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Documenting Cultural Heritage in very hostile fruition contexts: the synoptic visualization of Giottesque frescoes by Multispectral and 3D Close-range Imaging

E Grifoni[1], M Gargano[2], J Melada[2], M Interlenghi[3], I Castiglioni[4], S Romano Gosetti di Sturmeck[5], N Ludwig[2]

[1] National Institute of Optics, National Research Council, Florence, Italy
[2] Department of Physics Aldo Pontremoli, University of Milan, Milan, Italy
[3] DeepTrace Technologies S.R.L., Milan, Italy
[4] Department of Physics G. Occhialini, University of Milan-Bicocca, Milan, Italy
[5] University of Lausanne, Lausanne, Switzerland

Abstract. The paper reports the results obtained from the digital survey of Giottesque frescoes in the Archiepiscopal Palace of Milan. Multispectral Imaging and Image Based Modelling techniques have allowed the study, the high-resolution documentation and the virtual reassembly of the fragmented frescoes: the integration of spectral data with RGB ortho-images and 3D models has supported the interpretation of the pictorial cycle by virtually relocating the fresco fragments and evaluating their consistency from a technical, iconographic and art-historical point of view. The experimental results show that the proposed approach has great potential for the documentation of wall paintings preserved in highly hostile contexts of fruition. Due to its versatility and portability in the field, its sub-millimetric accuracy, and the different outputs that can be generated, Close-Range Digital Photogrammetry has proven to be the ideal tool in case of scattered and difficult-to-access data.

1. Introduction

Computational Imaging (CI) is one of the most efficient tools at the disposal of conservators, restorers, and art historians to document, analyze, monitor, and transmit Cultural Heritage to the future [1].

Recent history has shown how high-quality digitization has been a precious medium for preserving the cultural informative content in the face of the inestimable loss of works of art due to negligence or improper maintenance operations, looting, and intentional or natural destruction. Digitization stores and transmits cultural information, democratizes the fruition experience, and widens access to heritage in digital form in increasingly culturally appropriate manners. This is particularly useful in the case of all those works of art or monuments physically interdicted to the public due to restrictive environmental constraints, to conservation risks or to historical contingencies such as demonstrated by the current global pandemic that has limited mobility and precluded a first-person experience of Cultural Heritage.

Humanities research is rapidly changing its operational habits and cognitive tools, intending Computational Imaging as a heuristic strategy that uses the *virtual* to explore the *real*: nowadays this is a routine practice, widely used in all the most advanced conservation projects.

The recent convergence between digital photogrammetry and Computer Vision has increased the potential of documentary survey by allowing to record not only radiometric data but also well-resolved morphometric data in a multi-dimensional coordinate system. Image-Based

Modelling (IBM) is enhancing the analytical potential of Cultural Heritage by generating 3D digital models that are collectors of heterogeneous qualitative and quantitative information. It creates new knowledge about the execution techniques, assists the restoration tasks, and allows to perform a pro-active temporal monitoring of an artwork [2].

Current research projects concerning easel paintings, wall paintings but also poly-material artifacts of historical-artistic interest, proposed multimodal data fusion approaches in which IBM and Multispectral Imaging (MSI) are combined in tandem. This new method offers the advantage of merging spectral data with geometric information on a single digital product, considerably increasing the diagnostic and documentary content about the object [3-5].

IBM obviously can be exploited not only for inherently three-dimensional works of art, but also for quasi-planar ones such as wall paintings. In this specific case this technique allows to generate as possible outputs both accurate meshed and textured 3D models of the surface, but also digital surface maps (DSM) and ortho-rectified (or geometrically corrected) images with a high level of detail.

Orthoimages are increasingly in demand for studies on wall paintings because they allow the metric quantification of the observations by conservators/restorers on an easy-to-use 2D support, replacing the traditional documentary method based on 2D technical photography.

Generally, wall paintings are often difficult to image at high resolution because of their usual large surface area, high placement on the wall, and shooting distance. If on top of these critical issues, additional complications due to some environmental constraint that precludes visibility and shooting are added, proper survey becomes a truly difficult task. It is no coincidence that IBM is considered an excellent option for documenting all those hostile contexts where access is limited and acquisition is highly constrained, such as hypogeous structures and painted rock caves [6].

A similarly complicated setting was encountered in the case of the survey of Giottesque frescoes recently discovered in the archbishop's palace of Milan: these fragmentary wall paintings are currently interdicted to the public; some of them can be reached only through a narrow passageway and a permanent metal scaffolding hinders and partially limits their fruition at extremely close range.

This paper reports the strategy of IBM survey and multispectral analysis adopted by the authors for the digital documentation of the on-site frescoes and the virtual recomposition of the fragmentary off-site paintings related to the Giottesque pictorial cycle of the Archbishop's palace of Milan.

2. Research Aims

The Giottesque frescoes in the Archiepiscopal Palace of Milan are one of the case studies investigated as part of the MOBARTECH project.

These frescoes were accidentally discovered between the end of the 19th century and the first half of the 20th century. They were part of a more extensive pictorial cycle, probably referring to stories of the Foundation of the city of Rome, commissioned by Giovanni II Visconti during his early years as Archbishop of Milan (1339-1342 ca.) to decorate the great hall of his palace. Critics agree that this pictorial cycle is of extraordinary importance from an art-historical point of view because it represents a *unicum*: the extremely rare iconography, the advanced realism and the perspective complexity confer an internationally avant-garde role to the figurative culture of the Visconti court in the early 14th century. Its high technical and stylistic quality is undoubtedly influenced by the presence of Giotto, who arrived in the city of Milan in those same years to decorate the great hall of the neighboring palace of Azzone Visconti (now Palazzo Reale). Unfortunately, the cycle it is currently fragmentary and strongly degraded: many large fragments were detached, transferred on canvas before 1950 and currently hanging on the walls [7].

In very recent years, the scholar S. Romano and her research group at the University of Lausanne have uncovered additional remaining pictorial traces on the eastern wall of the palace's sub-roof. These latter mural paintings depict an illusionistic architecture (on the left) and a pastoral and bucolic scene (on the right). The sub-arch on the left is decorated with an extraordinary geometric and vegetal pattern in bright colors and with plaster stencil details (*pastiglia*). Although they are still preserved *in situ* they are not easily accessible or viewable: they can be reached only through a narrow steel walkway which constrains the viewing of the paintings at an extremely close distance (≈ 40 cm) and does not allow to appreciate the overall view. Moreover, they are partially hidden by the metal poles of a scaffolding that are only 2 cm from the surface. Also, the decoration of the sub-arch is not currently appreciable as it is located below the current walking level.

Only by attempting to virtually reunite together these sparse and fragmented traces can art historians understand the relationships between the subjects depicted and the physical architectural space to provide a proper interpretation of them.

Accordingly, the research goals were: *i)* to digitally document all the on-site and off-site mural paintings at very high resolution using multispectral techniques to obtain accurate information about colors, materials and execution techniques; *ii)* to reconstruct a synoptic visualization of the entire painted east wall by eliminating any visual obstruction; *iii)* to virtually relocate the frescoes to their original positions to support art historians in their critical interpretation efforts; and *iv)* to democratize the fruition of the pictorial cycle by disseminating its knowledge to a wider audience through realization of a digital musealization product.

3. Materials and Methods

The on-site frescoes of the North and South walls of what was originally the hall of the Palazzo di Giovanni Visconti were acquired by Multispectral imaging.

Digital documentation of the fresco on the East wall was particularly challenging: considering the highly restrictive environmental constraints and the poor and non-homogeneous ambient lighting, it was necessary to use flexible, portable, and lightweight instrumentation as well as to adopt a site-specific acquisition strategy.

To meet these requirements, the following were used: a RICOH GR II compact camera with 18mm fixed focal length lens (equivalent to a 28mm on a full frame sensor), equipped with a 16 MP APS-C CMOS sensor, and an external high sync Godox flash equipped with a diffusive dome to obtain a diffuse render on the area to acquire. The acquisition conditions did not allow the use of any tripod. 15 coded targets, automatically recognizable by the 3D photogrammetry software used, have been placed in the scene before photos were taken: in particular, they have been positioned on the metal poles and in strategic points of the surface of the frescoes. A calibrated scale bar has been included in the scene to be acquired to obtain a scaled 3D model.

For the photo-editing and 3D modelling operations, Capture One Pro and a recently released automated commercial Structure-from-Motion photogrammetry software were used.

4. Experimental data and Results

The 3D modeling and ortho-photomosaic generation workflow consisted of the following steps:

a) *Data capture process:* due to the forced close distance, the shooting plane was rather small. To achieve a full coverage of the mural painting and to maintain a 60% lateral overlap ratio between contiguous shots, a total of 556 images were captured, in native 14-bit RAW format, with a constant f/16 aperture value and a 1/125 sec. shutter speed. Low ISO values have been used to achieve optimal image quality while avoiding sensor luminance noise. A scanning shooting scenario was followed, distributing the shooting stations by vertical strips to cover the entire scene, and maintaining as much as possible the same camera-subject distance (≈ 40 cm) and some degree of coplanarity with the surface.

b) *Photo editing process* (color management and selection masks): each image was first properly balanced in Capture One Pro using the X-Rite Colorchecker® Passport target to ensure realistic color reproduction; it was then processed to reduce vignetting and hard shadow effects. Finally, regions of the photos concerning metal poles or areas of no interest have been masked to exclude them from the feature detection and alignment procedures.

c) Photogrammetric data processing: The dataset of balanced and chromatically corrected images, saved in .jpeg format, was loaded onto the 3D modelling software in a single chunk. Most of the steps in the digital processing pipeline, i.e., camera calibration and orientation, dense point cloud generation, polygon mesh surface reconstruction, and texture-mapping, were performed fully automatically. The initial phase of automatic image orientation and self-calibrating bundle adjustment resulted in automatic matching of image features and subsequent extraction of tie points. For image alignment the default parameters were used. Precision was set to “High” to work with the original image dimensions. The sparse point cloud obtained is composed of ≈ 460.000 points. The inclusion of coded targets and scale bars has improved the accuracy evaluation: Root Mean Square (RMS) reprojection errors averaged over all tie points on all images resulted in 0.5 pixels. Next, tie points were used as input to generate a dense point cloud based on the Multi-View Stereo method (MVS). The quality of the dense point cloud was set to “High” and the “Mild depth” filtering mode was chosen for preservation of important features: thus, a high-quality 3D point clouds of ≈ 81 million points was generated.

d) Dense cloud refining operations were performed to remove points referable to metallic poles that the software calculated despite the masking phase. Subsequently, a triangulated mesh with ≈ 13 million polygons was obtained from the dense cloud as an arbitrary surface, with the number of faces set to “High”. On this polygonal model limited editing operations were performed to close a few mesh holes and refine the edges of the 3D model.

e) Finally, the texture was created automatically by transferring the color information from the input images to the mesh, allowing for blending mode and color correction. Focusing the camera at 0,4 m distance and using a 18,3 mm effective focal length, the image texture spatial resolution (Ground Sampling Distance – GSD) resulted 0,1 mm/px on the sharp focus plane. The resulting 3D model of the entire mural painting was very accurate and faithful. For visualization purposes, since the model is of considerable size, it was necessary to decimate the mesh to partially reduce the amount of file data (from ≈ 13.000.000 to ≈ 1.218.000 polygons).

f) *Ortho-photomosaic generation and post-processing*: After setting up a local coordinate system, the same SfM photogrammetry software automatically generated an ortho-photomosaic from the rasterized close-range image data as a projection onto the best-fit plane. The resulting image (41832x19381 pixels size, with a resolution of 2,06 mm/pixel) was chromatically corrected using the blending mode to equalize color tones and then exported in .tiff format. Despite the previous operation of removing all the points related to the metal poles from the dense point cloud, unfortunately the software transferred on the texture residual traces of these elements as an error (Fig. 1). It was therefore necessary to export the ortho-photomosaic in the same photo-editing software used previously to carry out limited and precise operations of virtual restoration. The textured 3D model made it possible to explore and visualize the extraordinary decoration of the under-arch located below the floor level, recovering previously unseen details such as the stucco decoration (*pastiglia*) and brightly colored geometric and plant motifs.

Figure 1 Dense point cloud with the texture of the residual traces of metal poles.

5. Conclusions

The paper reports the results obtained from the application of multispectral imaging and image-based modeling techniques for the study, documentation, and dissemination of the Giottesque frescoes in the Archbishop's Palace of Milan.

Experimental results show that our proposed approach has great potential for the documentation of wall paintings preserved in highly hostile contexts of fruition. In fact, with this efficient solution we have overcome many of the limitations suffered by the traditional method of recording wall paintings. Thanks to its versatility and portability in the field, its millimeter accuracy and the different outputs that can be generated, close-range digital photogrammetry has proven to be the ideal tool in case of scattered and difficult-to-access data. Only through this technique it has been possible to recover valuable details otherwise not viewable.

6. References

[1] Wong, L., 2003. *Documentation: Objectives, Levels and the Recording Process*. In: *Conserving the Painted Past: Developing Approaches to Wall Painting Conservation* (Post-prints of an English Heritage Conference, 1999), edited by R. Gowing and A. 46–54. London: English Heritage.

[2] Pandey, S. C., and S. Cather. 2015. *Close-range 3D Imaging for Documenting and Monitoring Dynamic Deterioration Processes in Wall paintings*. In *ICOM CIDOC 2015: Documenting Diversity–Collections, Catalogues & Context*. Nueva Deli, India. Paris: ICOM.

[3] Pamart A., Guillon, O., Faraci, S., Gattet, E., Genevois, M., Vallet, J.M., De Luca, L., 2017. *Multispectral photogrammetric data acquisition and processing for wall paintings studies*. In: ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 42/2W3, pp. 559 - 566.

[4] Grifoni, E., Legnaioli, S., Nieri, P., ...Poggialini, F., Palleschi, V., *Construction and comparison of 3D multi-source multi-band models for cultural heritage applications*, Journal of Cultural Heritage, 2018, 34, pp. 261–267.

[5] Grifoni, E., Bonizzoni, L., Gargano, M., ...Mignani, I., Ludwig, N., 2020. *Multianalytical investigation and 3D Multiband modeling: An integrated survey of the Garnier Valletti pomological collection*, 2020 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, pp. 251–256.

[6] Rose, W., Bedford, J., Howe, E., and Tringham, S., 2021. *Trialling an accessible non-contact photogrammetric monitoring technique to detect 3D change on wall paintings*. In: Studies in Conservation, DOI: 10.1080/00393630.2021.1937457

[7] Romano, S., 2014. *La grande sala dipinta di Giovanni Visconti. Novità e rifessioni sul palazzo arcivescovile di Milano*. In: Pagliara, P. N., Romano, S., *Modernamente antichi. Modelli, identità, tradizione, nella Lombardia del Tre e Quattrocento*, Viella, Roma, pp. 119-167.