European Journal of Science and Theology, April 2017, Vol.13, No.2, 127-134

IMAGE BASED RECORDING OF THREE-DIMENSIONAL PROFILES OF PAINT LAYERS AT DIFFERENT WAVELENGTHS

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(Received 30 September 2016, revised 9 November 2016)

Abstract

In recent years, the documentary survey of Cultural Heritage (CH) has experienced an enormous evolution boost, thanks to the implementation and optimization of Digital Photogrammetry. In this paper we present the results obtained by applying a new method for the 3D reconstruction of multispectral surfaces. Reality-Based 3D Modelling (RBM) coupled with Multispectral Imaging (MSI) can be a valid tool able to analytically point out and to enrich with new, revealing dimensions any 'text to be queried'. The method is applied to the study of a Renaissance painting conserved at the Civic Museum of Sansepolcro (Arezzo, Italy), depicting the Plague of Sansepolcro in 1523. The comparison between the 3D profiles obtained at different depths under the surface evidences the profile changes that occur in the layers under the surface. All the analysis was performed using inexpensive or even open source software; the availability of this software, together with the great flexibility in the experimental setup and the very short time needed for the acquisition of the images, suggests the application of the proposed method on a routine basis in the multispectral analysis of paintings, to obtain a better understanding on the profiles of the different layers under the painted surface.

Keywords: Multispectral Imaging, Image-based 3D modelling, photogrammetry, paintings

1. Introduction

In recent years, the documentary survey of Cultural Heritage (CH) has experienced an enormous evolution boost thanks to the implementation and optimization of Digital Photogrammetry: the branch of the science of

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representation by which it became possible to determine the objective knowledge of reality starting from its digital representation [1, 2].

The *Reality-Based 3D Modelling* (RBM) was born from the convergence of photogrammetry - which has the measured object's documentation as its purpose - and *Computer Vision* - which aims to the automatism in computer-assisted generation of fine geometric and appearance detailed three-dimensional models. While keeping in mind that the object of the studies on the tangible CH "is the artwork, physical material and concrete" [3], the scope of these technologies - generically referred as *Digital Imaging* - is to bring documentation, preservation and restoration of CH to a more computational approach.

Thanks to their large processing capacity, these applications can increment, supplement or partially replace the traditional heritage recording systems, improving and extending the deductible information and revolutionizing the practices of acquisition, analysis, processing and data dissemination [4]. Furthermore, through this method the paintings, which are usually showed as flat and two-dimensional entities, can be virtually acknowledged by the wide audience in their effective three-dimensionality. This can be defined as the new 'Cultural (digital) Revolution', that is a point in space-time in which coalition of science, technology and art is openly combined.

A specific variant of *Reality Based 3D Modeling* technique associated with the *Multispectral Imaging* (MSI) technique is here presented.

The need to obtain a better spatially resolved imaging system in different spectral bands in order to analyse the paint layers is an actual issue. RBM coupled with MSI can be a valid tool able to analytically point out and to enrich with new, revealing dimensions any 'text to be queried'.

The Multispectral Imaging (MSI) is a diagnostic technique that provides qualitative information about materials and pigments used in painted surfaces, based on the dependency of the reflectivity on the wavelength. In particular, some hidden details referring to the usual artistic practice - such as drawings, sketches or *pentimenti* - can be revealed at certain wavelengths otherwise invisible to the human eye because of the overlying paint layers [5, 6]. However, the peculiarity of the optical radiation to penetrate at different lengths under the object surface can be exploited for determining the profiles at different depths under the surface, according to the wavelength used for the acquisition of the multispectral images. In particular, the wavelengths in the near-UV and Blue bands of the spectrum are very sensitive to the surface details, while the green, red and infrared bands usually give information about the layers progressively under the surface [7, 8].

Reality-based 3D surveying and modelling is meant as the digital recording and 3D reconstruction of CH using non-invasive optical recording sensors that can be divided in active (e.g. laser scanner or radar) [9] and passive systems (e.g. digital cameras). Using remote sensors all around the object and specific open source software it is possible to extract three-dimensional (3D) coordinate in a points cloud model from two dimensional (2D) digital images in a rapid, accurate, reliable, flexible and economical way. This is termed Multi-images Photogrammetry or Structure From Motion (SFM) [10, 11]. Accordingly, this digital photogrammetric approach can be extended to images acquired with multi-spectral systems for the generation of different three-dimensional models of the same objects [12], in principle one for each spectral band of the multispectral instrument.

This achievement is a key factor for the actual applicability of 3D multispectral imaging in real situations, since the available open source software relaxes most of the constraints on the geometrical setup at the acquisition time with respect to more expensive commercial systems, so that a standard multispectral imaging system can be now used without the need of complex (and expensive) camera movement devices.

For demonstrating the full feasibility of the 3D multispectral approach, in this paper we report the results on the in-depth 3D reconstruction of the multi-spectral surfaces applied to a 16th century painting (oil on wood) by *Giovanni del Leone*, representing the 1523 plague in Sansepolcro (Arezzo, Italy). The painting is conserved at the Civic Museum in Sansepolcro and was studied in the framework of the First International School for non-Invasive Diagnostics of Cultural Heritage, organized last summer by the National Research Council, the National Institute of Nuclear Physics and the National Interuniversity Consortium of Materials Science and Technology (INSTM), with the support of the *Opificio delle Pietre Dure* of Florence and the City of Sansepolcro (Figure 1).

2. Experimental

2.1. Multispectral system

The multispectral images used for reconstructing the 3D multispectral surfaces were acquired using 8 megapixels Chroma C4 multispectral camera, produced by DTA s.r.l. (Cascina, Italy). The camera was equipped with a Nikon 50mm objective; the multispectral acquisition was obtained using 4 interferential filters, in the interval between 450 and 1050 nm. The bandwidth of the filters was +/-25 nm around the central wavelength. The CCD sensor was electronically cooled at -10°C for reducing the electronic noise during the acquisition. The illumination of the painting was obtained using two halogen lamps (100 W, color temperature 2300 K) placed about 2 meters from the painting, at an angle of about 45 degrees with the painting surface.

The spectral behavior of the pigments used for the realization of the painting is complex and different in the different parts of the panel. The multispectral series acquired on the painted surface of the wooden panel is shown in Figure 2.

Figure 1. The painting analyzed in this work (RGB image).

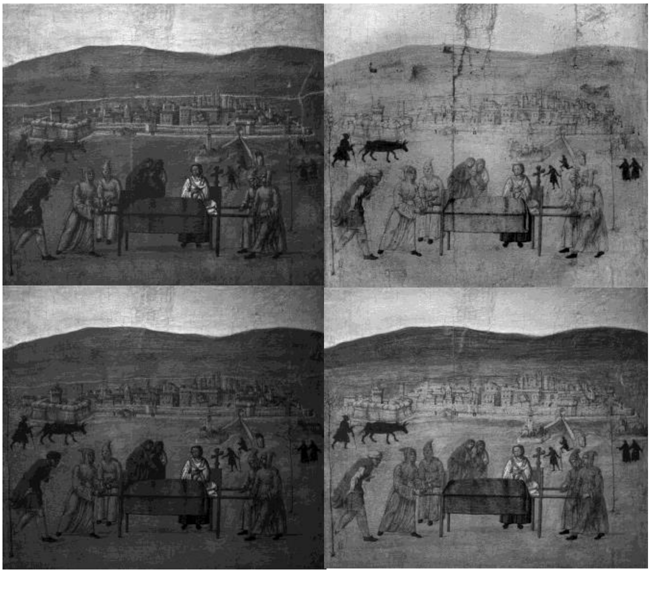

Figure 2. The multispectral sequence of the painting under study. Top left: 450 nm, top right 550, bottom left 650 nm, bottom right 1050 nm. The bandwidth is +/- 25 nm around the central wavelength.

The considerable difference between the multispectral images corresponding to the blue (450 nm), green (550 nm), red (650 nm) and infrared (1050 nm) images, suggests the possibility of obtaining different 3D information in correspondence of the layers under the painted surface.

2.2. Multispectral surfaces

For reconstructing the 3D model of the surfaces at different depths under the painting layer, a triplet of images was acquired at each wavelength, placing the camera at a distance of about 100 cm from the surface and moving it of about 15 cm at the left and the right of the central image. The multispectral camera was oriented to have the painting always at the center of the image. This geometry is much more flexible and easy to apply than the strategy adopted in other commercial photogrammetric systems, which impose a strict geometry with the optical axis of the camera always perpendicular to the surface, at a fixed distance.

The 3D models of the multispectral surfaces were obtained using Agisoft Photoscan ver. 1.0.4, low cost commercial software that implements the Bundler algorithm for the feature detection and camera calibration [13] and CMVS/PMVS2 package [14] for the dense point cloud reconstruction. Substantially similar results were obtained using fully open source software (Visual Structure from Motion (VSFM) [15] for the generation of the dense point cloud and Meshlab [16] for the creation of the 3D mesh with the Poisson reconstruction algorithm [17] and the texturization of the model). The level of accuracy obtained using Agisoft Photoscan or the open source alternatives has been demonstrated to be comparable, if not better, to the one achievable using an expensive commercial 3D micro-photogrammetry software [18].

3. Results and discussion

An example of the 3D multispectral surface, obtained at the wavelength of 450 nm, is shown in Figure 3a.

The clear brush signs that are evident in the 3D model corresponding to the painting surface (450 nm) disappear almost completely in the green band model (550 nm – see Figure 3b).

The 3D model corresponding to the red (650 nm) spectral band does not differ appreciably from the 3D model shown in Figure 3b. At these wavelengths, the light penetrates the painted layer, and the 3D model clearly evidences the profile of the preparation layer (Figure 3c).

Surprisingly enough, the infrared model (1050 nm) reveals several details (Figure 3d) that would suggest the (erroneous) conclusion on the existence of a deeper painted layer beneath the surface.

In fact, the upper layers should be substantially transparent to the infrared radiation, for that to explore and give information about the in-depth structure of the paintings.

The possible reason may be that the infrared radiation is not able to penetrate deeply as it should because it is strongly absorbed by some pigments of the paint film. Therefore, the infrared radiation in this case reveals details of the painting's surface in a way which is similar to the one obtained using the blue radiation at 450 nm (Figure 3a).

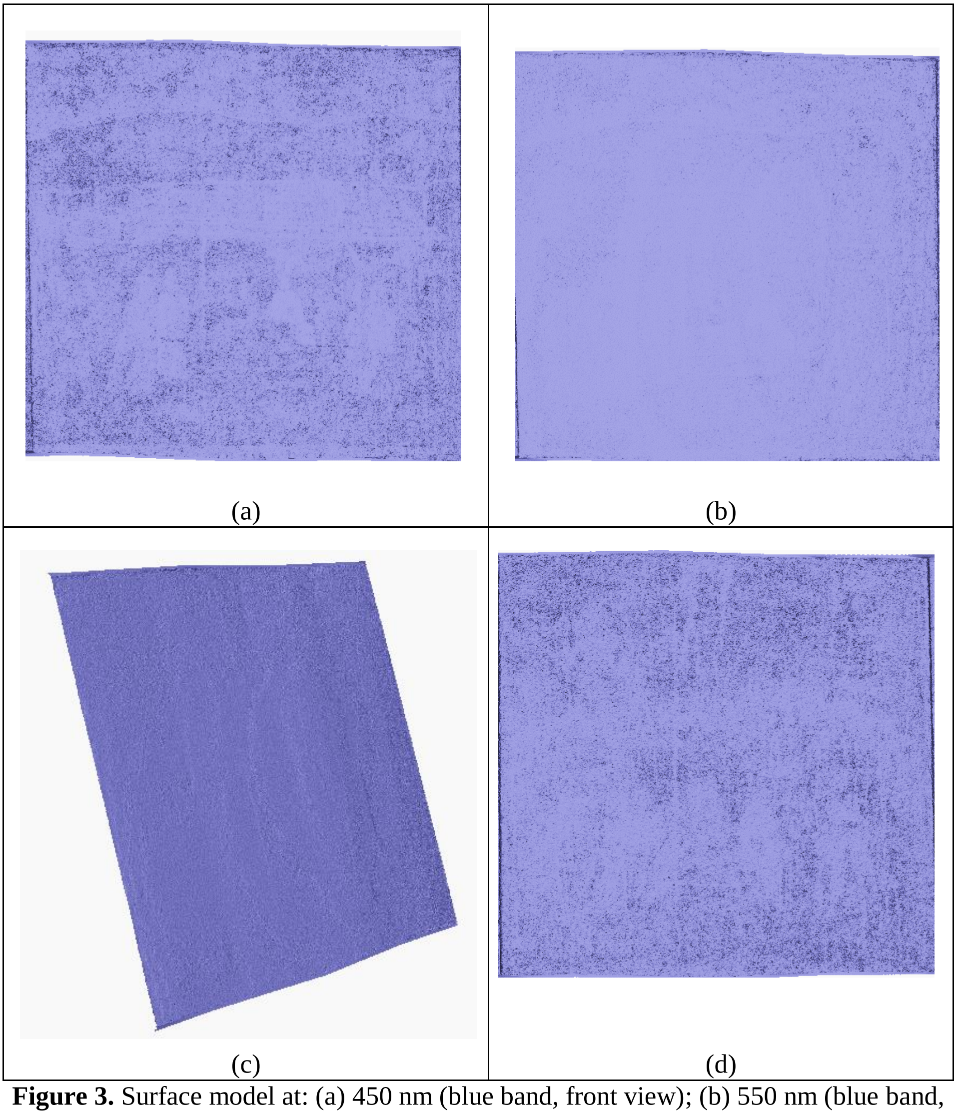

Figure 3. Surface model at: (a) 450 nm (blue band, front view); (b) 550 nm (blue band, front view); (c) 650 nm (red band, grazing view); (d) 1050 nm (infrared band, front view).

4. Conclusions

In this study, we have presented the results of 3D in-depth analysis of the multispectral surfaces on a 16th century painting. The comparison of the 3D surface models at different wavelengths can be roughly correlated with the depth of the layer under the surface probed by the radiation, under the hypothesis that the upper layers are transparent to this wavelength. In the presented case study, the surface layer appears to be partially transparent to the green and red radiation, and this allowed the reconstruction of the profile of the preparation layer underneath the painted surface.

The 3D model reconstructed using the infrared band, on the other hand, gives information on the pigments of the painting surface that are opaque at this wavelength.

The availability of inexpensive or even open source software for the 3D surface reconstruction and the flexibility of the experimental configuration would suggest for a routine application of the multispectral surfaces method in painting analysis. This method could give very useful information about the in-depth structure of the painted and the preparation layers in short time and at no additional cost with respect to a traditional multispectral analysis.

Acknowledgment

The authors thank the Director of the Civic Museum of Sansepolcro for the support during the painting's analysis and for allowing the publication of the present results.

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