spectral range was $3.5\text{--}5\ \mu\text{m}$ with a 50 mm lens (IFOV: 0.3 mrad). Each wall painting area was stimulated using a 1 kW halogen lamp, emitting a controlled thermal pulse lasting approximately 40 seconds. Thermographic sequences were captured before, during, and after stimulation at 5 Hz, allowing for detailed tracking of temperature evolution.

Post-processing analyses were conducted using FLIR ResearchIR (FLIR Systems Inc., Wilsonville, Oregon, USA) software. Emissivity values were set between 0.89 and 0.94, determined through reference materials and validated by a black matte emissivity standard. The measurements were carried out under environmental conditions with temperatures ranging from 20 to 24°C and relative humidity between 55% and 65%.



Fig. 1. Pictures of the MWIR thermal cameras and of the halogen lamp used for the Active Thermography measurements.

III. RESULTS AND DISCUSSION

AT was performed to conduct a structural analysis of the wall paintings present within the basilica complex. As an example, Figures 2 and 3 present representative case studies of some of the analysed artworks. The thermal maps in the figures refer to the induced thermal variation (ΔT) resulting from the applied thermal stimulation. Specifically, ΔT represents the temperature difference calculated for each pixel, obtained by comparing the first thermal frame acquired after the stimulation with the frame recorded immediately before the start of the stimulation. To enhance the spatial resolution of the acquired data, each painting was virtually divided into multiple sections that were analyzed individually. A complete image of the artwork was then reconstructed through mosaicking

A. Thermographic Mapping of Frescoes in San Giovanni

The first campaign focused on a large painting in the apse of the Basilica of San Giovanni, consisting of two main sections depicting, respectively, the Virgin Mary with Child and Saint Joseph. The visible inspection (Figures 2a and 2c) revealed no major surface losses, whereas the

thermal maps (Figures 2b and 2d) highlighted several subsurface anomalies. In the thermographic data acquired after thermal stimulation, areas with markedly reduced ΔT values (violet tones) were observed across different regions of the painting, suggesting localized moisture accumulation behind the plaster. In contrast, adjacent zones with higher ΔT values (yellow to red tones), highlighted with white circles, were detected, indicating possible detachment of the painted layer. These areas are particularly critical, as interstitial air trapped between layers reduces thermal conductivity, delays cooling, and produces a thermal signature characteristic of adhesion loss.

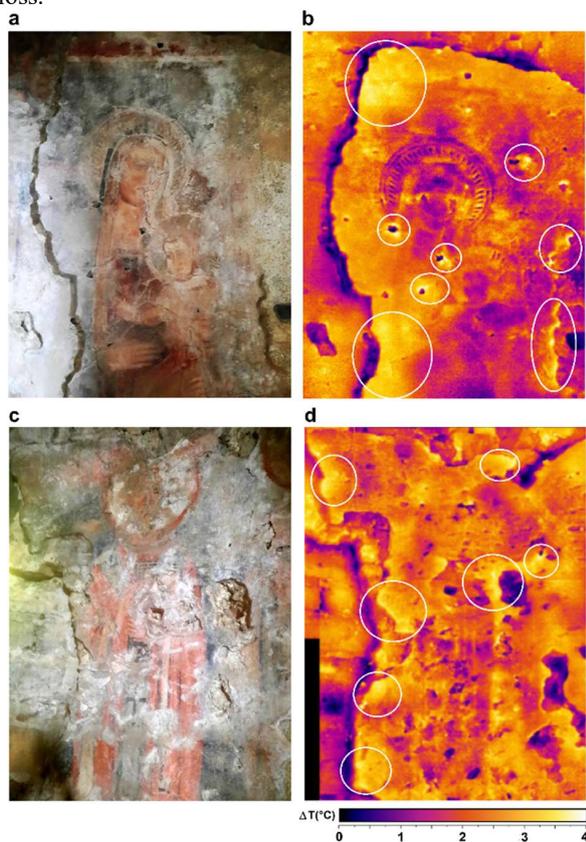


Fig. 2. Active thermography analysis of the wall painting in the apse of the Basilica of San Giovanni, depicting the Virgin and Child with Saint Joseph: visible images (a, c) and corresponding thermal maps (b, d).

B. Analysis of Wall Paintings in San Felice

Two additional significant wall paintings were analyzed on the Basilica of San Felice, one depicting the Virgin Mary with Child and the other Saint Nicholas. From the visible inspection (Figures 3a and 3c), both artworks showed evident surface degradation; however, the pigments used in their execution appear to be better preserved than those in the Basilica of San Giovanni. The thermal distribution observed in the maps (Figures 3b and

3d) was highly complex, partly due to the different emissivity and optical absorption properties of the pigments. The identification of suspected defects therefore required a careful comparison between the visible images and the corresponding thermal maps, in order to detect thermal anomalies with geometries inconsistent with the features present in the paintings. Following this approach, thermographic mapping enabled the recognition of multiple degradation mechanisms coexisting within the two works. In particular, high ΔT zones coincided with visible cracks and areas of flaking, through which air can infiltrate beneath the pictorial surface, while low ΔT zones (circled in white) were associated with areas suspected of moisture accumulation, likely caused by water infiltration from upper parts of the structure.

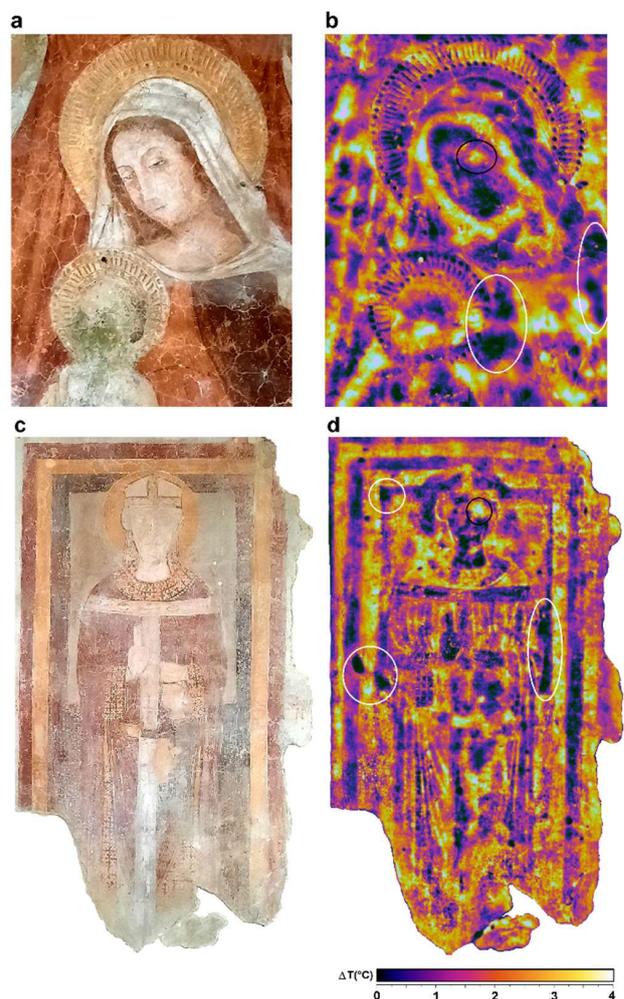


Fig. 3. Active thermography analysis of two wall paintings in the Basilica of San Felice, depicting the Virgin and Child and Saint Nicholas.: visible images (a, c) and corresponding thermal maps (b, d).

Notably, several regions showing little or no visible damage exhibited thermographic anomalies indicative of subsurface voids, such as those identified on the faces of both the Virgin and Saint Nicholas (circled in black), confirming the added value of this method for detecting hidden risks to preservation.

The presence of cracks in the surface and subsurface layers of the paintings was analyzed and mapped using thermal frames acquired during the heating phase. In this case, the reflected thermal component made it possible to better highlight the structural features of the surface. As an example, Figure 4 shows the thermal images obtained from these analyses, referring to the face of the Virgin (Figure 4a) and of the Child (Figure 4b). In both images, the surface and subsurface cracks are clearly visible and effectively mapped.

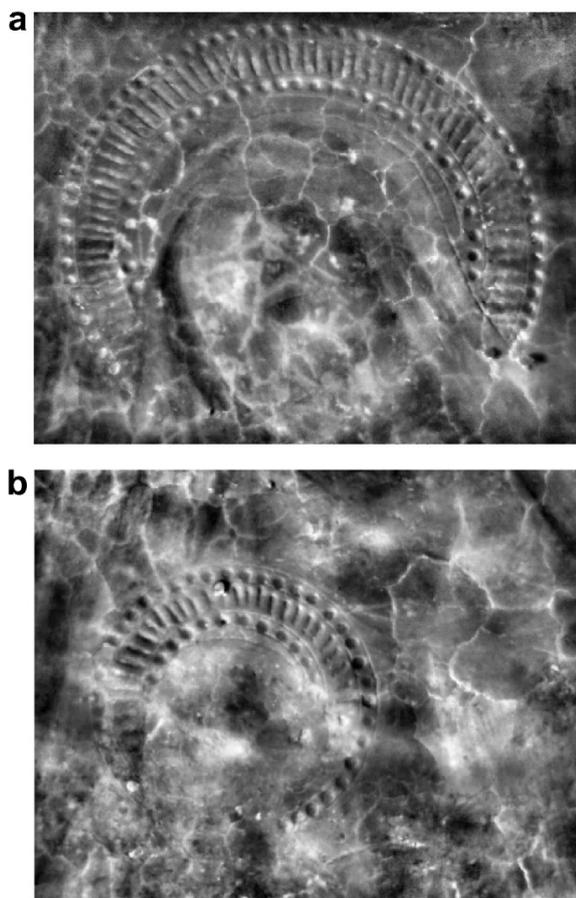


Figure 4. Images obtained by processing the thermal frames during the heating phase: Virgin's face (a) and Child's face (b).

C. Interpretation and Conservation Implications

The collected data reveal a complex network of interactions between environmental factors and structural

conditions beneath the pictorial layer. The ability of MWIR thermography to isolate and characterize these features with high resolution is instrumental in prioritizing conservation interventions.

In both basilicas, thermographic mapping facilitated the distinction between active and stable degradation phenomena, supporting a stratified approach to conservation planning. Moreover, thermographic datasets can be integrated into digital documentation systems for longitudinal monitoring of the frescoes' condition over time.

IV. CONCLUSIONS

This study demonstrates the effectiveness of AT in diagnosing the conservation status of wall paintings within the Cimitile Basilica Complex. The technique enabled the identification of key deterioration indicators such as moisture infiltration, interstitial voids, and detachment of the painted layer, many of which remain hidden from traditional visual inspection. The findings highlight the importance of non-invasive thermal imaging for cultural heritage diagnostics, particularly in complex archaeological environments where structural and environmental challenges coexist. By delivering high-resolution, subsurface data without physical contact, infrared thermography offers valuable support for targeted conservation efforts, minimizing unnecessary interventions while maximizing preservation outcomes.

Future research could integrate thermography with complementary techniques such as multispectral imaging, or 3D laser scanning to build a more comprehensive diagnostic model for mural conservation.

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