QIRT 2022

30th anniversary

16th Quantitative Infrared Thermography Conference

July 4-8, 2022
Paris, France

FULL PAPERS

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Université Gustave Eiffel

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About

This 16th edition is a particular one that is held at Paris for its 30th anniversary. The Local Organizing Committee is proud to organize the conference for this particular occasion and extends a warm welcome to all the participants, contributors, partners and exhibitors.

Scope

The biannual Quantitative InfraRed Thermography (QIRT) Conference is a meeting of the scientific and industrial community interested and actively working in research, application and technology related to infrared thermography. All conference topics are intended to quantitative results comprising temperature values as well as further parameters on the tested materials and structures. The latter ones are usually obtained through active thermography, e. g. by exploiting non-stationary heat transfer processes activated by additional heat sources or by considering wavelength dependent effects. Passive and active thermography methods and technologies are spread now along a multitude of areas of applications, which all profit from each other.

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COVID Info

On the 1st July 2022 mask wearing is not mandatory in France. But due to the evolution of the sanitary situation these last 2 weeks, we would like to encourage you to preserve yourself and your colleagues by using mask during sessions.

Active thermography for panel paintings inspection: A comparative study of mid-wave and long-wave Infrared spectral analysis.

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Abstract

Active thermography was used as a multispectral non-destructive approach for characterisation of multi-layered panel paintings and analysis of their defects caused by aging and environmental effects. Two oil compositions painted on canvas, provided by C2RMF in the Louvre museum (*Centre de Recherche et de Restauration des Musées de France*) were under inspection. Active Thermography was demonstrated as being appropriate for characterization of various defects on painting layers and detection of under−drawings, pentimenti and canvas. Pulsed thermography system (PTvis setup of EDEVIS GmbH, provided by Thermoconcept) was applied to obtain and to inspect a dynamic thermal response, which was recorded by mid- and long-wavelength infrared TELOPS cameras. Control, synchronization and data analyses were made by EDEVIS DisplayImg Professional software (provided by Thermoconcept). In our studies, the combined approach provided by mid- and long-wavelength infrared cameras allowed us to obtain simultaneous complementary information on the painting specimen for its internal defects characterization and *in situ* inspection.

1. Introduction

Modern scientific instruments and methods are extensively applied for obtaining information on heritage cultural art objects and paintings, thus providing comprehensive in-depth investigations of various artworks. For the studies on panel paintings and their heterogeneous multi-layer structures (concealed glues, gesso composed of glue and chalk or gypsum, paints and resin varnishes), analytical methods and procedures for their analyses allow one to study each individual layer to inspect the whole painting piece (wood frame, support, preparatory layers, paint and varnish levels) [1] and also to reveal unexpected underlying features (under-drawings, pentimenti, etc.).

Analytical procedures are aimed to improve readability of artefacts undetectable by the naked eye. The obtained information may provide deeper insights for understanding the particular context behind the painting under inspection. Indeed, painting media, such as wax, egg tempera, oils, and their combinations, can include materials of different thermo-mechanical properties [2]. External environmental effects (temperature, humidity, condensation-vaporization, air pollution, inappropriate light exposure, presence of bacteria, etc.) may cause mechanical deformations, like expansions and contractions of different zones on the layered structure. These deformations can be amplified by natural aging and may affect mechanical properties of each layer and, eventually, result in detachments, delamination, powdering and development of cracks [2, 3]. A non-invasive investigation of layer-by-layer of a painting may allow one to gain a better insight in defects formation and also to understand the specific modus operandi of the artist. Among numerous non-destructive diagnostics [4], active infrared (IR) thermography may be mentioned as a well-established technique [5, 6], which may provide a fast inspection of large surfaces.

In our studies, an active pulsed thermography system (PTvis setup of EDEVIS GmbH, provided by Thermoconcept) for the specimen analysis was used (**Figure 1**). This system offers non-destructive testing solutions for the evaluation of components or assemblies and subsurface defect detection without damaging the materials. The active thermography solution combines mid- and long-wavelength infrared TELOPS cameras (MWIR or LWIR), deferent external excitation sources solutions and user-friendly post-processing software. External excitation sources such as flash and halogen lamps or lasers are available along with electromagnetic and mechanical sources (inductive coils, ultrasound generators). A wide range of solutions is available from basic systems to compact integrated systems with a variable level of automatization depending on the measurement needs and constraints.

Active IR thermography for Heritage Science studies can provide inspection of subsurface layers. Due to the sensitivity of this method to different pictorial materials, it is possible to probe down to the preparatory layer to inspect possible under-drawings, subsurface defects and the presence of nails as well. During active IR thermography application, the surface of the inspected painting panel is heated by an external source in order to produce a dynamic thermal response, which can be detected and recorded with an infrared camera. A mid- or long-wave Infrared (MWIR or LWIR) camera is used to measure a thermal flux emitted by the specimen as a response to the excitation. Temperature estimation is performed on IR radiation emitted from the surface. MWIR or LWIR camera displays and records the corresponding evolution of thermal contrast. However, LWIR measurements are usually less sensitive to ambient illumination, while MWIR band exhibits a lower optical diffraction and background radiation, which results in a sharper imaging with a higher contrast for LWIR camera measurements. Also, using the spectral distribution of the emitted energy, it may be estimated that a blackbody at 293 K emits only 1.1% of its energy in MWIR band, compared to about 42.4% in LWIR band.

The results of our study have demonstrated that active thermography in MWIR or LWIR may allow both characterization of internal defects and in situ inspection of paintings for detection of under−drawings, pentimenti and analysis of preparatory layers and canvas, thus providing valuable insights into Artwork history and useful pre-restoration information. Active thermography was demonstrated as being appropriate for characterization of various defects on painting layers and detection of underdrawings, pentimenti and canvas. Such multispectral approach provided simultaneous complementary information on the specimen under inspection.

2. Materials and methods

2.1. Active Thermography Setup

An active thermography setup (**Figure 1**) was used for characterisation of multi-layered structures of panel paintings and analysis of defects caused by aging and environmental effects. Two oil compositions painted on canvas (**Figures 2a-b**) were provided by Centre de Recherche et de Restauration des Musées de France (C2RMF) in the Louvre museum. Pulsed Thermography PTvis setup (EDEVIS GmbH) was applied to provide and inspect a dynamic thermal response, which was recorded by mid- and long wavelength infrared TELOPS cameras. Control, synchronization and data analyses were provided by EDEVIS DisplayImg Professional software provided by Thermoconcept.

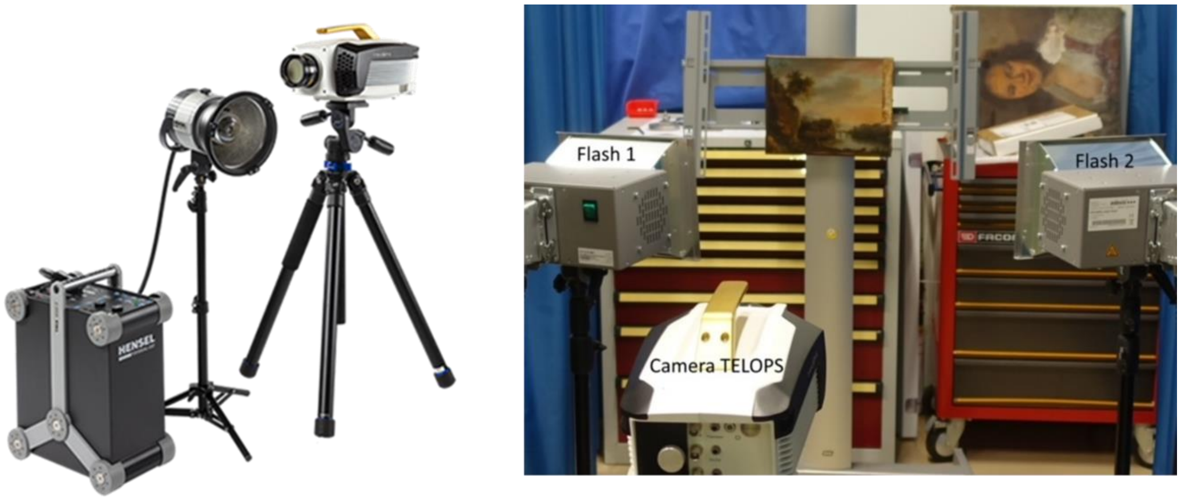

Figure 1. Active thermography set up and experimental configuration including the paintings, TELOPS camera and two flash lamps.

Active Pulsed Thermography (PT) was used for two−spectral band (LWIR and MWIR) inspection of the painting specimen. PT method may be seen as one of the earliest one among those of active thermography [7]. The method is often referred to as “flash thermography” since in its classical configuration, a set of industrial flashes is used to heat the surface of the inspected object. Pulsed Phase Thermography (PPT) [8] was used as an advanced processing technique to analyse the acquired data. In our studies, two flash-pulse excitation sources were used. The maximum output power of each excitation source was 3 kJ, and a flash-pulse duration was about 3 ms. Thermal response of each specimen was measured by high-speed, high-sensitive cooled IR cameras (TELOPS), such as MWIR (FAST M350, 1.5-5 µm) and LWIR (FAST L200, 7.5-11.5 µm), having 640 × 512 pixels resolution and ~20 mk of Noise Equivalent Temperature Difference (NETD) at 25 °C. An optical lens (50 mm focal length) and the camera/sample distance in the range of 0.8 - 3 m allowed one to obtain the spatial resolution between 200 and 900 µm/pixel. The camera frame rate was 100 Hz, and the IR acquisition duration was about 30 s.

2.2. Samples.

In this work**,** two panel paintings provided by C2RMF were analysed (**Figures 2a and 2b**). The painting in **Figure 2.a** is about 26 cm x 32 cm, the XIX century. The top right zone of the painting was peeled off for the previous analysis (not discussed in this paper). The painting in **Figure 2.b** is about 46 cm x 55 cm and represents a replica (46 cm x 55 cm) of Frans Hals, “*La Bohémienne*”, (1628-1630). Some zones on this painting were also intentionally peeled off for the previous analysis (not discussed in this paper).

Figure 2. Photographs of the paintings analysed by active pulsed thermography, (a) - XIX century painting (26 cm x 32 cm), XIX century, (b) - replica of Frans Hals *La Bohémienne* (46 cm x 55 cm).

3. Results.

3.1. Time-domain infrared measurements.

The replica of Frans Hals "*La Bohémienne*" painting (see **Figure 2b)** was under Pulsed Thermography experiments performed in reflection mode. The panel painting sample with the three zones with different painting thickness (indicated as red, green, and blue circles in **Figure 3**) was submitted to the thermal pulse generated by the flash lamp, which resulted in non-stationary heat flow in the sample. Then, during the cooling process, the thermal infrared radiation emitted by the replica "*La Bohémienne*" painting was recorded by the IR camera as a function of time. The distance between the camera and the panel painting was one meter in this case. Both the flash excitation and the temperature profiles of the three zones of different painting thickness were measured before, during and after the flash lamp excitation (**Figure 3**, the lower panel). Continuous non-periodical signal decays can be seen after the temperature increase generated by the flash. The cooling dynamics in the three zones was different, which shows the different heat propagation properties in the zones with different thermomechanical properties and thickness.
For a further analysis, the obtained time dependent data were transformed to the frequency spectra by using the dimensional discrete Fourier transform (DFT). This analytical method is referred to as Pulse-phase-thermography (PPT).

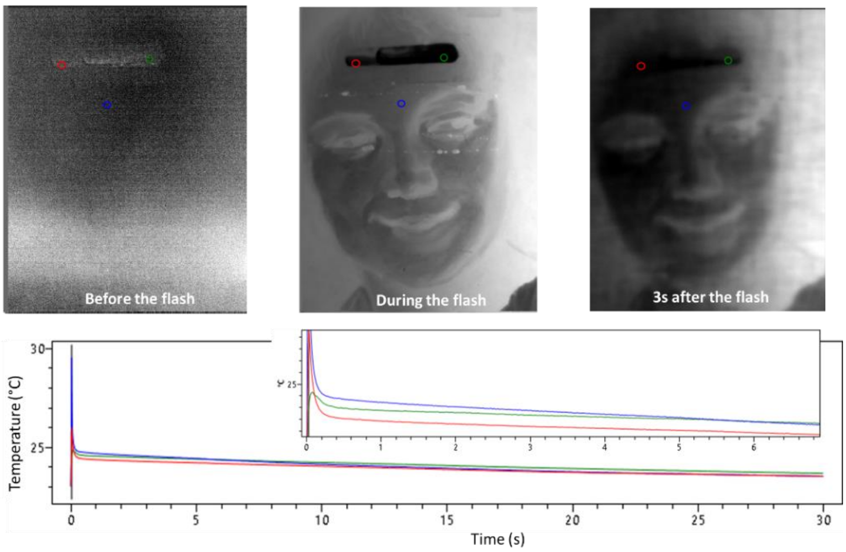

Figure 3. Temperature map of the replica "La Bohémienne" recorded before, during and after the flash lamp excitation (upper panels) at 1m distance between the camera and the painting, and Transient temperature curve of the three zones of different thickness (indicated by red, blue, green circles) with a zoom from 0 to 7 sec (lower panel).

3.2. Phase and Amplitude results obtained by Discrete Fourier transform (DFT)

The data analysis of pulsed thermography obtained with the replica "*La Bohémienne*" was made with the EDEVIS DisplayImg Professional software (provided by Thermoconcept). This software provides an optimum workflow, while offering a wide range of powerful functions to analyse and post-process images and image sequences. The Discrete Fourier transform (DFT) was used to compute the amplitude and the phase images. **Figure 4** (lower panel) presents the example of phase and amplitude data obtained from the measurements of the replica "*La Bohémienne*". For pulsed thermography analysis, the phase data are of particular interest because they are less affected by environmental reflections, emissivity variations, non-uniform heating, surface geometry and orientation if compared to raw thermal data. This consideration is of particular importance for a quantitative analysis. From **Figure 4,** one can see that the phase image reveals more details (for example, possible pencil drawings underneath) as compared to the amplitude image.

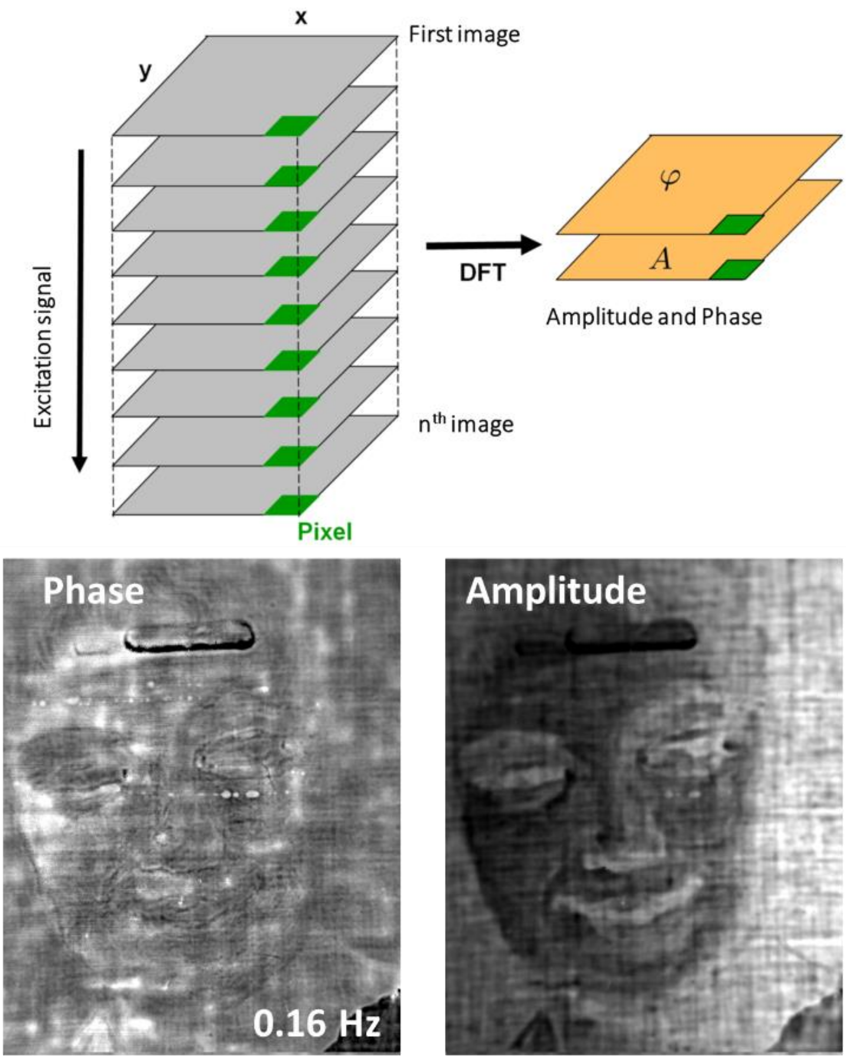

Figure 4. Workflow of the Pulse-phase-thermography used by DisplayImg Professional software. The example of phase and amplitude images computed by the software for ν = 0.16 Hz for a distance between the painting and the camera of one meter.

3.3. Comparative study of mid-wave and long-wave results

Both the two panel paintings (see **Figure 2a** and **Figure 2b**) were under comparative analysis of mid-wave and long-wave results. To study different spatial resolutions and thermal behaviour of the painting surface during and after the thermal pulse excitation, the specimens were analysed at different distances from the IR camera. The obtained data were processed by DisplayImg Professional software. Measurements should be specially processed in order to improve signal-to-noise ratio, to enhance defect contrast, to make adjustment correction for artefacts, and to characterize the defects.

Phase images were of a particularly interest since most of the detrimental thermal and optical effects observed in pulse phase thermography could be considerably reduced. **Figures 5.a-f** (for the replica "*La Bohémienne*" painting) and **Figures 6.a-f** (for the XIX century painting) present the Fourier transformation and phase analysis results that were obtained with a MWIR camera (**Figures 5.a-c** and **Figures 6.a-c**) and LWIR camera (**Figures 5.d-f** and **Figures 6.d-f**) at a distance camera-painting of 3 m and 1.7 m respectively. In pulse phase thermography, the deeper layers are seen at low frequencies, while shallow ones are seen at high frequencies.

For the replica painting**, Figure 5b** (MWIR) and **Figure 5e** (LWIR) clearly show the textile support of the canvas. The canvas fibres are observed with the same resolution in both infrared bands, thus demonstrating the potentiality of pulsed infrared thermography to penetrate the paintings from the front side down to a decent depth for *in situ* measurements. It should be noted that the replica "*La Bohémienne*" was more clearly seen on MWIR phase images at all frequencies than that on LWIR ones. The paint layers were intentionally removed in a limited zone to analyse the preparation layer. In this layer, phase images of a stronger contrast were obtained in LWIR than in MWIR. Identical defects were also seen at 2 Hz both in MWIR and LWIR, but the contrast was higher in LWIR. For the XIX century painting, pulse phase thermography imaging also allowed us to identify the canvas in two infrared bands (MWIR and LWIR in **Figure 6b** and **Figure 6e**, respectively). Numerous random dark spots (**Figure 6c** and **Figure 6f**) may be interpreted as a possible presence of glue droplets used to attach the old canvas on the new one. Indeed, previous investigations have shown that the original painting underwent a transposition in early XX century, which is a common practice in restoration process. And this painting is contested undergo this process. The pulse phase thermography imaging of this painting has revealed that the painting pigments are seen more clearly in MWIR phase images (see **Figure 6a** with a tree painted at the top left). In contrast, the painting pigments in LWIR phase images are practically not visible (see **Figure 6d**, for comparison). Our analysis revealed the presence of a pentimento (**Figures 6.d-e**, on the lower right part with a church steeple shape). The pentimento appears to be less detectable in MWIR images. Other features, such as, underdrawings and pencil marks were also detected during the analysis of the XIX century painting.

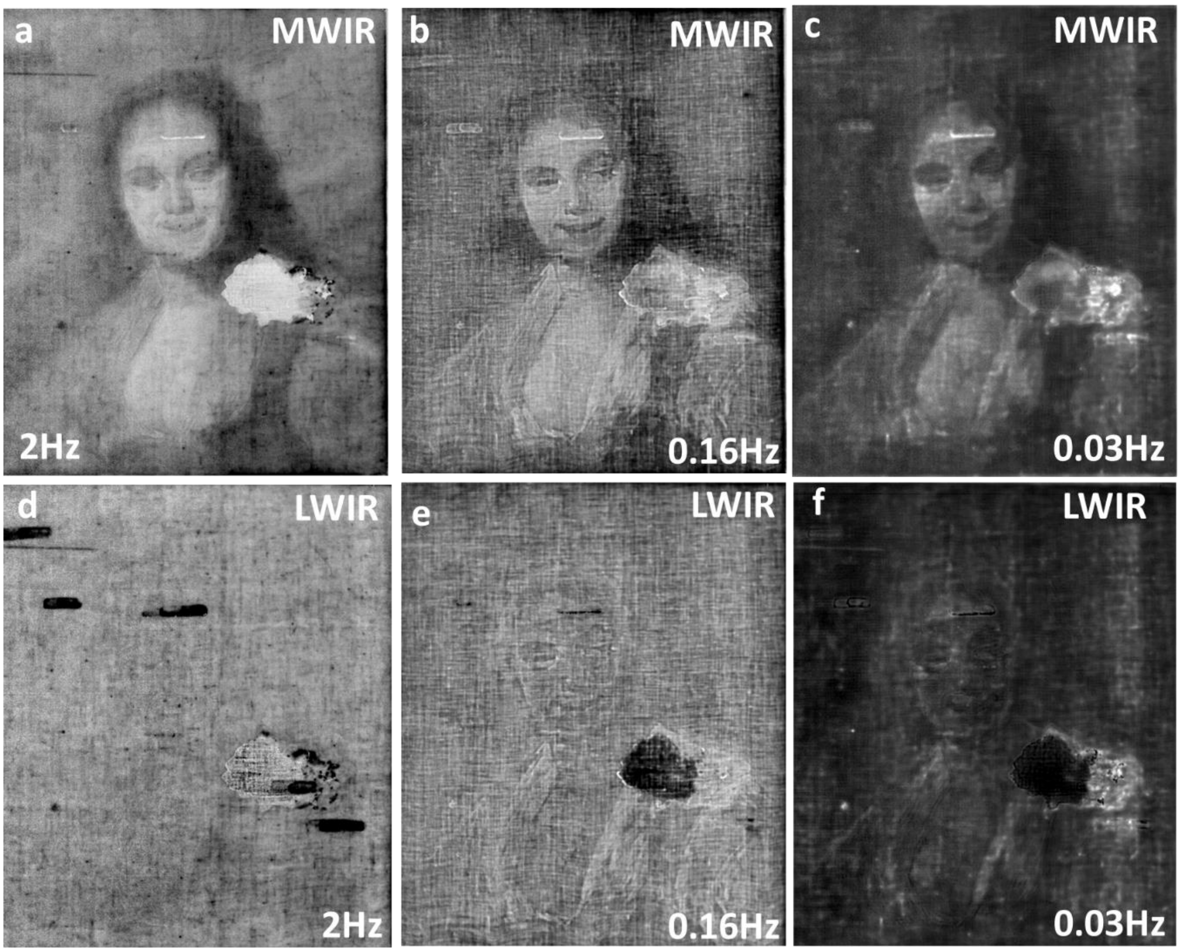

Figure 5. Phase images of the Franz Hals replica obtained with a MWIR camera (a, b, c) and LWIR camera (d, e, f) for different ν (Hz) at a distance camera-painting of 3 m .

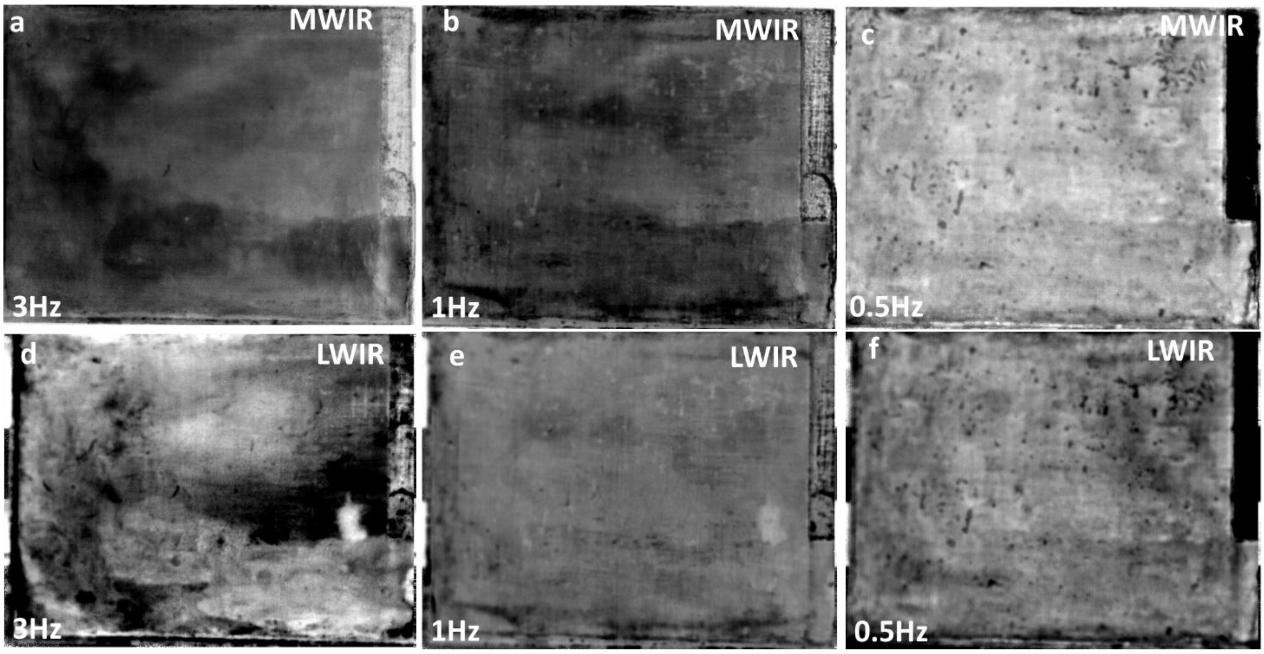

Figure 6. Phase images of the XIX century painting obtained with a MWIR camera (a, b, c) and LWIR camera (d, e, f) for different ν (Hz) at a distance camera-painting of 1.7 m.

4. Conclusions

In our studies, the combined approach based on Active Thermography in combination with MWIR and LWIR multispectral detection was used for non-destructive characterisation of multi-layered paintings panels and *in situ* analysis of their defects. Two oil compositions painted on canvas were under inspection.

The experimental results of our study revealed that analysis in MWIR and LWIR may provide complementary information due to the differences between imaging in these spectral bands, the background ambient radiation and spectral response of painting constituents. It was demonstrated that pulsed thermography in MWIR or LWIR may provide internal defects characterization, *in situ* inspection of paintings for detection of underdrawings, pentimenti and analysis of preparatory layers and canvas, thus providing valuable insights to heritage science and restoration community. Thus, pulsed thermography may be regarded as a promising analytical method for paintings inspection and efficient methodology to obtain valuable information on historical paintings, their preparation and painting procedure, preservation conditions, and defect analysis. The obtained data can be stored as Artwork unique finger print, which can help the curator to follow, identify and document the artworks.

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