The *Pulcinella* Diagnostic Project: Introduction to the Study of the Performances of Close-Range Diagnostics Targeted to a Wooden Physical Twin of a Carnival Historical Mask

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Abstract. The *Pulcinella* diagnostic project here presented aims at testing a wide range of methodologies, technologies, and instrumentations against the imaging diagnostics of the various natural and artificial features present in the wooden physical model reproducing an archetypical historical artifact and its most common defects and in homogeneities. Due to its experimental purposes, it configures as an open diagnostic protocol – or a protocol of protocols – allowing a scalability to as many tools as wanted and, within this approach, being able to compare standard and innovative diagnostics methods related to historical wooden sculptures. The first round of diagnostic techniques includes Structure from Motion photogrammetry, Multispectral imaging, active Infrared Thermography and Terahertz imaging. The first experimental datasets and their preliminary results are analyzed against their effectiveness and failures in retrieving and characterizing standardized, specific, and known defects and features of the wooden mask investigated.

Keywords: Sculptures diagnostics · Physical twin · Wooden artworks

1 Introduction

Non-destructive or even sometimes non-invasive diagnostics are the core techniques of protocols to investigate precious and delicate goods like the ones belonging to the Cultural Heritage (CH), from artifacts to landscapes.

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The physical parameters of the inspected bodies are particularly indicated for being non-destructively retrieved. The societal relevance of Cultural Heritage issues has recently made possible an overcrossing of traditional disciplinary limits to new methods and technologies which of-ten start from consolidated disciplines to resolve specific issues linked to the new diagnostic targets [1].

One of the less invasive diagnostic technologies is remote sensing. Nowadays, remote sensing methods are an evolving research field taking advantage of the knowledge contamination from many specializations related to surveys and technology [2].

The most immediate demand for the documentation of historical architecture or other volumetric assets is the reconstruction of detailed and reliable 3D models of the monuments or their elements, which can be achieved by remote sensing techniques like photogrammetry or Terrestrial Laser Scanner [3–8]. Photogrammetry is a technique that allows to metrically determine the shape and position of an object, starting from at least two distinct frames (stereoscopic pair) showing the same object. This technique is often used in cartography, geomorphology, architecture, and cultural heritage [9–12]. Structure from Motion (SfM) digital photogrammetry uses computer vision algorithms derived from computer graphics to extract the corresponding points in two or more overlap-ping images, deduce the photographic parameters, cross the corresponding points on multiple photos and find the coordinates in the space of the points themselves [13].

Moving to a wider range of targets to study, thermal infrared (IR) sensing is becoming an important tool for sensing the apparent surface temperatures of valuable assets and therefore to infer, at different scales, inhomogeneities below the visible surfaces [14]. The Infrared Thermography (IRT) technique operates with active or passive measurements of the IR radiation emitted by the object under study. From the acquired data, it is possible to obtain a reliable estimation of the main physical properties of the materials; in particular, both the thermal properties (e.g. conductivity, diffusivity, effusivity, and specific heat) and spectral properties (emissivity, absorption, reflection and transmission coefficients) of the material can be assessed. IRT acquisitions allow the assessment of various issues linked to monuments and artistic studies, like detection of moisture presence, cracks, voids, and foreign materials [3, 15−22]. The application of IRT to small objects reliably identified hidden defects or invisible restoration works [15, 22−27].

For intermediate to large depths geophysical and micro-geophysical techniques can retrieve inaccessible bodies with anomalous physical properties to their surrounding backgrounds for precious and delicate targets like for instance architectonic and archaeological sites [28–30].

One of the most recently emerging proximal sensing techniques in the field of Cultural Heritage inspection is based on the transmission and backscattering of electromagnetic (EM) waves at the terahertz frequencies (wavelengths ranging from 30 μm to 3 mm, across air) [31]. Terahertz (THz) technology is used on various kinds of archaeological or historical items allowing, under specific experimental setups, to image studies bodies at various very small depths and to produce tridimensional dataset of the recorded EM signals representing the superficial stratification of the materials of the investigated artifacts [16]. Penetration depths on small artifacts can reach the supporting structures and image their spatial in homogeneities but, thanks to its very high resolution, it is also

possible to investigate and distinguish between the various pictorial layers of precious artworks [16, 31–34].

Multispectral (MS) remote and proximal sensing is a big family of techniques able to investigate precious surfaces at the widest dimensional ranges covering transnational landscapes to paintings surfaces. At the smallest depths, multispectral proximal sensing inspects the surface finishes through their interaction with the electromagnetic radiation recorded at different wavelengths, both visible and invisible to the human eye, across the EM spectrum [35, 36]. MS proximal sensing applied to CH targets includes a family of techniques that investigate the surface finishes by means of their responses to extremely high-frequency electromagnetic waves. Depending on frequency ranges used for energizing and/or sensing the artifacts, it is possible to choose transmission or re-flection experimental configurations, also depending on the thickness of investigated objects. Reflectometry, in the bands ranging from ultraviolet to near-infrared, can be used to highlight finishes defects and can enhance the readability of preparatory works, drawings, and paintings (sometimes even evidencing drawings completely invisible to eyes) by overcoming the shielding of exterior paintings layers and dirt patinas [9, 22, 34–39].

2 The *Pulcinella* Project – An Open Diagnostic Protocol

2.1 The Physical Model of the Traditional Carnival Mask

The mask under study aims to reproduce an archetype of the local sculptural tradition of small wooden artifacts. To this end, all construction techniques were guided by knowledge of the state of the ancient art for the creation and finishing of these wooden sculptures [40, 41].

Looking at the first wooden sculptures of the tradition, in ancient times, they start with coarse artifacts made from a single block of wood and arrive, in more recent times, to complex artifacts made from a set of adequately sculpted pieces. These pieces, bound with joints (Fig. 1a), will become the modeling, which in turn will be the support of the numerous finishing layers above (preparatory layers and pictorial layers), thus giving life to complex, innovative, and precious works of art created by scrupulously following the wise "Rules of Art" handed down to the master sculptors.

The mask created by a professional restorer reproduces the shapes and colors of a leather artisan scene mask with the features of *Pulcinella* (carnival mask of the Neapolitan tradition). In order to represent the most common defects or peculiar points in historical wooden sculptures, all the singular points of natural origin in the sculpture have been mapped and some simulated defects have been created (like the *pentimenti* in Fig. 1b, for instance). Their preliminary knowledge will allow validating the effectiveness of the various diagnostic approaches and tools. The wood chosen for the sculpture of the physical model of the *Pulcinella* mask is cypress. In Fig. 1c two orthogonal projections of the sculpture that is the object of the present research project are shown, with the main dimensions (before the pictorial finish).

2.2 A First Round of Proximal Sensing Diagnostics

The *Pulcinella* diagnostic project aims at testing a wide range of methodologies, technologies, and instrumentations against the imaging of the various natural and artificial

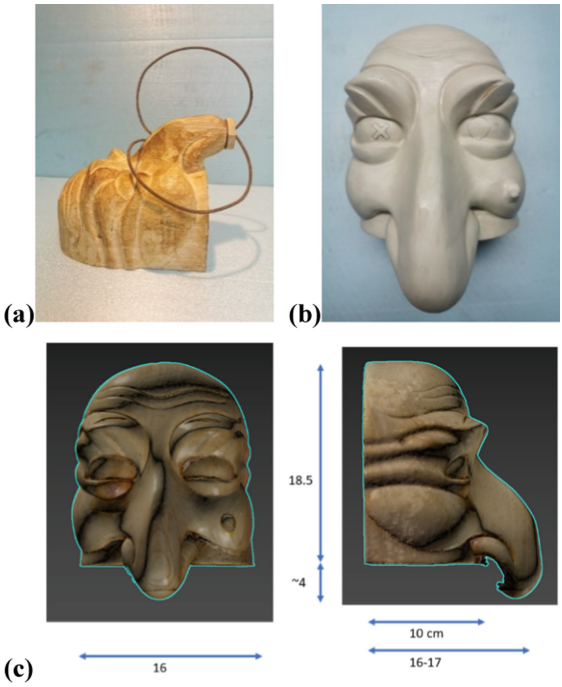

Fig. 1. Constructive phase of the *Pulcinella* physical model: roughly sculpted mask **(a)** and pre-painted mask with the second layer of *pentimenti* **(b)**. Main dimensions of the mask modeled **(c)**.

features present in the physical model simulating a real historical artifact and its most common defects and inhomogeneities.

The first round of diagnostic techniques is including:

- Structure from Motion (SfM) photogrammetry,
- Multispectral imaging,
- IRT,
- THz imaging.

In the followings, the authors present some of these first acquired datasets and occasionally some preliminary results.

3 Preliminary Datasets and Results

3.1 Photogrammetric Geometric Reconstruction of the Model

For the photogrammetric survey, the mask was filmed at the two main steps of realization (before spreading the pictorial plaster base and after painting) for the most complete documentation of the physical model and to crosscheck the diagnostic results with the two finishing levels.

The mask was positioned on a sheet of graph paper to correctly scale the final models. The videos were recorded by using a smartphone camera and moving that camera around the mask, recording all its solid angles (Fig. 2). This operation was repeated with the face oriented up-wards and downwards, for each finishing level. During the processing, individual frames were parametrically extracted from the videos using the 3DF Zephyr software by entering the extraction parameters, like similarity auto-discard and sharpness. The obtained pictures were im-ported in two separate projects inside the Agisoft Metashape software, one for each finishing condition. Each project contains two chunks, one with the mask facing up and one facing down. The Metashape photogrammetric software was used to orient the various frames of each chunk and to generate a sparse cloud for each one. The next step was the generation of dense point clouds and the iterative manual cleaning of the outliers. The dense clouds, in pairs, were aligned with the scale-rotate-translate (SRT) transformation software function, subject to final manual cleaning, and then the mesh and texture were generated. This procedure, which is summarized in Fig. 3, was repeated for the two datasets (raw and painted mask). The final virtual model reconstructed for the raw mask is presented in Fig. 4.

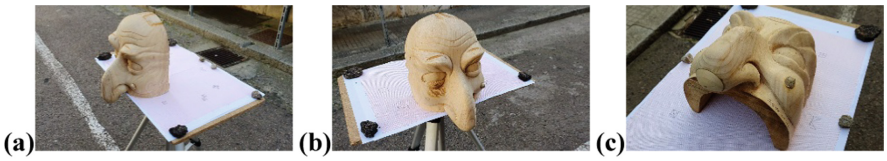

Fig. 2. Some examples of the photographic acquisitions of the raw mask (extracted from the two videos)

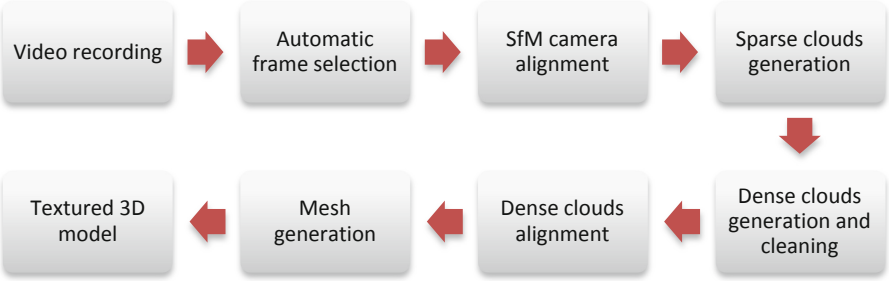

Fig. 3. Photogrammetric processing workflow for each mask model



Fig. 4. SfM digital model of the raw mask

3.2 Multispectral Reflectography

To now, two different multispectral technologies have been tested on the painted mask:

- A drone-controlled multispectral camera,
- A modified Digital Single Lens Reflex (DSLR) camera.

In the following two sub-sections, the authors preliminarily present some raw data acquired.

Drone-Controlled Multispectral Camera

To our knowledge, this is the first time that a drone multispectral sensor (typically designed for a quite more distant monitoring of soil and vegetation) is used on a Cultural Heritage asset, especially of a similar dimension.

The sensor employed is a MicaSense RedEdge-MX™ camera mounted on a DJI Matrice 600 Pro drone, from which it takes power alimentation and can be controlled for triggering the acquisitions (control possible even by proper software).

The RedEdge-MX™ camera is an optical instrument with five distinctive optics, each one linked to a quite narrow band sensor for the acquisitions in the bands: Blue, Green, Red, Red Edge, and Near-Infrared (NIR) as illustrated by Table 1 and Fig. 5.

Figures 6, 7 and 8 present the raw data acquired by the MicaSense RedEdge-MX™ camera on the finished mask. Figures 6 show the acquisitions at Blue, Green and Red channels and represent the decomposition of the finished mask colors: dark tones indicate low intensity of the specific components, while bright tones indicate a high intensity (as an example, look at the blue/cyan eyes of the mask: they appear bright on Blue channel and dark on the two others, indicating a prevalence of Blue light reflection as we can also appreciate with human sight). Particularly significant are Red Edge image (Fig. 7) and NIR image (Fig. 8) which are characterized by a spectrally different behavior, especially the transparency, of the pigments used on the eyes of the *Pulcinella* mask as evidenced

Table 1. Spectral information of the MicaSense RedEdge-MX™ camera [42].

Band number	Band name	Center wavelength (nm)	Bandwidth FWNM (nm)	Range (nm)
1	Blue	475	32	459–491
2	Green	560	27	546.5–573.5
3	Red	668	16	660–676
4	Red Edge	717	12	711–723
5	NIR	842	57	813.5–868.5

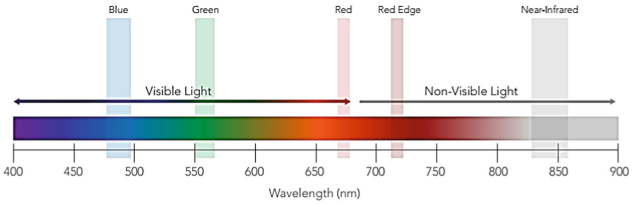

Fig. 5. RedEdge-MX™ acquisition bands [42].

by different readability of the *pentimenti* located them over the pictorial plaster base and just below the paintings.

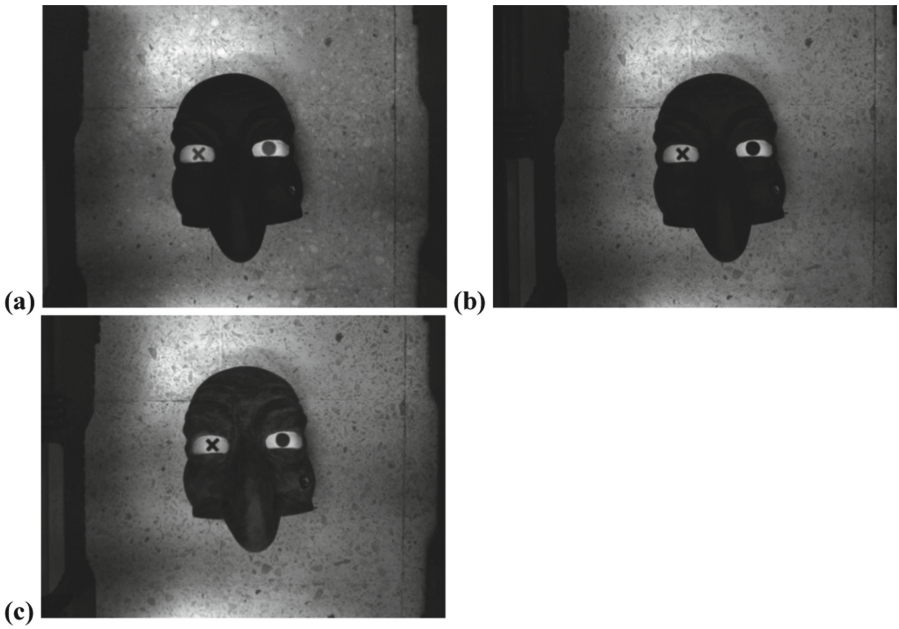

Fig. 6. RedEdge-MX™ raw data: Blue channel **(a)**, Green channel **(b)**, Red channel **(c)**.



Fig. 7. RedEdge-MX™ raw data: Red Edge channel.



Fig. 8. RedEdge-MX™ raw data: NIR channel.

Modified DSLR Multispectral Camera

A second set of multispectral data was acquired by means of a modified Digital Single Lens Reflex (DSLR) camera by which the factory internal bandpass filter in the visible range was removed to allow the recording of the pictures across the sensitivity full-range of the internal sensor that is typically quite larger than only the visible light. The acquisitions were done applying over the optics of the camera alternated narrower bandpass filters. The external filters employed in the acquisitions and the sensitivity of the three camera RGB channels of a modified DSLR camera with characteristics similar to the Nikon D 750 used are illustrated in Fig. 9a. The acquisition instrumental setup is shown in Fig. 9b.

Figures 10, 11 and 12 show some of the raw data acquired with the Ultraviolet (UV), Fig. 10, the visible, Fig. 11, and the wider Near-Infrared (NIR1), Fig. 12, filters. It is

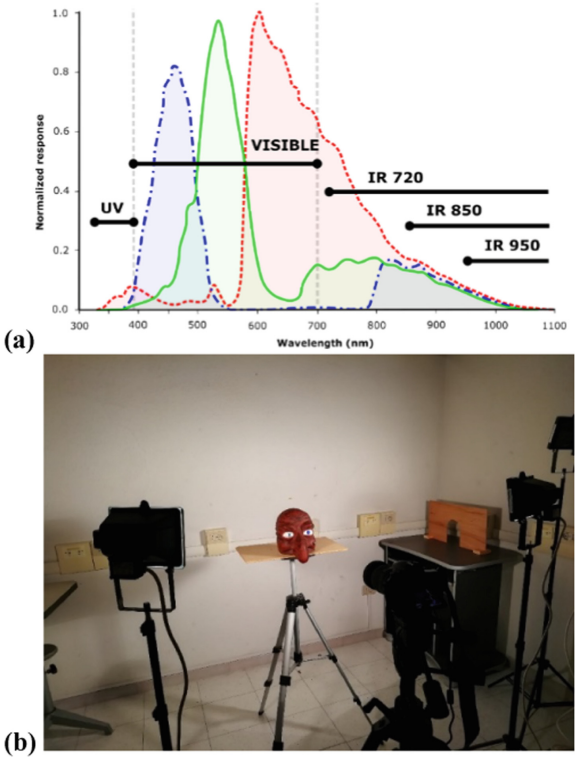

Fig. 9. Representation of multispectral bands configurations (black lines indicate the fives EM filters), plotted over the sensitivity curves of the three RGB channels of a camera, the Nikon D200, similar to the one used during MS acquisition (RGB channels sensitivity from [39] **(a).** Acquisition of the modified-Nikon-D750 multispectral dataset **(b).**

worth of noting the difference of the modified-D-750 pictures from the RedEdge-MX ones, because DSLR cameras acquire three RGB channels for each image.

3.3 Active Infrared Thermography

The active IRT was carried out via a digital thermal camera (FLIR System AB model P30 PAL, 320 × 240 pixels). The experimental setups were configured with different points of view and heat lamps positions; they were repeated in same conditions for both the two finishing stages (raw and painted) of the *Pulcinella* mask (Fig. 13). The investigated wooden mask was initially heated by one to four IR lamps for different energization time lengths that were tested in order to verify the potentialities and limits of each configuration. For each IRT experiment, the scene was recorded by the thermal camera during the heating and cooling phases for different positions of the mask to study specific defects or other peculiarities. Three samples of a raw IRT dataset are reported in Fig. 14.

Different processing approaches are being tested across the experimental datasets, such as linear regression models - aiming at detecting some of the main features in



Fig. 10. Nikon D750 raw data: UV-range filter (320–390 nm).



Fig. 11. Nikon D750 raw data: visible-range filter (390–700 nm).



Fig. 12. Nikon D750 raw data: NIR1-range filter (>720 nm).

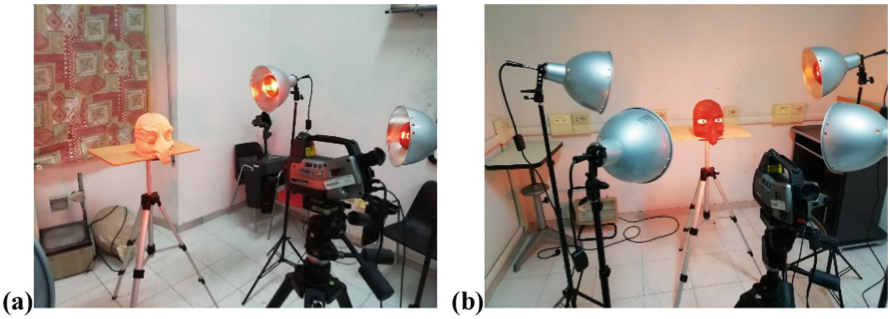

Fig. 13. Acquisition of IRT data: raw mask **(a)** and finished mask **(b)**.

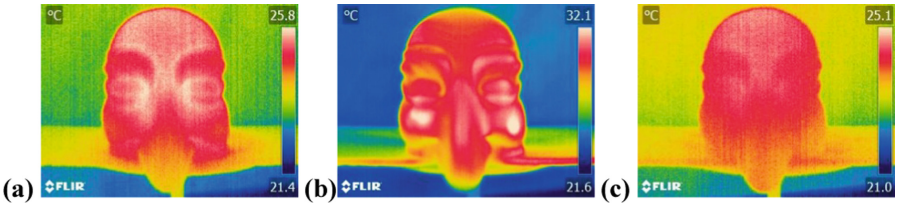

Fig. 14. IRT raw data during time-lapse acquisition (raw mask): thermogram at 5" heating **(a)**, at 7′10" heating **(b)** and at 40′30" cooling **(c)**.

the data by compacting the dynamic behavior into few images with approaches similar to some IR environmental monitoring [43]. Figure 15 shows the interpolated Thermal Gradient of the first ten thermograms of a cooling stage recorded at the highest sampling rate of the employed thermal camera on the raw *Pulcinella* mask: from these preliminary data, some defects are possible to be recognized within the specific experimental setup.

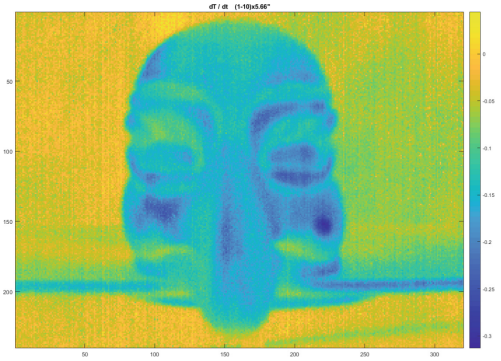

Fig. 15. Preliminary IRT processed data (raw mask): thermal gradient

3.4 THz Imaging

THz investigations are currently going on and are performed by means of a Fiber-Coupled Time-Domain (TD) - THz system equipped with a normal reflection imaging module (see Fig. 16a) which allows the scanning of planar areas with a minimum spatial offset of 0.15 mm. Such a system is designed to perform high resolution non-invasive subsurface inspections suitable to characterize the stratigraphy of the object under test and to reveal hidden details like author' signature, preparatory drawings and not visible defects. The measurements are carried in laboratory without controlling temperature and humidity values and filtering procedures, devoted to reduce the environmental noise, are exploited to improve the imaging capabilities. Specifically, beyond 2D false color THz images, time of flight imaging will be performed to achieve 3D reconstruction of the probed areas and obtain images referred to increasing constant depths starting from the surface and moving into the object. Details about the system and the data processing are given in [31] while, as an example, Fig. 16b shows a painted wood sample (left panel) and its 2D false color THz image (right panel), assessing the ability to retrieve carbon drawings covered by the black paint. THz inspected areas of the *Pulcinella* mask and related preliminary results will be presented at the conference.

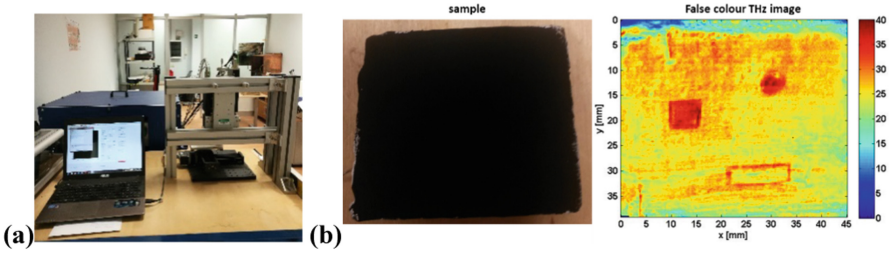

Fig. 16. The THz imaging system **(a)** and an example of the possible THz imaging results **(b)**.

4 Conclusions

In this paper, an integrated experimental testing-framework is presented as a base for an expectable future standard comparability of non-destructive and non-invasive diagnostics techniques and protocols applied to the study and characterization of wooden artifacts, and, especially, precious historical sculptures.

The *Pulcinella* diagnostic project has been explained in its main features, first giving a brief description of the physical model representing the historical architype of the wooden sculptures through the shapes of a well-known carnival mask of the regional tradition. The first diagnostic approaches are also illustrated, with a description of methods, technologies and first experimental datasets.

The preliminary experimental results demonstrate effectiveness and limits of the first employed protocols, mainly, and currently, by means of the raw datasets but also by means of some processed data. The first round of diagnostic techniques has

included Structure from Motion photogrammetry, Multispectral imaging, active Infrared Thermography and Terahertz imaging.

Due to its experimental purposes, the *Pulcinella* diagnostic project configures as an open diagnostic protocol – or a protocol of protocols – allowing a scalability to as many tools as wanted and, within this approach, being able to compare standard and innovative diagnostics methods related to historical wooden sculptures.

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References

1. Piro, S., et al.: Geophysics and cultural heritage: a living field of research for Italian geophysicists. First Break **33**(8), 43–54 (2015)
2. Lillesand, T., Kiefer, R.W., Chipman, J.: Remote Sensing and Image Interpretation. Wiley, Hoboken (2015)
3. Costanzo, A., Minasi, M., Casula, G., Musacchio, M., Buongiorno, M.F.: Combined use of terrestrial laser scanning and IR thermography applied to a historical building. Sensors **15**(1), 194–213 (2015)
4. Fiorino, D.R., et al.: The management of the restoration site. Diagnostic techniques, problems and perspectives. In: Geores 2019 2nd International Conference on Cultural Heritage: challenges, new perspectives and technology innovation. Springer, Berlin Heidelberg (2019)
5. Salonia, P., Scolastico, S., Pozzi, A., Marcolongo, A., Messina, T.L.: Multi-scale cultural heritage survey: quick digital photogrammetric systems. J. Cult. Herit. **10**, e59–e64 (2009)
6. Shi, R., Xu, M., Zhu, L.: New techniques of remote sensing in the university of architecture and planning. In: 2009 IEEE International Geoscience and Remote Sensing Symposium, vol. 2, pp. II-642. IEEE (2009)
7. Xu, Z., Wu, L., Shen, Y., Li, F., Wang, Q., Wang, R.: Tridimensional reconstruction applied to cultural heritage with the use of camera-equipped UAV and terrestrial laser scanner. Remote Sens. **6**(11), 10413–10434 (2014)
8. Yastikli, N.: Documentation of cultural heritage using digital photogrammetry and laser scanning. J. Cult. Herit. **8**(4), 423–427 (2007)
9. Ranieri, G., Trogu, A., Loddo, F., Piroddi, L., Cogoni, M.: Digital museum from integrated 3D aerial photogrammetry, laser scanner and geophysics data. In: 24th European Meeting of Environmental and Engineering Geophysics, pp. 1–5. European Association of Geoscientists & Engineers, Houten, The Netherlands (2018)
10. Colica, E., et al.: Using unmanned aerial vehicle photogrammetry for digital geological surveys: case study of Selmun promontory, Northern of Malta. Environ. Earth Sci. **80**(17), 1–14 (2021). https://doi.org/10.1007/s12665-021-09846-6
11. D'Amico, S., et al.: Multitechnique diagnostic analysis and 3D surveying prior to the restoration of St. Michael defeating evil painting by Mattia Preti. Environ. Sci. Pollut. Res. **29**(20), 29478–29497 (2021). https://doi.org/10.1007/s11356-021-15880-5
12. D'Amico, S., et al.: Geophysical investigations, digital reconstruction and numerical modeling at the Batia Church in Tortorici (Messina, Sicily): preliminary results. In: Proceedings of the 2020 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, pp. 22–24. Trento, Italy (2020)

13. Ma, Y., Soatto, S., Jana Košecká, S., Sastry, S.: An Invitation to 3-D Vision. Springer, New York (2004). https://doi.org/10.1007/978-0-387-21779-6
14. Maldague, X.P.: Nondestructive Evaluation of Materials by Infrared Thermography. Springer, London (2012). https://doi.org/10.1007/978-1-4471-1995-1
15. Ibarra-Castanedo, C., Sfarra, S., Ambrosini, D., Paoletti, D., Bendada, B., Maldague, X.: Subsurface defect characterization in artworks by quantitative pulsed phase thermography and holographic interferometry. Quant. InfraRed Thermography J. **5**(2), 131–149 (2008)
16. Cosentino, A.: Terahertz and cultural heritage science: examination of art and archaeology. Technologies **4**(1), 6 (2016)
17. Avdelidis, N.P., Moropoulou, A.: Applications of infrared thermography for the investigation of historic structures. J. Cult. Herit. **5**(1), 119–127 (2004)
18. Carlomagno, G.M., Di Maio, R., Meola, C., Roberti, N.: Infrared thermography and geophysical techniques in cultural heritage conservation. Quant. InfraRed Thermography J. **2**(1), 5–24 (2005)
19. Arndt, R.W.: Square pulse thermography in frequency domain as adaptation of pulsed phase thermography for qualitative and quantitative applications in cultural heritage and civil engineering. Infrared Phys. Technol. **53**(4), 246–253 (2010)
20. Liu, K., Huang, K.L., Sfarra, S., Yang, J., Liu, Y., Yao, Y.: Factor analysis thermography for defect detection of panel paintings. Quant. InfraRed Thermography J. 1-13 (2021)
21. Tao, N., Wang, C., Zhang, C., Sun, J.: Quantitative measurement of cast metal relics by pulsed thermal imaging. Quant. InfraRed Thermography J. **19**(1), 27–40 (2020)
22. Piroddi, L., Calcina, S., Fiorino, D., Grillo, S., Trogu, A., Vignoli, G.: Geophysical and remote sensing techniques for evaluating historical stratigraphy and assessing the conservation status of defensive structures heritage: preliminary results from the military buildings at San Filippo Bastion, Cagliari, Italy. In: Gervasi, O. (ed.) ICCSA 2020. LNCS, vol. 12255, pp. 944–959. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-58820-5_68
23. Mercuri, F., Zammit, U., Orazi, N., Paoloni, S., Marinelli, M., Scudieri, F.: Active infrared thermography applied to the investigation of art and historic artefacts. J. Therm. Anal. Calorim. **104**(2), 475 (2011)
24. Ibarra-Castanedo, C., Sfarra, S., Ambrosini, D., Paoletti, D., Bendada, A., Maldague, X.: Diagnostics of panel paintings using holographic interferometry and pulsed thermography. Quant. InfraRed Thermography J. **7**(1), 85–114 (2010)
25. Orazi, N., et al.: Thermographic analysis of bronze sculptures. Stud. Conserv. **61**(4), 236–244 (2016)
26. Di Tuccio, M.C., Ludwig, N., Gargano, M., Bernardi, A.: Thermographic inspection of cracks in the mixed materials statue: Ratto delle Sabine. Heritage Sci. **3**(1), 1–8 (2015). https://doi.org/10.1186/s40494-015-0041-6
27. Peeters, J., et al.: IR Reflectography and active thermography on artworks: the added value of the 1.5–3 μm band. Appl. Sci. **8**(1), 50 (2018)
28. Wiewel, A., Conyers, L., Piroddi, L., Papadopoulos, N.: An experimental use of ground-penetrating radar to identify human footprints. Revue d'archéométrie **45**(1), 143–146 (2021)
29. Piroddi, L., Calcina, S.V., Trogu, A., Ranieri, G.: Automated Resistivity Profiling (ARP) to explore wide archaeological areas: the prehistoric site of Mont'e Prama, Sardinia Italy. Remote Sens. **12**(3), 461 (2020)
30. Piroddi, L., Vignoli, G., Trogu, A., Deidda, G. P.: Non-destructive diagnostics of architectonic elements in San Giuseppe Calasanzio's church in cagliari: a test-case for micro-geophysical methods within the framework of holistic/integrated protocols for ARtefact knowledge. In: 2018 IEEE International Conference on Metrology for Archaeology and Cultural Heritage, pp. 17–21, New York, USA. IEEE (2018)

31. Catapano, I., Soldovieri, F.: THz imaging and data processing: State of the art and perspective. In: Persico, R., Piro, S., Linford, N. (eds.) Innovation in Near-Surface Geophysics, pp. 399–417. Elsevier, Amsterdam, Netherland (2019)
32. Seco-Martorell, C., López-Domínguez, V., Arauz-Garofalo, G., Redo-Sanchez, A., Palacios, J., Tejada, J.: Goya's artwork imaging with Terahertz waves. Opt. Express **21**(15), 17800–17805 (2013)
33. Stübling, E., Staats, N., Globisch, B., Schell, M., Portsteffen, H.D., Koch, M.: Investigating the layer structure and insect tunneling on a wooden putto using robotic-based THz tomography. IEEE Trans. Terahertz Sci. Technol. **10**(4), 343–347 (2020)
34. Catapano, I., Ludeno, G., Cucci, C., Picollo, M., Stefani, L., Fukunaga, K.: Noninvasive analytical and diagnostic technologies for studying early renaissance wall paintings. Surv. Geophys. **41**(3), 669–693 (2020). https://doi.org/10.1007/s10712-019-09545-9
35. Jones, C., Duffy, C., Gibson, A., Terras, M.: Understanding multispectral imaging of cultural heritage: determining best practice in MSI analysis of historical artefacts. J. Cult. Herit. **45**, 339–350 (2020)
36. Pelagotti, A., Del Mastio, A., De Rosa, A., Piva, A.: Multispectral imaging of paintings. IEEE Sign. Process. Mag. **25**(4), 27–36 (2008)
37. Colantonio, C., Pelosi, C., D'Alessandro, L., Sottile, S., Calabrò, G., Melis, M.: Hypercolorimetric multispectral imaging system for cultural heritage diagnostics: an innovative study for copper painting examination. Eur. Phys. J. Plus **133**(12), 1–12 (2018). https://doi.org/10.1140/epjp/i2018-12370-9
38. Piroddi, L., Ranieri, G., Cogoni, M., Trogu, A., Loddo, F.: Time and spectral multiresolution remote sensing for the study of ancient wall drawings at San Salvatore hypogeum, Italy. In: Proceedings of the 22nd European Meeting of Environmental and Engineering Geophysics, Near Surface Geoscience 2016, Houten, The Netherlands, pp. 1–5. EAGE (2016)
39. Piroddi, L., Calcina, S.V., Trogu, A., Vignoli, G.: Towards the definition of a low-cost toolbox for qualitative inspection of painted historical vaults by means of modified DSLR cameras, open source programs and signal processing techniques. In: Gervasi, O., et al. (eds.) ICCSA 2020. LNCS, vol. 12255, pp. 971–991. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-58820-5_70
40. Marincola, M.D., Kargère, L.: The Conservation of Medieval Polychrome Wood Sculpture: History, Theory, Practice. Getty Publications, Los Angeles (2020)
41. Cennini, C.: Illibro dell'arte, o Trattato della pittura. F. LeMonnier, Firenze (1859)
42. Micasense: RedEdge.MX sensor documentation (Product sheet, Specifications), downloadable at. https://micasense.com/rededge-mx/. Accessed 27 Mar 2022
43. Piroddi, L.: From high temporal resolution to synthetically enhanced radiometric resolution: insights from Night Thermal Gradient results. Eur. Phys. J. Spec. Topics **230**(1), 111–132 (2021). https://doi.org/10.1140/epjst/e2020-000247-x