2022 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
University of Calabria, Italy, October 19-21, 2022

Innovative diagnostics through Hypercolorimetric Multispectral Imaging and Pulse-compression Thermography to support the restoration of a 16th wall painting in Palazzo Gallo (Bagnaia, Italy)

Riccardo Vettraino[1], Valeria Valentini[1], Paola Pogliani[1], Marco Ricci[2], Stefano Laureti[2], Serena Calvelli[2], Giovanni Messina[2], Luca Lanteri[3], Claudia Pelosi[3]

[1] University of Tuscia, DIBAF Dept., Via San Camillo de Lellis snc Viterbo, Italy, vettrainor@gmail.com; valeria.valentini@unitus.it; pogliani@unitus.it
[2] University of Calabria, DIMES Dept., Via P. Bucci, Rende (CS), Italy, marco.ricci@unical.it; stefano.laureti@unical.it; calvelliserena@gmail.com; giovanni.messina1998@gmail.com
[3] University of Tuscia, Dept. DEIM, Via del Paradiso 47, Viterbo, Italy, llanteri@unitus.it; pelosi@unitus.it

Correspondence: pelosi@unitus.it

***Abstract* – This paper summarizes the main results of the study, restoration and diagnostics applied to the 16th century wall painting (a portion of the frieze and the Riario coat of arms) in Palazzo Gallo (Bagnaia, Viterbo – Central Italy) recently concluded and object of a master's degree work in Conservation and Restoration of Cultural Heritage. Innovative imaging techniques were used for the first time on a wall painting on-site: Hypercolorimetric Multispectral Imaging (HMI) and Pulse-compression Thermography (PuCT), combined with more traditional analysis. Multispectral imaging allowed for mapping the conservation status before and after the removal of the *scialbo* layer that covered the original paintings. It also allowed to compare between different areas of the painting and to verify the effectiveness of the cleaning. PuCT allowed to detect cracks and discontinuities in the ground layers and to evaluate the depth of such anomalies giving a valuable support in the consolidation step.**

I. INTRODUCTION

In the present paper the main phases of the restoration process of a valuable 16th century wall painting will be presented and discussed, which are highly interconnected and essential in any intervention on artworks: (i) the study of the historical and artistical context of the painting; (ii) the analysis of the materials and techniques of the artwork through direct observation, comparison with similar and coeval cases, diagnostics and laboratory analysis; and (iii) interventions on the painting (consolidation, cleaning, final aesthetical restitution). Starting from this approach, the historical and artistical contest of the wall paintings must be given. These are in Palazzo Gallo, Riario room, in Bagnaia a small hamlet in Viterbo (Central Italy) (Fig. 1) [1].

Fig. 1. The wall paintings before the restoration. Photo by Gaetano Alfano.

Palazzo Gallo was built within 1500-1520 AC, probably commissioned by Giuliano Gallo and financed by Cardinal Raffaele Riario, lord of Bagnaia. The paintings in the Sala Riario, the second most important in the Palazzo and the most richly decorated, consist of an antique-style frieze and the great coat of arms of Raffaele Riario, flanked by that of the Gallo family and the civic

coat of arms of Bagnaia, just above the fireplace. The coats of arms are carried by putti through ribbons and the decoration in its simplicity is rich and varied. In 1576 Sulpizio Gallo, Giuliano's heir, sold the building to the Municipality "a complex of over twenty rooms (...) beautiful paintings in the reception rooms, a huge fireplace in the living room and a delightful porch on the square" [2, p. 61]. The importance of Bagnaia is given by the abundance and refinement of the artworks created there. After that date, there is not much information on the history of the Palace, but it is certain that the rooms were used as private residences for those displaced by the war since 1943 and consequently adapted by adding balconies, partitions, and installing an economic kitchen. Furthermore, during this period, many superimposed layers were added to cover the original paintings in the area above the fireplace more and more heavily to hide them largely. The antiquity of the Palace and its conservation events led to a serious situation of adhesion defects and deep cracks, provoking a deformation of the plaster in the upper right area, mainly due to the presence of the fireplace and the flue. In addition, the central part of the wall is made up of bricks arranged by cutting, otherwise the rest of the work is built on solid masonry in blocks made of *peperino*, the typical local stone of Viterbo. Finally, the use of the fireplace and the kitchen produced carbon black deposits on the painting surface which, together with an altered protective applied in the past, made it difficult to read the artwork, as visible in the image before the restoration activities started (Fig. 1).

The recently ended restoration of the paintings was a very important chance to investigate the materials, the techniques and to closely observe all details giving new light on this not-still-attributed wall paintings. The restoration gave the possibility to make a comparison with other paintings and to suggest possible dating (within 1530) and possible artist workshop for the realization of the artworks [1, pp. 71-79]. The study of the materials of the paintings and of their state of preservation was supported by the diagnostics that combined innovative imaging techniques, *i.e.* Hypercolorimetric Multispectral Imaging (HMI) and Pulse-compression Thermography (PuCT), used for the first time together to investigate a wall painting on-site, with traditional analysis such as passive thermography, X-ray fluorescence spectroscopy, micro-stratigraphic analysis and Fourier transform infrared (FTIR) spectroscopy. In the present paper, the discussion will be focused mainly on the more innovative imaging techniques, HMI and PuCT, with some hints to the results gathered by the spectroscopic analysis.

II. MATERIALS AND METHODS

The wall paintings were investigated before and after the intervention needed for the various restoration steps. The adopted approach was aimed at obtaining detailed information through non-invasive and non-destructive analysis on the entire surfaces, being this approach fundaments when examining works of art [3-4]. For this reason, multispectral imaging and thermography were selected to investigate both the painting layers and the ground. Multispectral imaging was performed by HMI technique based on a modified digital (full range from 300 to 1000 nm) camera Nikon D800 equipped with 17-35 zoom lens. The HMI apparatus is composed also of three filters named A (UV-Vis), B (Vis-NIR) and UV-IR cut, this last used in combination with filter A for obtaining the ultraviolet fluorescence (UVF) acquisition [5]. The acquisition set is completed with standard white patches and a color-checker positioned in the scene, and an illuminating system based on modified flashes, as described in [6]. For obtaining the UVF images, two CR230B-HP 10W UV LED projectors, peak emission at 365 nm, were used. The acquired images are then calibrated through SpectraPick® software that produces seven high resolution spectral images in .tiff format from UV to NIR at 350, 450, 550, 650, 750, 850 and 950 nm and the RGB image. The entire folder is then loaded into the processing software, named PickViewer®, that provides several diagnostic imaging and statistical tools to produce various outputs depending on the requirements of the restoration.

The PuCT setup is composed of a portable TiePie HS5 Handyscope for both generating the coded waveform and grabbing the thermograms from the FLIR T660 thermal camera. A pseudo-noise code modulates the ON/OFF state of a TDK Lambda GEN 750 W power supply. In this way, ten halogen lamps have been driven to emit light following the coded sequence for an overall heating stimulus duration of 440 s. The heating system and the thermal camera have been placed on the same side at about 600 mm from the inspected surface, so that the resulting inspection was performed in reflection mode. A laptop has been used to store the data using an in-house routine developed in LabVIEW. The results are reported using a grey colormap, where the darker pixels are related to lower temperature/emissivity. Further details of the experimental setup and of the technique's principles are reported in [7-9].

X-ray fluorescence analysis (XRF) was performed by Dr. Claudio Falcucci of MIDA society with a portable apparatus equipped with an Au anode operating at 40 kV; acquisition time 50 s.

Fourier transform infrared spectroscopy (FTIR) was performed on micro-samples with a Nicolet Avatar 360 instrument equipped with a diffuse reflectance accessory. The spectrometer operates in the 400-4000 cm^{-1} region with a resolution of 4 cm^{-1}. Potassium bromide was used as background.

III. RESULTS AND DISCUSSION

The first relevant result was obtained with the UVF

acquisition before the cleaning. In fact, UVF images give fundamental information about the state of preservation of the painting surfaces, on the presence of retouched areas and grouting, etc. [5]. By observing the UVF images of the two paintings, the first evidence is related to an intense yellow response in the coat of arms of Bagnaia and Gallo family that can be associated to a repainting (Fig. 2). Pointwise XRF analysis confirmed such hypothesis as in the areas with the yellow fluorescence the presence of zinc that could associated to the pigment based on the oxide of this element (ZnO) was revealed [1, pp. 103-105] (Table 1, Point 5). XRF was performed in situ on twenty-two points, as reported in [1]. Here, due to the limited space, the most representative colours of the painting palette and of the repainting are reported.

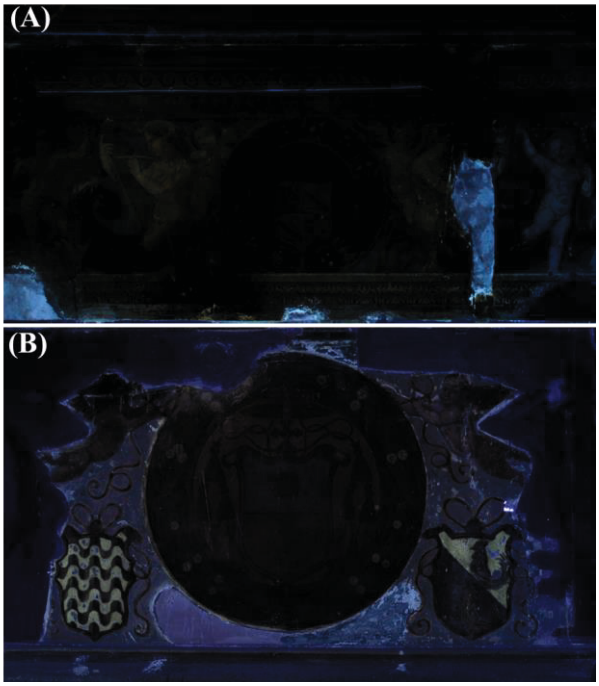

Fig. 2. UVF photomosaic of the wall paintings before the restoration. The upper frieze (A) and the Riario coat of arms (B).

The areas characterised by a blue fluorescence correspond to grouting made to compensate for the lack of painted plaster. UVF also shows a general dark brown response of the surface due to superimposed layer over the original paintings. UVF was repeated at the end of the intervention, when the cleaning operation for removing the different *scialbo* (slaked-lime) layers, applied in previous restoration and re-making on the wall, was almost completed. At this stage, UVF highlighted a general increasing of the painting visibility due to the removal of the brown layer, especially in correspondence of the background in the lower painting that acquire both a blue and pale-yellow fluorescence probably associated to organic binders (Fig. 3).

Table 1. Results of XRF analysis on some selected and representative zones of the wall paintings. The XRF measurements were performed by Dr. Claudio Falcucci of MIDA society.

Point	Colour	Detected elements	Possible pigment
	Light green (repainting) Point 5	Zn (main) Ca, Fe, Sr	Zn-based pigment, probably zinc-white
	Light blue Point 16	As (main) Sr, Fe, Co	Blue smalt
	Red Point 2	Hg (main) Fe, Ca, Sr	Hg- based red, vermillion /cinnabar
	Green Point 4	Fe (main) Sr, Ca, Pb	Green earth
	Green (possible repainting) Point 8	Cu (main) As, Sr, Ca	Cu-based green, Emerald Green or Sheele's green

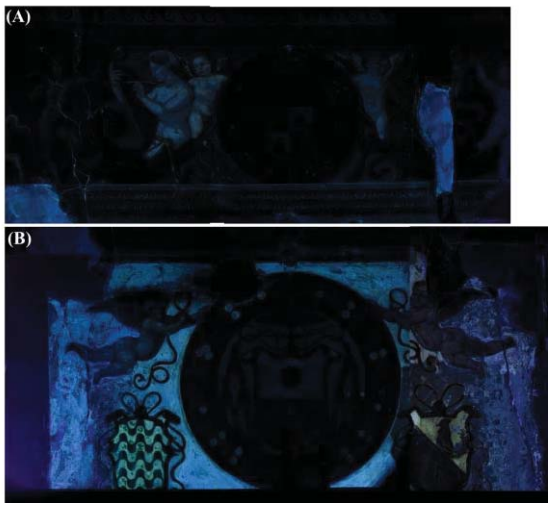

Fig. 3. UVF photomosaic of the wall paintings after the almost complete removal of scialbo. The upper frieze (A) and the Riario coat of arms (B).

UVF in the last step of the cleaning was very important for addressing the final interventions on the surfaces.

The presence of organic materials has been confirmed

by FTIR spectroscopy performed on micro-samples of the paintings. FTIR showed traces of proteins (characteristic bands at 1644 cm^{-1}, 1563 cm^{-1} and 1448 cm^{-1} partially overlapped with those of gypsum and calcium carbonate), lipidic substances (oils and/or wax with the characteristic strong signatures at 2919 cm^{-1} and 2853 cm^{-1} due to C-H stretching of long-chain molecules) and a lot of gypsum, (bands at cm^{-1}: 3531, 3400, 2240, 2317, 1623, 1151, 1120, 672, 603 and 467) probably used in the grouting (Fig. 4).

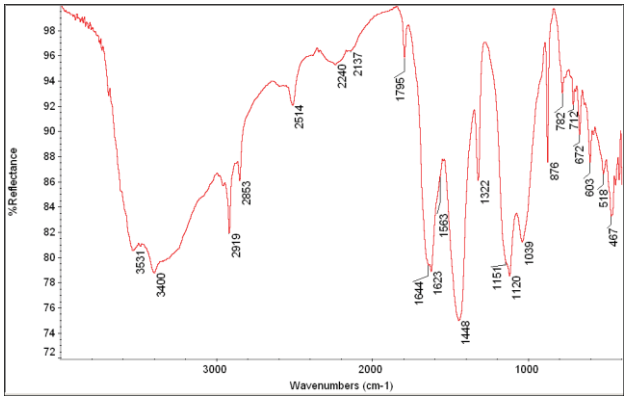

Fig. 4. FTIR spectrum of a sample taken from the upper frieze in correspondence of a brown surface layer.

The presence of oxalates further confirms the organic materials on the surface of the paintings (characteristic bands at cm^{-1}: 1623 -in common with gypsum-, 1322 and 782).

In the same stage of the restoration, HMI was also applied to investigate the material distribution, to map the *scialbo* layer still present on the surface and to check the effectiveness of the cleaning intervention. Specifically, this last aim was reached by applying the colour measurement algorithm of PickViewer® software to un-cleaned and cleaned areas to compare the chromatic coordinates. PickViewer® was used for obtaining the infrared and ultraviolet false colour (IRFC and UVFC) images of the painting that allowed to hypothesize the composition of some pigments: blue smalt that appears vine colour in IRFC (Fig. 5), vermilion/cinnabar that becomes yellow and different greens (earths and Emerald green) that exhibited different response in false colours.
All these pigments were confirmed by XRF spectroscopy that detected cobalt and arsenic for smalt, mercury for vermilion/cinnabar, iron for green earth and copper associated to arsenic for Emerald or Scheele's green (non-original pigment), (Table 1).

PickViewer® was used also for mapping different areas on the paintings, such as the blue colour (due to smalt) in the Riario coat of arms and the yellow (characterized as ochre) in the frieze, by applying the spectral similarity algorithm (Fig. 6).

Fig. 5. IRFC images of the wall paintings after the almost-complete removal of scialbo, obtained with PickViewer®.

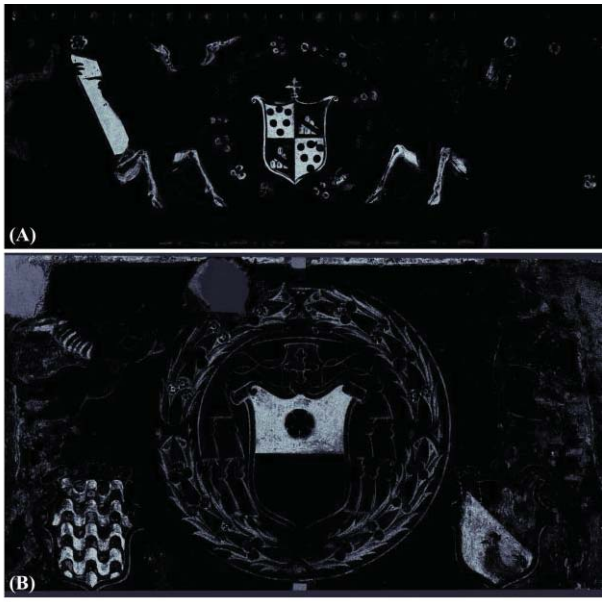

Fig. 6. Result of the spectral similarity algorithm applied to the yellow ochre in the frieze (A) and in the blue smalt in the Riario coat of arms (B).

I. THE RESTORATION

The restoration was firstly addressed to solve the most urgent critical issues of the paintings: the serious adhesion defects in the frieze with the deformation of the plaster and the removal of the *scialbo* layer applied around the paintings above the fireplace, made evident in the PuCT emissivity images (Fig. 7).

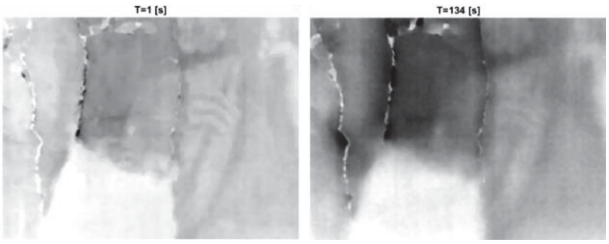

Fig. 7. Emissivity images at 1 s and 134 s of a portion of the frieze obtained with PuCT before consolidation that show deep cracking, detachment and deformation.

Cleaning was carried out with water and 2% Tween 20 surfactant supported by Japanese paper (17 gr.). Repeating the operation as necessary, this allowed to fully examine the nature and quantity of the superimposed layers. A total of 13 recent layers were found, sometimes discontinuous, then mechanically removed with a scalpel. The *scialbo* removal (*descialbo*) was a time-consuming step and was performed step-by-step with the use, as usually in the restoration practice, of stratigraphic test areas, small *descialbo* zones studies on similar decorations for epoch and context and imaging diagnostics (Fig. 8). In Fig. 8, the yellow colour underwent a significative increase of saturation with values of a* and b* chromatic coordinates changing from 6.05 and 11.49 to 22.47 and 26.10 respectively; the values are calculated by the specific algorithm of PickViewer® and reported in the bar under the image in the graphical user interface of the software. The values before cleaning are indicated as L1, a1 and b1 and those after cleaning as L2, a2 and b2. The colour measurements are possible thanks to the procedure used by HMI system based on calibration of the acquired images with the use of reference white patches and the color-checker. This procedure allows to obtain calibrated images centered at specific wavelengths whose reflectance and colour data are characterised by high precision (verified by Profilocolore by a laboratory spectroradiometer) [10-11].

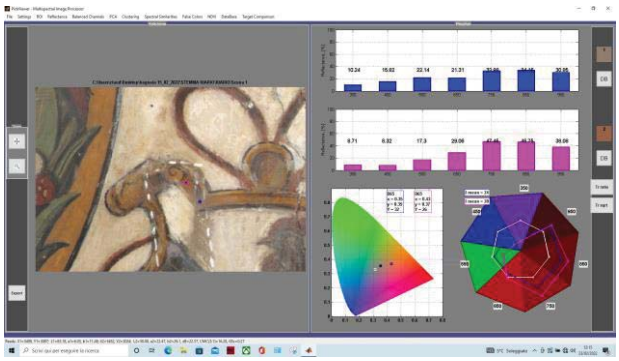

Fig. 8. Chromatic and reflectance comparison between cleaned and uncleaned areas on the yellow colour in Riario coat of arms showing a clear increase in saturation due to the removal of the surface soot layer.

In the figure 8 also the CIE1931 xyY colour coordinates are reported together with the position of the two selected points (the blue is referred to the uncleaned area and the pink to the cleaned one). The values of reflectance are reported in the upper right side of the graphic user interface of PickViewer® by using blue (uncleaned area) and pink bars (cleaned). The main changes occur at 650 nm (increase of reflectance) and in the IR further indicating an increase of yellow colour saturation.

At the end of the removal intervention, the pictorial layer with the original colours and new details hidden by time has been restored. The consolidation of the preparatory layers was important to recover the artwork and was carefully studied by thermographic techniques. Through injections of various hydraulic mortars (from Ledan series), applied from bottom to top, the adhesion between the preparatory layers was restored, with special attention to the deformation area. Here, through the creation of pins made of Ledan Adesiva, the major gaps were fixed. After setting the product, a filling with a mixture of Ledan Ristat B and Ledan Ristat Extra was applied. This mixture has excellent adhesive, filling, and light characteristics. In case of well-circumscribed detachments, the LEDAN TB1 was used by monitoring the consolidant penetration with the thermal camera to verify the effectiveness of the treatment (Fig. 9).

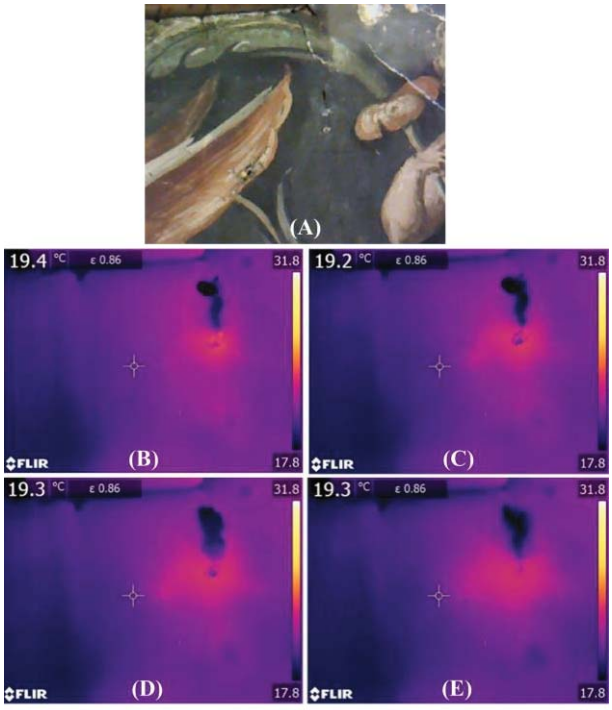

Fig. 9. RGB image (A) and timeline of thermograms (B), (C), (D)and (E) of the area investigated with passive thermography where the (warmer) Ledan is visible spreading in the preparatory layers after injection by a syringe. (E) has been taken after 5 minutes.

The emissivity images over time obtained with PuCT, show some anomalies (highlighted by yellow circles), and the appearance of the crack, after having infiltrated water and alcohol, and how the dark areas are less intense after the injection (Fig. 10) [12].

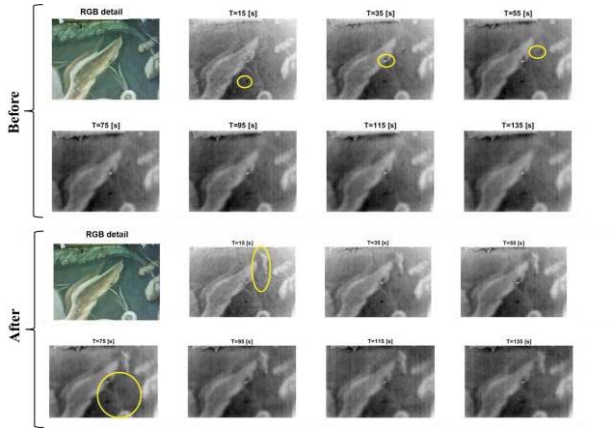

Fig. 10. Sequence of emissivity images at different times obtained through PuCT before and after Ledan injection.

Fig. 11. The wall paintings after the restoration. Photo by Gaetano Alfano

After this consolidation work on the painting ground layers, the previous grouting materials, unsuitable and incompatible with the original materials, were mechanically removed. The brick support was restored in correspondence with the through-hole of the kitchen and the large grouting was subsequently treated with a sub-level approach. The painting-level grouting was mimetically reintegrated while all the abrasions, lacunae, whitening and lack of patina were treated with lowering of tone. With an overall chromatic balance, the painting is once again legible, lively in the colours, fully showing the compositional rhythm and the refined pictorial taste of the workshop of the artists working in Palazzo Gallo (Fig. 11).

REFERENCES

[1] R. Vettraino, “Il restauro del fregio a grottesca e e dei dipinti sulla parete del camino nella Sala Riario di Palazzo Gallo a Bagnaia”, Master degree Thesis, University of Tuscia, Viterbo, Italy, 2022.

[2] V. Frittelli, “Bagnaia Cronache d'una Terra del patrimonio”, Frittelli V., Bagnaia (Viterbo), Italy, 1977.

[3] C. Miliani, F. Rosi, B.G. Brunetti, A. Sgamellotti, “In Situ Noninvasive Study of Artworks: The MOLAB Multitechnique Approach”, Acc. Chem. Res., vol. 43, No. 6, pp. 728-738.

[4] D. Thickett, C.S. Cheung, H. Liang, J. Twydle, R.Gr. Maev, D. Gavrilov, D “Using non-invasive non-destructive techniques to monitor cultural heritage objects”, Insight - Non-Destructive Testing and Condition Monitoring, vol. 59, No. 5, 2017, pp. 230-234.

[5] L. Lanteri, C. Pelosi, “2D and 3D ultraviolet fluorescence applications on cultural heritage paintings and objects through a low-cost approach for diagnostics and documentation", Proc. SPIE 11784, Optics for Arts, Architecture, and Archaeology VIII, 2021, Article number 1178417, pp. 1-10.

[6] S. Laureti, C. Colantonio, P. Burrascano, M. Melis, G. Calabrò, H. Malekmohammadi, S. Sfarra, M. Ricci, C. Pelosi, “Development of integrated innovative techniques for the examination of paintings: the case studies of The Resurrection of Christ attributed to Andrea Mantegna and the Crucifixion of Viterbo attributed to Michelangelo’s workshop”, J. Cult. Herit., vol. 40, 2019, pp. 1-16.

[7] S. Laureti, S. Sfarra, H. Malekmohammadi, P. Burrascano, D.A. Hutchins, L. Senni, G. Silipigni, X.P.V. Maldague, M. Ricci, “The use of pulse-compression thermography for detecting defects in paintings”, NDT & E Int., vol. 98, 2018, pp. 147–154.

[8] S. Sfarra, S. Laureti, G. Gargiulo, H. Malekmohammadi, M.A. Sangiovanni, M. La Russa, P. Burrascano, M. Ricci, “Low Thermal Conductivity Materials and Very Low Heat Power: A Demanding Challenge in the Detection of Flaws in Multi-Layer Wooden Cultural Heritage Objects Solved by Pulse-Compression Thermography Technique”, Appl. Sci., vol. 10, No. 12, article No. 4233, 2020, pp. 1-15.

[9] M. Ricci, S. Laureti, H. Malekmohammadi, S. Sfarra, L. Lanteri, C. Colantonio, G. Calabrò, C. Pelosi, Surface and Interface Investigation of a 15th Century Wall Painting Using Multispectral Imaging and Pulse-Compression Infrared Thermography, Coatings, vol. 11, article No. 546, 2021, pp. 1-24.

[10] M. Melis, M. Miccoli, D. Quarta, “Multispectral Hypercolorimetry and automatic guided pigment identification: some masterpieces case studies”, Proc. SPIE 8790, Optics for Arts, Architecture, and Archaeology IV, 2013, Article number 87900W, pp. 1-14.

[11] M. Melis, M. Miccoli, “Trasformazione evoluzionistica di una fotocamera reflex digitale in un sofisticato strumento per misure fotometriche e colorimetriche”, Colore e Colorimetria contributi multidisciplinari, Maggioli Editore, Santarcangelo di Romagna, 2013, pp. 28–38.

[12] G. Cadelano, P. Bison, A. Bortolin, G. Ferrarini, F. Peron, M. Girotto, M. Volinia, “Monitoring of historical frescoes by timed infrared imaging analysis, Opto-electronics review, vol. 23, No. 1, 2015, pp. 102-108.