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Extended Abstract

Challenges in Detecting Delamination in Lined Oil Paintings Using Pulsed Phase Thermography: Considering the Effects of Paint Variations †

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Abstract: This study investigates the effect of paint-related properties on the accuracy of delamination detection in lined oil paintings using pulsed phase thermography (PPT). Mock-ups of lined oil paintings were examined by PPT under both normal and angled illumination to induce apparently localized heating. Spectral characteristics in the excitation and detection wavelength ranges were analyzed and related to phase contrast variations in the resulting images. While paint-dependent energy absorption under localized heating may blur phase contrast and lead to misidentification of delamination, emissivity properties appear to contribute to stabilizing phase signals. These findings underscore the importance of accounting for paint properties in conservation diagnostics.

Keywords: Delamination, Wax-Resin Lining, Oil Paint, Pulsed Phase Thermography, Nondestructive Examination, Conservation

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1. Introduction

Lining is a conservation technique applied to damaged paintings to enhance structural stability. Among the various methods, wax-resin lining—applied by impregnating canvas with wax-based adhesives—was widely used in the 20th century. Although no longer common today, many such treated paintings remain in collections. Partial delamination in these linings has been a concern, highlighting the need for simple, accessible, and nondestructive methods to assess this issue in conservation practice.

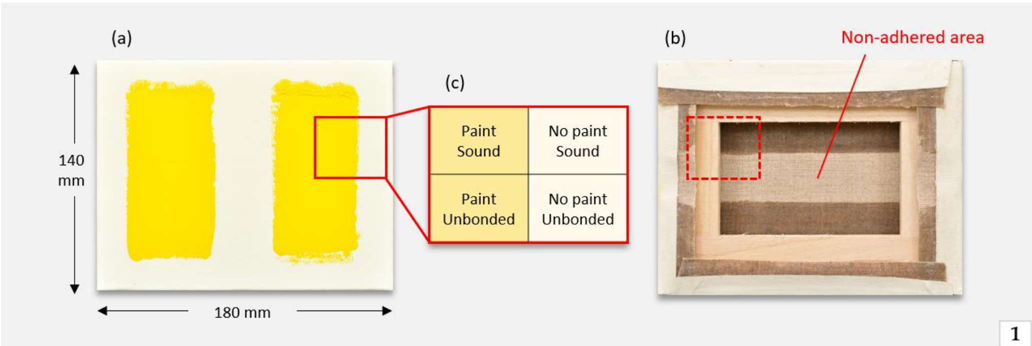
Pulsed phase thermography (PPT) has proven effective for detecting delamination in wax-resin linings; however, non-delaminated areas sometimes exhibit grayscale patterns resembling those of delaminated areas in phase images [1]. This is likely due to localized thermal variations under suboptimal lighting, which often arise in constrained on-site environments. Previous studies have noted that non-uniform heating, even on flat surfaces, can occur due to factors such as heat source position or ambient conditions and compromise detection accuracy [2]. One hypothesis is that certain paints possess properties that make them more susceptible to such interference, resulting in misleading phase images.

To investigate this phenomenon, mock-ups of wax-resin-lined oil paintings with different paint types and simulated delamination within the linings were examined using PPT under both normal and angled illumination setups intended to induce apparently localized heating. Spectral characteristics of the paint were analyzed through imaging and spectroscopy in two key wavelength ranges—Mid-infrared (MWIR; camera detection) and Ultraviolet–Visible–Near-Infrared (UV–Vis–NIR; excitation illumination)—to explore their potential influence on phase image interference in PPT. This study aims to clarify paint-related properties affecting the reliability of lining delamination detection in in-situ conservation contexts.

2. Materials and Methods

2.1. Mock-ups of Wax–Resin–Lined Oil Paintings

Mock-ups were prepared using F0-sized commercial primed linen canvases. Oil paints (YUICHI, Holbein) were applied with an applicator to separate canvases for each type of paint, in two thicknesses (50 and 200 µm); this present abstract focuses only on the 200 µm-thick paint layers. After drying, wax–resin lining was applied to each canvas, leaving an unbonded region in the center to simulate delamination (see **Figure 1**). The canvases were then re-stretched onto wooden frames.



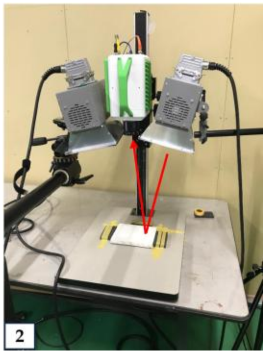


Figure 1. Mock-up of wax-resin lined oil painting. (a) Front view. (b) Back view. (c) Schematic diagram of the PPT measurement focus area, corresponding to the red-marked region in (a) and (b).

Figure 2. Experimental setup with angled illumination intended to create apparently localized heating, particularly in the focus area shown in **Figure 1**.

2.2. Experimental Methods

2.2.1. PPT in reflection mode with normal and the angled illumination (see **Figure 2**)

System: PTvis (Ken Automation Inc., Japan), equipped with DisplayImg Professional software (EDEVIS GmbH, Germany);
Camera: Noxcam640 (Noxant, France), InSb detector, 3–5 µm, 640 × 512 pixels;
Acquisition rate: 100 Hz;
Excitation: Xenon flash lamp (HENSEL Tria 6000s, Germany), 6 kJ, 10 ms pulse;

2.2.2. Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS)*

Instrument: Bruker ALPHA II with DRIFTS accessory;
Measurement range: 4000–400 cm^{-1} (corresponding to 2.5–25 µm);
Resolution: 4 cm^{-1}; **Number of scans:** 16;
*Non-invasive alternative to emissivity measurement to avoid sustained heating

2.2.3. UV–Vis–NIR Reflectography

Camera: PENTAX 645D IR (Ricoh Imaging Co., Ltd., Japan), CCD sensor, approx. 380–1100 nm, 7264×5440 pixels; **Filter configuration:** No Vis-cut filter;
Excitation: Broncolor Unilite strobes (Broncolor AG, Switzerland);

2.2.4. UV–Vis–NIR Reflectance Spectroscopy

Instrument: SolidSpec-3700 (Shimadzu Corp., Japan) with integrating sphere;
Measurement range: 200–2600 nm; **Resolution:** 0.1 nm;
Measurement method: double-beam reflectance measurement;

3. Results

3.1. Phase Image Analysis under Different Heating Conditions

Unbonded areas consistently showed distinct phase delays under normal illumination, indicating reliable detection of delamination in wax-resin linings (**Figure 3(b)**). Although phase delays also occurred under the adjusted illumination, the phase difference ($\Delta\varphi$) between sound and unbonded regions became significantly smaller, particularly in paints such as Titanium white and Cadmium yellow (**Figure 3(c)**). This reduction in contrast made delaminated areas more difficult to distinguish based on phase contrast and suggests a risk of misidentification. Conversely, in paints like Ivory black and Vermilion, $\Delta\varphi$ were relatively stable regardless of illumination conditions, and the detectability of delamination was less affected.

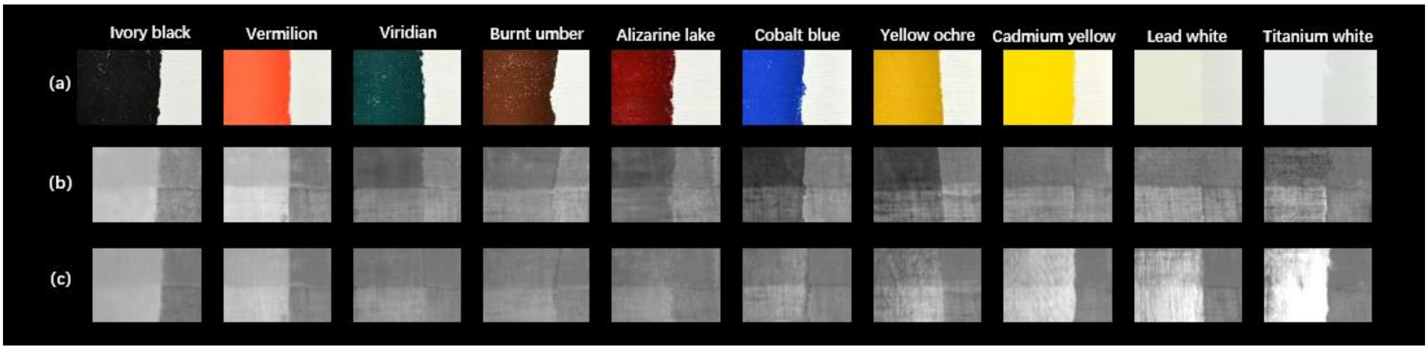


Figure 3. Comparison of images from the mock-ups, focusing on the selected areas marked in red in **Figure 1**. (a) Normal lighting photography. (b) Phase images from PPT under uniform illumination (2.0 Hz). (c) Phase images from PPT under the angled illumination (2.0 Hz).

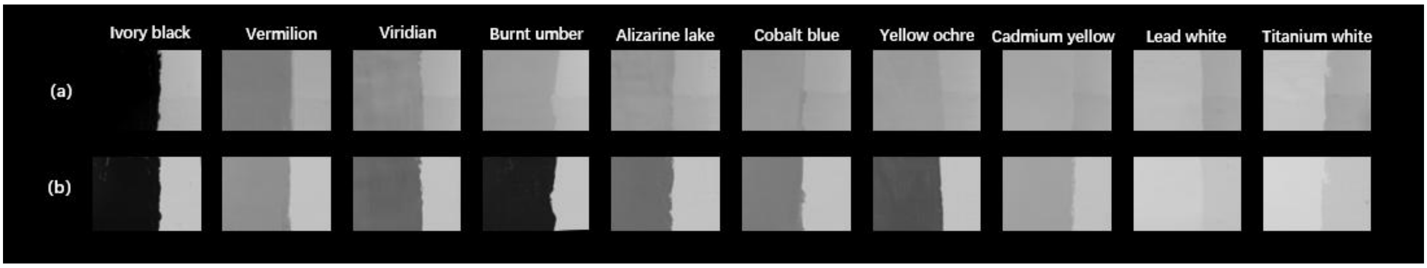
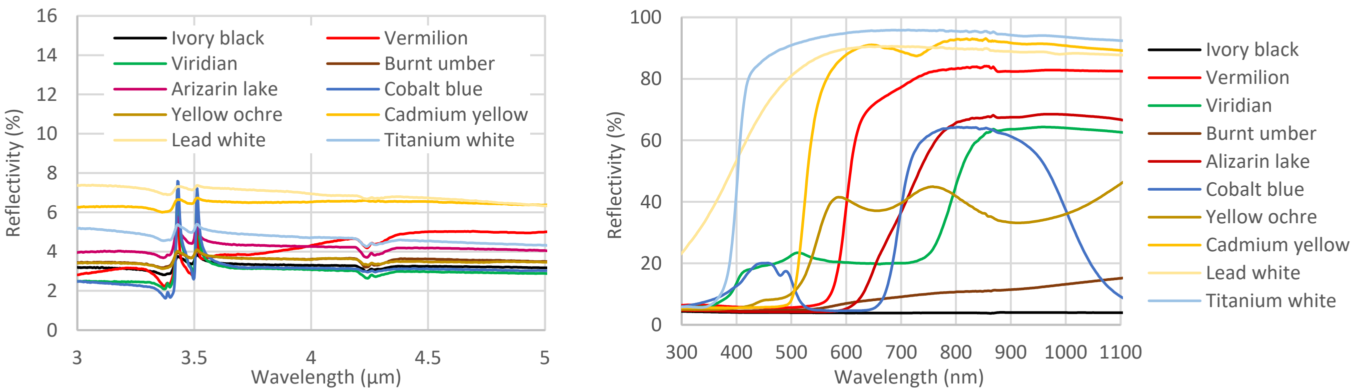


Figure 4. Spectral characteristics of different paints visualized through imaging techniques. (a) MWIR thermal images (3–5 μm) acquired during PPT measurements under uniform illumination. (b) UV–Vis–NIR reflectance images (approx. 380–1100 nm) captured under xenon flash illumination.



(**a**) (**b**)

Figure 5. Spectra of different paints. (a) MWIR reflectance spectra (3–5 μm) obtained by DRIFTS. (b) UV–Vis–NIR reflectance spectra (mainly 380–1100 nm) obtained by spectrophotometry

3.2. Correlation with Spectral and Thermal Properties: Analysis by Imaging and Spectroscopy

3.2.1. MWIR range (3–5 μm; camera detection range)

Thermal images acquired during PPT measurements (**Figure 4(a)**), taken at the moment of the surface temperature peak immediately after excitation, are considered to predominantly reflect optical features associated with MWIR reflectance. Compared to the reflectance spectra obtained by DRIFTS in the same wavelength range (**Figure 5(a)**), trends in image contrast did not consistently align with spectral intensities. This discrepancy suggests that DRIFTS spectra may have limitations in representing surface reflectivity.

Measured FT-IR transmittance for all paints was negligible (<0.001%), allowing the approximation *absorptance ≈ 1 − reflectance*. Based on this, a qualitative estimation of relative emissivity was derived from the reflectance images. In this context, Ivory black appeared to exhibit notably higher emissivity, followed by paints such as Vermilion. White paints and Cadmium yellow showed the lowest.

3.2.2. UV–Vis–NIR range (mainly 380–1100 nm; typical xenon flash lamp spectrum)

Both the reflectance images (**Figure 4(b)**) and the corresponding spectra (**Figure 5(b)**) in the UV–Vis–NIR range showed paint-dependent variations with similar trends. White paints and Cadmium yellow showed relatively higher reflectance across the range, while Ivory black and Burnt umber showed lower values.

4. Discussion

The reduction in phase contrast (Δφ) caused by changes in illumination angle suggests that strong specular reflection of the excitation light from the paint surface may have suppressed heat absorption. If this assumption holds, paints with particularly high reflectance may undergo less temperature rise, leading to a more significant decrease in Δφ.

However, Vermilion was an exception, exhibiting minimal Δφ reduction, despite belonging to the higher-reflectance group in the excitation wavelength range, alongside white paints and Cadmium yellow. This deviation may reflect the influence of emissivity, suggesting that the relative detectability of thermal emission on the detection side potentially contributed to the stability of the phase signals under non-uniform illumination.

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Conflicts of Interest: The authors declare no conflicts of interest.

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