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IMAGING AS A FIRST STEP FOR CULTURAL HERITAGE AND ARCHAEOLOGY ANALYSES

1. Introduction

The ubiquitous diffusion of modern smartphones has brought, as a collateral effect, the ready availability of relatively good imaging systems that can be used in any circumstance, and in particular in field research, exploiting the intrinsic portability of the smartphone. Although the quality of the images acquired with a smartphone cannot be compared with the ones of a medium-quality professional camera, in many occasion even a smartphone camera can be useful for non-trivial applications, as the 3D-reconstruction of art and archaeological objects, and even the modelling of large architectonic or archaeological structures.

2. 3D modelling with a smartphone

A smartphone is more than enough for reconstructing photogrammetrically a medium size archaeological excavation, with results that might be practically indistinguishable from the models obtained using aerial photogrammetry. In these applications, in fact, the technical limitations of the smartphone cameras are compensated by the software used for reconstructing the 3D model of the object/site, to obtain excellent results with minimum efforts (Fig. 1). There are several excellent open source (VisualSFM), free (3DF Zephyr free), as well as relatively cheap commercial software (3DF Zephyr, Agisoft Photoscan) which can be usefully exploited for this purpose.

3. Multispectral imaging with commercial cameras

With a slight increase in the cost of the equipment, but still remaining in the field of 'conventional' photography, a low-cost amateur or semi-professional camera can be easily converted in a multispectral camera, by removing the infrared filter in front of the CCD/CMOS detector. The results can be amazing, since the detector of a conventional camera is sensitive in a spectral range (from 350 to 900 nm, usually), much wider than the visible. Once freed from the IR-cut filter, it is possible to exploit the sensitivity of the detector to obtain multispectral information in reflection – UV, visible and IR reflection – and fluorescence – UV-VIS, VIS-IR (also known as VIL), VIS-VIS (VIVL) and UV-IR (UVIL) fluorescence.

The use of modified camera, even compact and semi-professionals, possibly associated with conventional cameras, allows considerably expanding

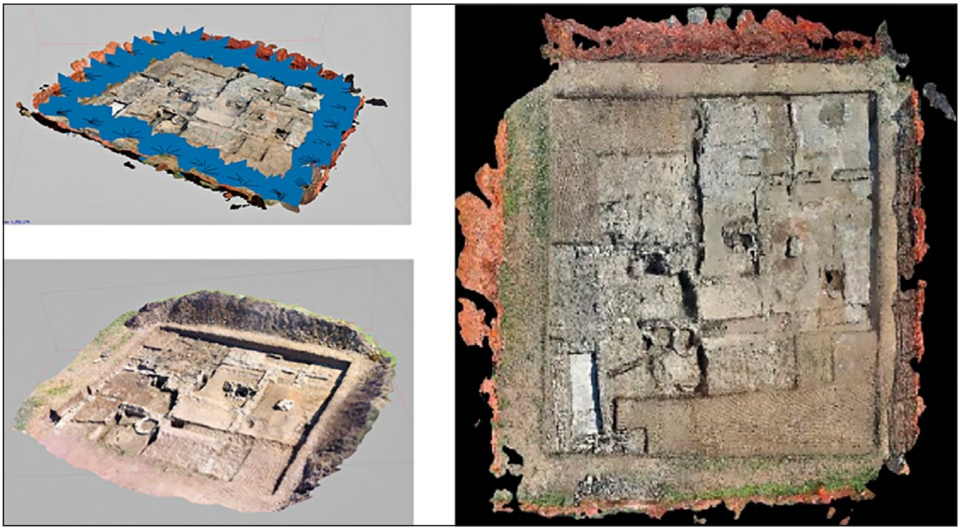

Fig. 1 – On left side: top 3D-model of the archaeological excavation in Luni (2017-Photos by J. Lucchesi, smartphone); bottom 3D-model taken by a drone; on right side: orthophoto of the site, from the model obtained on the ground with the smartphone.

the range of information obtained. Up to 3 bands in reflection and 4 in fluorescence may be easily acquired; through the use of common image software digital channel blending (false colours) can be performed to obtain first level information about metameric pigments. Affordable professional LED, characterized by a balanced irradiation and very low amount of parasitic emissions, in combination with suitable filters, allows splitting the VIVL into two subbands, while the VIL can be modulated to obtain further information beside traditional identification of specific pigments.

Moreover, the flexibility of a commercial camera allows producing images in diffuse reflectivity, transillumination, grazing light and specular reflection mode, also providing the reconstruction of dynamic lighting of large surfaces using the RTI (Reflection Transformation Imaging) technique. Although RTI is designed to give the best results in visible light, application in multispectral mode enrich the diagnostics performance: in fact, it is applied in the field of UV fluorescence, UV reflection and IR, as well as in the field of VIL luminescence.

Conventional and modified portable flashes represent the preferred in-field use irradiation sources. Consistently to the sensitivity characteristics of the camera sensor, flashes can reduce or suppress the ambient light disturbance, even without more complex procedures as digital subtractive masks. Flashlight also produces infrared emission and, if subjected to simple modifications,

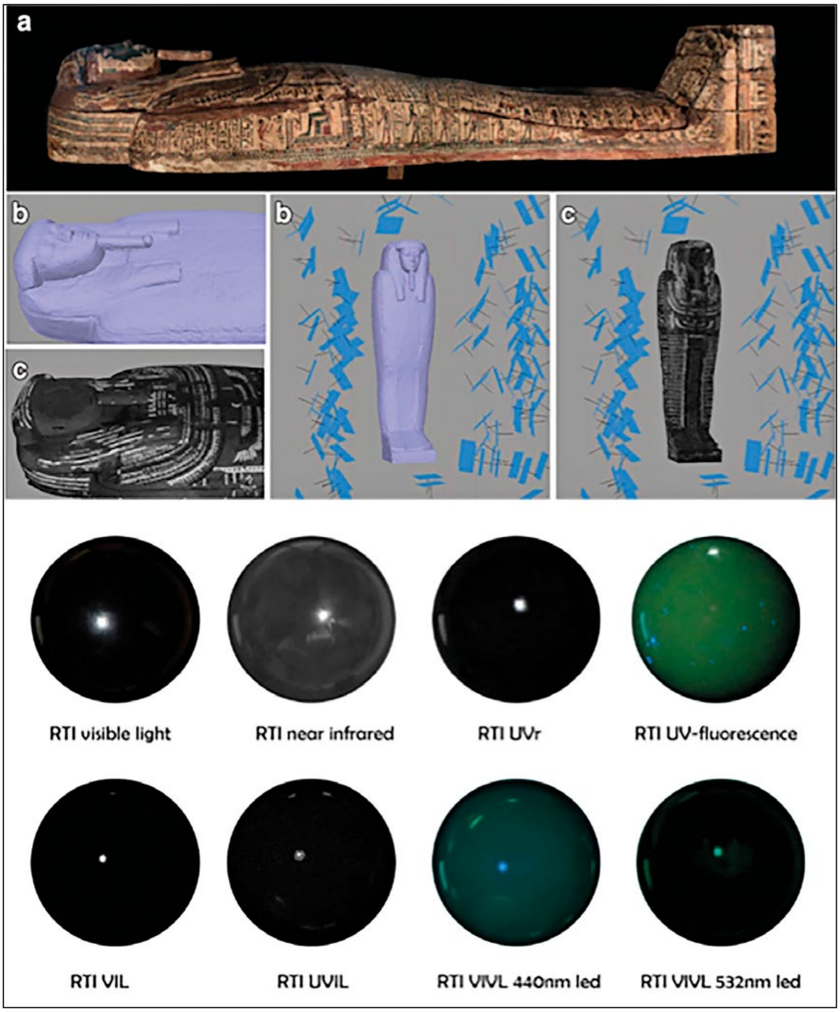

Fig. 2 – Top: Pasherienaset's sarcophagus (Ligurian Archaeological Museum in Pegli, Genoa, Italy): VIL 3D model in b) polygonal view and c) texturized view; bottom: RTI's reference spheres in multispectral mode.

provides an intense UV radiation. In the VIL field, the combination with a proper gradual filtering allows the acquisition both of correct images and of 'peculiar' shots, with a commensurate introduction of parasitic infrared light. These are aimed to produce RTI-VIL and 3D-VIL photomodeling, based on native integrated texturization and performable even through museal glass cases (Triolo *et al.* 2020).

4. Multispectral imaging with dedicated cameras

A further reasonable increase of the budget would allow the upscaling of the imaging system with the use of a full multispectral system. The use of a specialized multispectral system, while retaining the full portability of the alternative based on modified commercial cameras, would add the possibility

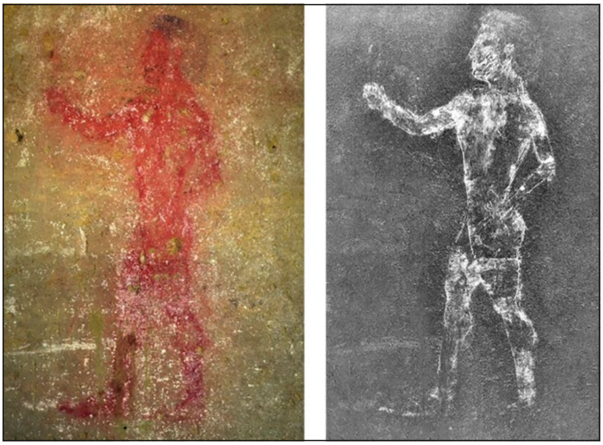

Fig. 3 – On left side: visible image of a Etuscan painting (Tomb of the Monkey); on right side: the image recovered after application of the MHX method.

Fig. 4 – On left side: visible image of a Etuscan painting (Tomb of the Monkey); on right side: the image recovered after application of the MHX method.

of controlling and optimizing by software the image acquisition process. Moreover, the use of a multispectral camera would permit to extend the sensitivity of the system beyond 1 micron in the infrared, and to catch minimal signals in UV-VIS and UV-IR fluorescence analysis, thanks to the possibility of acquiring long-exposure images with minimal thermal noise.

The use of an internal filter wheel for spectral selection is particularly useful for the acquisition of hyperspectral series. A 10-places internal filter wheel can be exploited for covering the visible range (from 400 nm to 650 nm) with 6 filters of 50 nm bandpass and the IR from 750 to 1050 with other 4 filters with 100 nm bandpass. However, in order to have the possibility to use external filters in case of need, it is customary to leave one filter place empty. In this case the alternative could be between removing the lower wavelength visible (400 nm) or IR (750 nm) filter. This is a matter of choice, to be decided according to the forecast needs of analysis.

This kind of hardware is at the basis of the MHX method, developed by CNR in the last years. The acronym stands for Multi-illumination Hyperspectral eXtraction and exploits the use of high spectral purity illumination

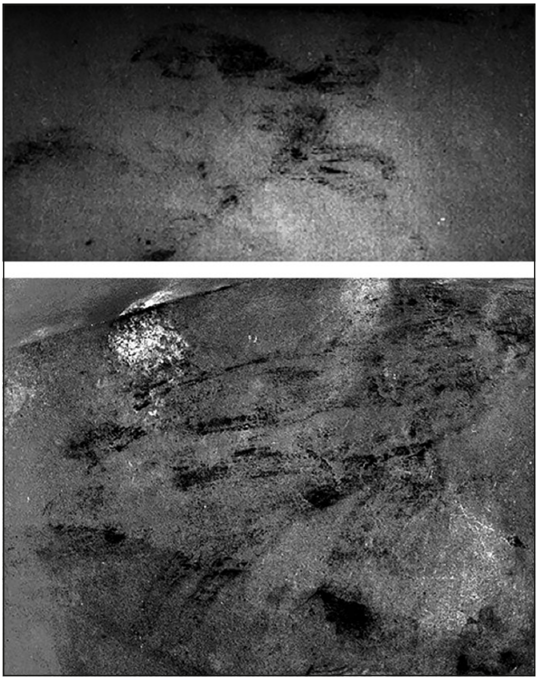

Fig. 5 – Application of the Infrared True Color method to merge the images in Fig. 4 for recovering a faithful chromatic apparence of the painting.

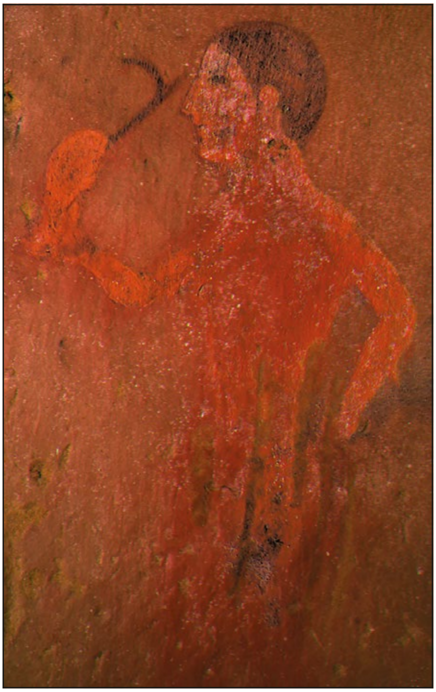

Fig. 6 – Top: the caracal hunting the deer; bottom: the wild boar. Tomb of the Blue Demons (Tarquina, Italy).

sources for the acquisition of hyperspectral images, that are subsequently elaborated with advanced statistical methods for the extraction of hidden information (Salerno *et al.* 2014; Legnaioli *et al.* 2018).

The MHX method has been successfully used in many archaeological and cultural heritage contexts and represents at the present the most advanced approach in the field of multi/hyperspectral image analysis for Archaeology and Cultural Heritage. Particularly important are the results obtained on the Tomb of the Monkey, in Chiusi (Siena, Italy). The Tomb of the Monkey, one of the most beautiful Etruscan painted tombs in Tuscany, was studied by the authors, who realized in 2014 a full 3D model (Giancristoforo *et al.* 2014) and examined in detail the two red painted figures in the front chamber, whose details seemed to be irrecoverably lost. As a result of the application of the MHX method, the readability of the two figures was greatly improved (Legnaioli *et al.* 2013), as shown in Fig. 3 and Fig. 4.

The application of the True Color Infrared (TCI) method developed by the Laboratory of Applied and Laser Spectroscopy in Pisa (Grifoni *et* *al.* 2019) allows a faithful merging of the MHX image, which by its nature does not carry the colour information, with the visible image, as shown in Fig. 5. It can be observed that the merging of the two images improves the readability of the image while maintaining a faithful chromatic appearance.

A further successful application of the MHX method was obtained on the Tomb of the Blue Demons (Tarquinia, Italy). In this case, a megalography covering the whole entrance wall, completely vanished and invisible at naked eye, was brought again to the light (Adinolfi *et al.* 2019). After the application of the MHX method, through the acquisition of reflectance and fluorescence hyperspectral images and the use of statistical separation methods for their analysis, a full hunting scene appeared. Two hunters were depicted to the left, in the process of killing a huge wild boar, assaulted from the back by a hunting dog. On the right part of the megalography, another hunter chase a deer, recognizable from his large antlers, while a wild cat (caracal) trained to hunt, lies in wait on the top of a rock (Fig. 6).

5. Conclusion

Imaging techniques are usually considered as a simple extension of traditional photography. In some sense, this is true, because at the basis of these techniques is the acquisition of (a set of) images, eventually resolved in wavelength. However, the potential of imaging techniques, for documentation and study, goes well beyond the one of conventional digital photography. What is particularly important is the fact that relevant information can be recovered using relatively cheap equipment (from a medium quality smartphone to a modified commercial camera, to possibly a full dedicated hyperspectral system), coupled to a proper (eventually open source) software. For these reasons, a large expansion in the use of these techniques in Cultural Heritage and Archaeology applications can be easily forecast.

Paolo Triolo
Università di Genova (Distav), Università di Urbino (Dispea)
triolox@libero.it

Luciano Marras
Art-Test Studio di Luciano Marras, Pisa
marras@art-test.eu

Gloria Adinolfi, Rodolfo Carmagnola
Società Pegaso, Roma
pegasocarmagnola@alice.it

Stefano Legnaioli, Simona Raneri, Vincenzo Palleschi
Applied and Laser Spectroscopy Laboratory (ICCOM) – CNR, Pisa
stefano.legnaioli@cnr.it, simona.raneri@pi.iccom.cnr.it, vincenzo.palleschi@cnr.it

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ABSTRACT

Imaging systems are the basic tools of the trade for art historians, conservators, and archaeologists, when they are called to document the results of their work. However, photo cameras and imaging systems are also powerful research tools. These systems, in fact, are inherently portable and give the possibility of acquiring high-resolution, spectrally resolved digital images that can be elaborated exploiting the most advanced algorithms of information science. In this contribution, we will outline the many possibilities opened by the available instrumentation and techniques, to suggest the use of image analysis as the first step of the diagnostic process in Cultural Heritage conservation and study.