

Multi-technique integrated analysis to discover the invisible on the Camponeschi Monument in L'Aquila

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Abstract – Technical-scientific activities have been developed by ENEA, in the frame of the PNRR CHANGES-Cultural Heritage Innovation for Next-Gen Sustainable Society-project, aimed at the diagnostic-cognitive analysis of the Camponeschi Monument in the Basilica of San Giuseppe Artigiano in L'Aquila. As a product of late Gothic eclecticism, this Monument holds particular significance due to the controversies surrounding its attribution and the complexity of its relief surfaces. The measurement campaign was conducted by applying a multi-technique integrated approach. Following the indication of the restorers and art historians, particular attention has been devoted to identifying details not clearly visible to the naked eye. A new imaging prototype system based on LIF (Laser Induced Fluorescence) has been applied. Moreover, a 3D photogrammetric model has been produced to integrate the diagnostic analysis. Some useful information for deepening the knowledge of the artwork has been obtained.

I. INTRODUCTION

As part of the PNRR CHANGES (Cultural Heritage Innovation for Next-Gen Sustainable Society) project [1], the GSSI - Gran Sasso Science Institute, co-leader of Spoke7 "Protection and Conservation of Cultural Heritage against Climate Changes, natural and anthropic risks", entrusted ENEA with a technical-scientific activity service aimed at the diagnostic-cognitive analysis of a case study represented by the equestrian funerary Camponeschi Monument in the Basilica of San Giuseppe Artigiano in L'Aquila. Built ante 1432, it is a funerary monument to an important component of the Camponeschi family. The controversies surrounding its attribution, to the German sculptor Walter Mönich by some critics [2,3], and its appearance of a complex monumental sculptural apparatus with typical late-Gothic elements, make this monument of particular interest. The investigative project underwent an

initial phase of diagnostic imaging analyses [4]. In this second phase, the ambitious objectives were: 1) to understand if the date in the lower right of the commemorative stone was contemporaneous with the artifact; 2) to find any trace of the now-lost painted inscription on the central molding; 3) to reconstruct the monument's original polychrome appearance, thereby affirming its full integration within the flourishing visual culture of European cathedrals' International Gothic.

In this work, a multi-technique integrated approach has been applied for the diagnostic analysis of this monument, shown in Fig. 1, more than 7 meters high and made of local limestone. The analysis was focused on in-depth knowledge of the artwork, in synergy with expert connoisseurs and guided by their insights, with particular attention on identifying details imperceptible to the naked eye, such as residual traces of inscriptions or original pictorial materials. Several instruments based on different technologies have been put in field, both innovative, like laser scanning diagnostic systems based on laser induced fluorescence (LIF) technique [5,6], and commercial, as hyperspectral imaging camera and thermo-camera. Some prototype systems designed and realized in ENEA, thanks to the high skills developed in technologies aimed at remote diagnostics through the implementation of laser techniques, have been tested and applied. LIF based systems, in particular, have found widespread application in Culture Heritage field for materials study and characterization thanks to its properties to be non-destructive and non-invasive technique, remote, meaning able to work at several meters of distance from the target, with no sampling requirements, based on transportable or portable instruments that can provide first results in real time [7,8]. Chemical information on the surface composition of the analysed target can be quickly obtained [9,10]. In order to improve the knowledge of this artwork from different points of view, inspecting also areas difficult to be reached, a drone equipped with a camera to



Fig. 1. Camponeschi Monument in the Basilica of San Giuseppe Artigiano in L'Aquila.

create 3D photogrammetric models has been further used. This activity was finalized to support and integrate the other investigation techniques, improving the overall documentation of the monument and providing a representation useful for successive eventual intervention actions.

II. EXPERIMENTAL

The multi-technique integrated analysis has been developed by the application of several instruments based on different techniques. Among the spectroscopic techniques appropriate to remote application, LIF is able to supply valuable information thanks to its ability to analyse substances having specific spectral signature [11,12]. The generation of multispectral imaging suitable to the identification and the localization of the surface materials makes the LIF scanning systems particularly useful in the cultural heritage field. In this case, 2 prototype LIF systems developed at the Diagnostics and Metrology Laboratory of the ENEA research center in Frascati were used. The first one, already described in previous paper [13] is a hyperspectral point scanning system with a pulsed Nd:YAG laser source, working at 266 nm with pulse duration of 10 ns, repetition rate of 20 Hz and laser fluence in the range 1 - 50 mJ/cm². Its small size and light weight allow an easy transport of the system and its current maximum range for remote operation is around 5 m. The second LIF system used in this campaign of measurements, shown in Fig. 2 at work in the Basilica, is a new imaging prototype called IRIS - Integrated time Resolved Imaging Spectroscopy. The innovative nature of the system lies in the integration of different scanning LIF



Fig. 2. IRIS system in the Basilica of San Giuseppe Artigiano in L'Aquila.

systems in a single instrument and in the consequent restitution not only of multispectral fluorescence maps but also of hyper-spectral point measurements, thanks to the insertion in the optical collection path of a spectrograph and a filter wheel, appropriately coupled to the ICCD, able to operate alternatively very quickly. This system, also, uses a 266 nm source, but with a short pulse (< 2ns), high repetition rate (200 Hz) and provides fluorescence images at pre-selected spectral bands using a series of filters. Its characteristics are to the advantage of the speed of the investigation, reducing the time of measure, and with low production and maintenance costs. The combined use of systems with different characteristics is advantageous for the optimization of the analysis work. In this case, IRIS allows it to locate very quickly, through the generation of multispectral images of large surfaces, the areas with the materials of interest. The punctual system, on the basis of the indications also obtained from the data collected with IRIS, is used to analyze in more detail some specific points. In this way the reduction of the time measurement and a limited number of sampling points can be obtained. In addition to LIF, further measurements have been performed with different techniques able to provide results to be integrated into the monument analysis. In particular, a Specimen IQ camera has been used to obtain hyperspectral images in the spectral range 400–1000 nm, with spectral resolution of 7 nm and 204 bands in the wavelength range. The number of pixels per line is 512 and the camera always captures a square image with a resolution of 512 × 512 px. Beyond it, a FLIR C5 thermal imaging camera equipped with a 160 × 120 pixel sensor, thermal sensitivity of 0.07°K, field of view (FOV) 54° × 42°, minimum focal length of 0.1 m, spectral range 8–14 μm and image frequency 8.7 Hz has been employed. Images with the Dino-Lite digital microscope, used with magnifications between 150x and 250x, have been also recorded.

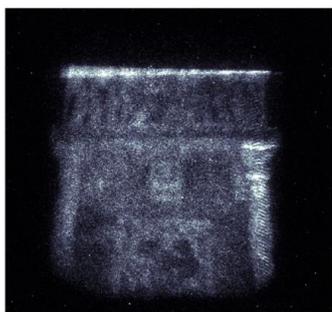


Fig. 3. Fluorescence image at 340 nm of the central part of the monument by IRIS system.

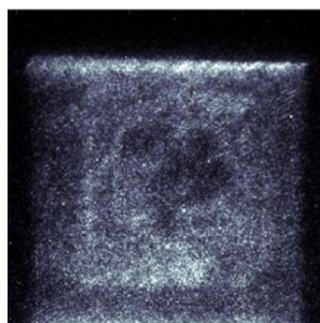


Fig. 4. Fluorescence image at 340 nm of the memorial stone by IRIS system.

The 3D photogrammetric model of the Camponeschi monument was obtained through the video/photographic acquisition of multispectral data with cameras equipped on two DJI drones, in particular the DJI Mini drone for more detailed acquisitions in the visible range of the monument and the DJI Phantom Multispectral for multispectral acquisitions. The software to process photogrammetric data is Agisoft Metashape, capable of elaborating both images from traditional cameras and multispectral data acquired with the DJI Phantom. The Metashape software also allows you to perform operations between multispectral layers, in order to obtain useful indexes for classifying parts of the scene in question.

III. RESULTS

Multispectral images resulting by the scanning LIF systems define a mapping of the materials on the investigated artistic surface. As can be observed in the fluorescence images obtained by IRIS, reported in Fig. 3 and Fig. 4, related to the central part of the monument and to the memorial stone on the lower part, respectively, some areas of discontinuity are evident. In particular, more intense fluorescence emissions at 340 nm, highlighted in white, are in correspondence of the right column, the frieze of the sarcophagus and the central shelf. This result can be attributed to the presence of different surface restoration materials or consolidant used in previous intervention not visible to the naked eye. The upper part of the monument



Fig. 5. Detail of the inscription in the lower part of the commemorative stone.

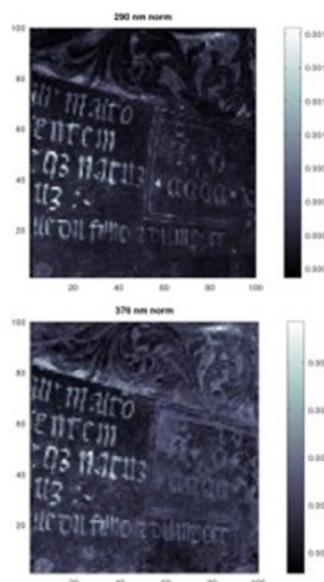


Fig. 6. Fluorescence images at 290, 375, nm recorded on the inscription on the Monument's commemorative stone with the point LIF system and normalized with the spectral integral in the considered range 270-750 nm

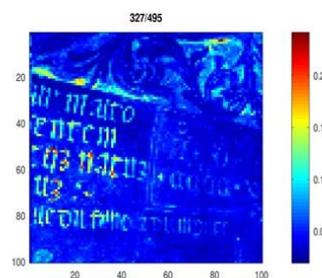


Fig. 7. Elaborated fluorescence image nm on the inscription on the commemorative stone with the point LIF system



Fig. 8. Microscope images of a point of the writing on the left side of the commemorative stone. The different focus distance of the three images highlights the presence of an incision inside which the black pigment is found. The images cover an area 2 mm wide.

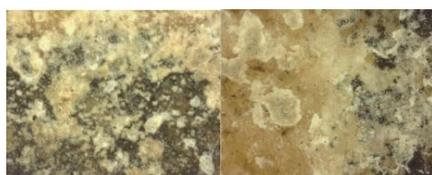


Fig. 9. Microscope images recorded on the inscription on the right side of the commemorative stone (date area), on the left, and along the line separating the two areas of the commemorative stone, on the right. The images capture areas 2 mm wide.

appears more homogeneous than the lower part. The LIF point scanning system has been then applied to analyze the inscription in the lower part of the commemorative stone of particular interest for art historians (Fig. 5). Fluorescence images at different emission wavelengths significant for the study of stone materials have been obtained. In Fig. 6 the images at 290 and 315 nm, are reported as example. The images were normalized with the spectral integral in the considered range 270-750 nm to take into account any experimental and geometric factors that might affect the LIF point measurements. As can be observed, the section on the left of the commemorative stone is clearly distinct from the one on the right.

These differences are reflected in the spectral results obtained from the punctual analysis of the area. For a greater number of points, even if with different intensities, the measured fluorescence spectra are characterized by a broad band centered at 485-500 nm, attributable to the stone substrate, while a low intensity band in the range 290-315 nm, associated with a band of greater intensity at approximately 450 nm, is present in the spectra related to some other points. Further processing of the data to better highlight the inhomogeneities present on the surface was done (Fig. 7). The inhomogeneity seems to be attributable to the presence or absence of restoration treatments in correspondence with the individual letters, as confirmed by the band at 290-315 nm in some recorded spectra, and to a different technique used to create the epigraph. Some images collected in situ by the microscope from different points related to the measurements carried out with punctual LIF, highlight the great inhomogeneity of the



Fig. 10. Greyscale thermographic image of the upper part of the Monument

surface. The images recorded in correspondence with the characters of the writing on the left side of the commemorative stone, as can be seen in Fig. 8, show evidence of the presence of engravings, unlike the writing on the right side (Fig. 9).

Thermography was carried out both in passive mode (without heating the surface) and in active mode (with heating the surface using R7S white halogen lamps). In both cases, the results highlight a fundamental homogeneity of the surface. Only a few small points of discontinuity, like for example on the nose of the angel on the right and part of the horse's limbs, as regards the upper part of the Monument (Fig. 10). Furthermore, the thermographic images show the absence of rising damp, infiltration or water leaks inside the walls behind the Monument. Hyperspectral images collected by Specimen IQ camera allowed us to perform analyses and formulate hypotheses on the monument under study. In particular, attention was focused, according to the restorers and art historians' requests, on the two portions with inscriptions present in the monument, on the commemorative stone and in the lower frame of the sarcophagus, respectively (Fig. 11).

As regards the inscription on the commemorative stone in the lower part of the monument, the analysis of each layer acquired on the different channels in the spectral range 400-1000 nm has been carried out. As can be observed in Fig. 12, relative to the 440.66 nm, a deterioration of the outlines of the letters making up the final part of the penultimate sentence of the writing appears, suggesting that this portion of the writing presents different characteristics compared to the rest of it. As the wavelength increases these differences become thinner, remaining evident only for some characters.

PCA algorithm has then been applied to all the information layers obtained with the hyperspectral camera, to which the k-means algorithm was subsequently applied to



Fig. 11. commemorative stone, on the left, the lower frame of the sarcophagus, in the yellow line.

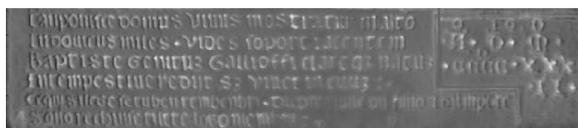


Fig. 12. Hyperspectral image at 440.66 nm

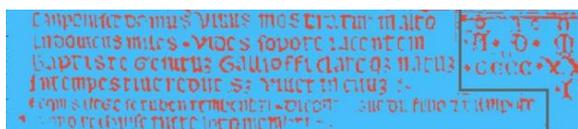


Fig. 13. False color hyperspectral image to distinguish the background (light blue) from the writing (red) of the commemorative stone

segment the portion of text involved in the analysis. The 2-cluster classification then obtained suggests that some letters in the penultimate line of the text on the left do not belong to the original writing. In fact, they do not appear among the red color that defines the letters (Fig. 13), blending in with the background.

A different type of pigmentation or a retouching performed in some restoration can also be hypothesized from the 4-cluster classification, confirming LIF results.

Regarding the lower frame of the sarcophagus, the main aim was to detect possible traces of the complete original writing. To train the dimension reduction (PCA) and k-means clustering algorithms, two different masks, for background and writings respectively, were taken. After performing a SNV (Standard Normal Variate) on the spectra of each single pixel, the obtained result is reported in Fig. 14.

The traces highlighted in red in the false color image on the sides of the writing still visible in the center, can indicate residues of some letters that have disappeared over time. For a more complete analysis it would be appropriate to compare the typology of characters of the time in order to obtain those that could best fit the traces found.

3D model was obtained with traditional photogrammetry algorithms and with the Gaussian Splatting methodology.



Fig. 14. False colour hyperspectral image to distinguish the background (light blue) from the sarcophagus writings (red)



Fig. 15. details of the 3D model built up by the Gaussian Splatting algorithms.

In this case, the entire model is reconstructed through artificial intelligence models that use points determined with classical photogrammetry algorithms to learn to reconstruct the scene, to predict the missing parts and to reconstruct the entire scene no longer through the approximation of triangulated meshes, but with the interpolation of three-dimensional Gaussians, obtained by interpolating the estimated points. In Fig. 15 is an example of some views obtained with the help of Gaussian Splatting algorithms. As can be seen, the model offers the possibility of easily inspecting even parts of the monument that are not easily accessible, such as the upper part of the monument located 7 meters high, and of observing the work even from angles that in reality would be considered impossible to perform.

IV. CONCLUSIONS

The multi-technique integrated analysis produced data of interest for different aspects with complementary characteristics. The presence of materials that were not clearly visible due to conservation and restoration actions was highlighted by LIF spectroscopic technique.

Hyperspectral imaging, in synergy with the LIF technique, confirmed interventions that occurred at different times on the inscriptions of the commemorative stone, starting a comparison between experts to identify times and motivations for any integration, recovery or restoration actions. This finding is particularly significant, as it lends support to the hypothesis proposed by the art historian that the date may instead represent a *terminus ante quem*, possibly corresponding to the moment when the tomb was reopened and subsequently sealed, as mentioned in the inscription. Furthermore, the last two lines of the commemorative stone differ notably from the other four

above, both linguistically and epigraphically. LIF analysis reveals slight differences in these lines as well, with the final line appearing more consistent with the right-hand portion of the inscription. Furthermore, the study carried out on the painted inscription of the monument highlights the possibility of new investigations that allow us to bring to light any information lost over time. Traces of writings obtained with the data processing pave the way to the use of Artificial Intelligence, and in particular of Neural Networks, for the completion of the inscriptions that today appear incomplete.

The photogrammetric model (3D) not only allows the inspection of the entire monument, even in parts that are difficult to access, but can be enriched with data from other tools to allow the study of the monument in its different parts, even with immersive reality systems. The fusion of data between the 3D model and multispectral analyses is useful both for dissemination and deeper knowledge of the monument by visitors, and for use by professionals for monitoring and studying the state of health of the monument itself. The study carried out on the monument, in addition to providing a zero state of conservation of the same, contributed to a deeper knowledge of the work itself.

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