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MONITORING OF THE SURFACE PATTERN OF ARTISTIC AND ARCHITECTURAL ARTEFACTS BY MEANS OF ULTRA CLOSE RANGE PHOTOGRAMMETRY

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Abstract

Today 3D technology and new digital instruments allow to represent the features of shape and colour of the objects in three dimensions, and constitute an useful tool for archaeological research, conservation and monitoring of Cultural Heritage assets. The ultra-close range photogrammetry approach, based on the same principles of classical photogrammetry, allows to generate a measurable3D model of small area, or artefacts of small size, by means of digital images. The technique, totally non-invasive, is currently used to assess the state of conservation and monitoring of objects and artefacts directly on-site.

In the present work two examples of application of ultra-close range photogrammetry for assessing of state of conservation of surfaces of artistic and architectural interest are illustrated. The first case study regards the evaluation of cleaning treatments performed by chemical method and laser procedure on the detached fresco from the intrados of the *Arco della Pesa* in Sansepolcro (AR), Italy. The second case study regards the façade of Santa Croce in Lecce made by bioclastic limestone (Pietra di Lecce). In this case the effectiveness of consolidating treatments was controlled on several areas on the facade of Santa Croce in Lecce made by. The portability and the non-destructivity of such methodology (no-contact measurement method), suggest this methodology to be used, during the restoration works, for an easily and effective documentation method of the surface pattern, for control and monitoring of weathering processes of the intervention.

Keywords: photogrammetry, documentation, surface monitoring, pattern analysis

1. Introduction

The documentation of artistic and architectural surfaces is usually performed by photographic surveys (photos and grazing light photos). These techniques only give 2D information while the third dimension (depth or elevation) is lost. The depth or elevation is a crucial feature in order to

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investigate the surface pattern. 3D data can provide essential information for an early detection of any change, which is crucial to prevent irreversible damage. The laser scanner technique and photogrammetry are candidates to give this important information.

Digital photogrammetry is an image-based technique to obtain metric information of objects from their photographic images, the principal application of photogrammetry is the production of topographic maps (aerial photogrammetry).

Photogrammetry is often used in the field of Cultural Heritage to document the state of conservation of surfaces of objects of artistic and architectural interest. Surveys obtained by photogrammetric techniques provide models easily measurable, and allow highlighting dimensional variations occurring during natural ageing (physical-chemical processes).

The analysis of deformations of the wooden painting panels and canvas supports in relation to changes of environmental conditions (relative humidity and temperature) were already performed by a digital 3D surveying methods [1, 2]. The accuracy required for this surveying application is less than 1 mm while highest precisions (ranging from 1 to 100 μm) are required for a proper characterization of surface changes due to restoration operations, such as cleaning treatments or consolidating operations. Recent works focused on the 3D tool based on the 'shape-from-focus' technique [3] and ultra-close range photogrammetry [4], both for assessing of micro-morphological features during laser treatments to clean surfaces of artworks.

The cleaning intervention on painted surfaces is one of the most important and sometimes controversial stages of the restoration, because it can be a process that changes in irreversible way the surface if it is performed in no correct way. During the cleaning intervention, the restores have to decide, regarding to the patina (dirty, varnish, etc.), which are the optimal parameters of the cleaning process that allow the removal of undesired layers without damaging the underlying ones.

This topic is discussed in this paper, focusing on the use of ultra-close range photogrammetry to assess the amount of patina removed during a cleaning treatment.

The case study is a detached wall painting from the intrados of the Arco della Pesa in Sansepolcro (AR), Italy. The wall painting is dated from the 16thcentury, while the first detachment of the fresco was due to Leonetto Tintori around the mid-1950s.

The decorative cycle has been largely lost, only several fragments that frame the family crest of Altoviti are preserved. Today the paintings are housed at the Territorial Superintendent in Palazzo Pitti in Florence, and some of these have been moved for restoration interventions to the laboratories of Opificio delle Pietre Dure of Florence.

The second topic presented in this paper, concern the application of ultra-close range photogrammetry to assess consolidating treatments performed on stone substrate. It is clear that the assessment approach depends on the substrate

if it is plaster or stone well as the type of applied product. On wall paintings the effect of the treatment is concentrated on superficial layers, while on stones the applied product must also penetrate in depth. In both case cases the surface texture must be evaluated to establish the effectiveness of the applied product, when it is no possible to use invasive tests, such as peeling test for example, the ultra-close range photogrammetry allows an assessment of the surface morphology.

This work introduces the possible application of ultra-close range photogrammetry for on-site evaluation of the effectiveness of cleaning treatments on frescoes and of the consolidating intervention on bioclastic limestone performed by ammonium oxalate and ammonium phosphate.

2. Materials and methods

The ultra-close range photogrammetry is a non-destructive method useful for monitoring of surfaces after/during restoration activities, or of structural anomalies such as cracks, fissures and detachments of painted layer or small parts in unstable equilibrium.

The ultra-close range photogrammetry is based on the same principles of classic photogrammetry, but is applied to a different scale: this technique allows to generate a RGB points cloud of a surface acquiring only three images (or more if necessary), defined triplet, shooting from different angles, of the same area.

The sizes of the acquired area can vary from 2 cm^2 to a maximum of 20 cm^2 with regard to the distance between the shots and the lens of the camera.

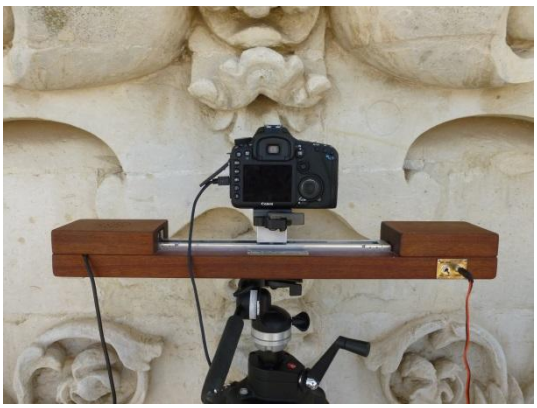


Figure 1. Micro-photogrammetry system (by Menci Software Srl,, Arezzo, Italy).

The system (Figure 1) [5-8] is composed by a hardware part that consists in a motorized bar 260 mm long, and a digital reflex camera (Canon 7D) equipped with calibrated lens (28 mm or 60 mm depending from the target

sizes).The process of acquisition is controlled by a dedicated software that moves the camera along the bars and the acquisition parameters.

Once the area of interest was chosen, the program gives an automatic evaluation of the distance between the camera and the surface of interest, and suggests the better distance for the sequence shoots (*step*).

As soon as the shooting parameters were fixed, the system produces three shots of the same area, by moving the digital camera from right to left along the motorized bar.

The acquired images were then processed by a dedicated software that generate a points cloud through a specific algorithm. The generation process of the points cloud includes following steps:

- image rectification to eliminate geometrical and optical distortions,
- selection of the area that must be processed,
- definition of the step resolution value,
- production of the points cloud.

On the 3D model can be applied a texture (derive from photographic image) that permitted to appreciate the variations colour and the surface pattern.

By using commercial devices it is possible to choose different focal lengths, e.g. the use of a 28mm lens allows the reconstruction of larger areas after the acquisition of multiple shots, the single models are mosaicked in order to obtain a single one.

In order to align several individual models, at least five homologous points on the surface must be selected, trying to arrange them consistently over the entire surface, the software will automatically rotate, move, and overlapped the single models. If it is not possible recognize homologous points on surfaces, as is the case for homogeneous surfaces from the standpoint of colours or roughness, several markers can be fixed on the surface in order to facilitate the operations of overlapping.

Once the acquisition has been done and 3D model has been achieved, another specific software is used to generate the Digital Elevation Model (DEM) selecting a reference plane (UCS – Users Coordinate System) through the seeding points, and finally the metric information (i.e. the xyz data)can be extracted.

The analysis of the surface pattern is performed by a dedicated routine in Matlab [R. Manganelli Del Fà and C. Riminesi, *Sistema ultra-closerangephotogrammetry per la conservazione dei Beni Culturali: principi di base, prestazioni e possibili applicazion (Ultra-closerangephotogrammetry tool for the conservation of Cultural Heritage assets: basic principle, performance and possible applications)*, IFAC-CNR TSRR, Firenze, in press]. The best accuracy in the xy plane is about ±40 μm, and about ±30 μm in elevation, these performances have been obtained with controlled light conditions.

3. Results and discussion

3.1. Assessment of cleaning treatments

The ultra-close range photogrammetry was used to evaluate the thickness of the patina (calcium oxalate) removed by cleaning treatments from the painting layer of the detached fresco of the Arco della Pesa in Sansepolcro (AR), Italy. Three areas were chosen to compare the effectiveness of three different cleaning treatments (chemical, *Long Q-Switching laser* (LQS), and *Short Free Running laser* (SFR)) by the photogrammetry approach. Each area was divided in four sub-areas. One of the four sub-areas for each area was non-treated and dedicated for controlling (sub-area A). The others sub-areas were treated by a progressive cleaning procedure in 3 step each one with the same aggressiveness. For the sub-area B was applied only one step of cleaning, for the sub-area C was applied two step of cleaning and at last for the sub-area D was applied 3 step of cleaning.

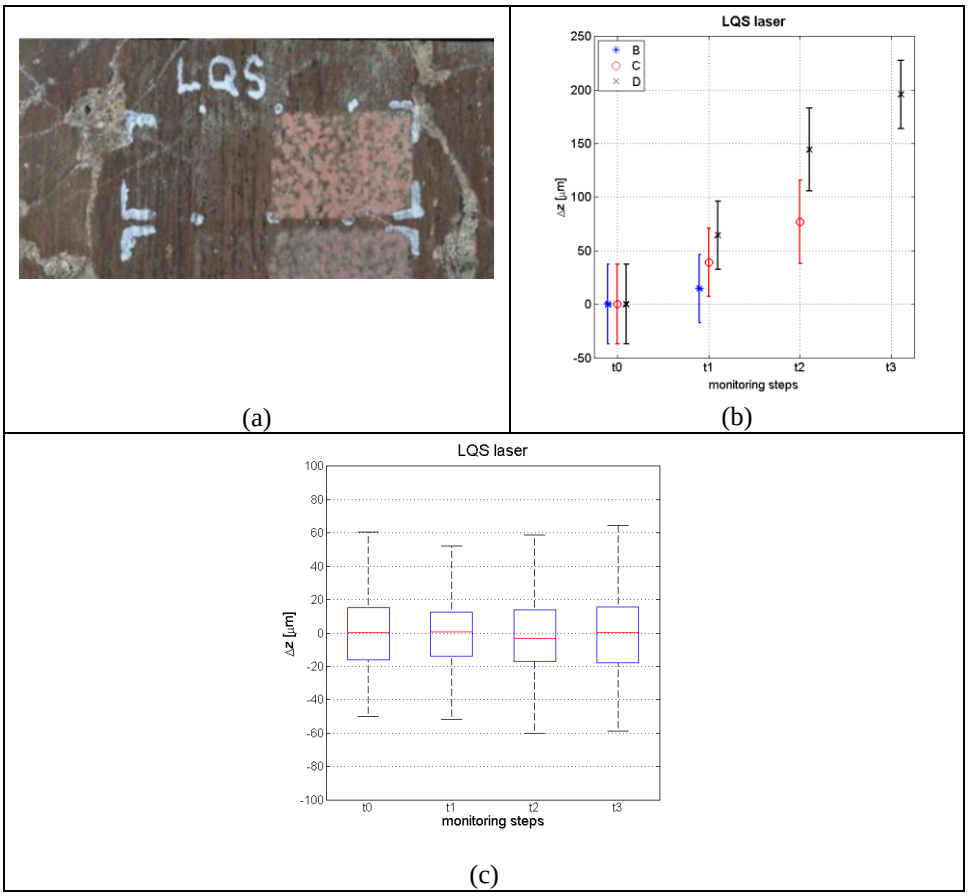


Figure 2. (a) The 3D sub-model arranged into a single one; (b) the graphic shows the thickness (Δz) of the removed as a function of the monitoring step; (c) a statistical evaluation of the roughness by boxplot.

The motorized bar was positioned at 320 mm from the surface painting, and the acquisition step was fixed to 16 mm (this value is congruent to the distance of the acquisition). Five shots were needed to cover all the cleaning area, and three 3D sub-model were generated, and arranged into single one model (Figure 2a).

For each treated area a single model was realized, and for each sub-area (A, B, C, and D), xyz coordinates of the surface have been exported. The points within the single areas (at t_0) were used to create an interpolation plane (reference plane) to which were referred all points of the same area (B, C, and D).

The orientation of the reference plane respect to the acquisition plane of the camera was known. By evaluating the distance of each points of the treated sub-area from its reference plane, it was possible to determine the thickness of the material removed during each cleaning treatment phase.

On Figure 2b, the thickness (Δz) of the removed material is shown as a function of the control step (the error bar is equal to the root mean square). On the x-axis, t_0 indicates the evaluation of the surface before of the treatment (reference), while t_1, t_2, and t_3 are related to the control after first, second, and third steps of cleaning, respectively.

The roughness is a descriptive parameter of the surface morphology and its control can help in the selection of the cleaning treatment. In Figure 2c is presented a statistical evaluation of the roughness by boxplot.

In descriptive statistics, a boxplot is a convenient way of graphically depicting groups of numerical data through their quartiles (the quartiles of a ranked set of data values are the three points that divide the data set into four equal groups, each group comprising a quarter of the all data). Boxplots may also have lines extending vertically from the boxes (whiskers) indicating variability outside the upper and lower quartiles. Boxplots display differences between populations without making any assumptions of the underlying statistical distribution: they are non-parametric. The spacing between the different parts of the boxplot helps to indicate the degree of dispersion (spread) and skewness in the data [R. Manganelli Del Fà and C. Riminesi, *Sistema ultra-closerangephotogrammetry per la conservazione dei Beni Culturali: principi di base, prestazioni e possibili applicazion*].

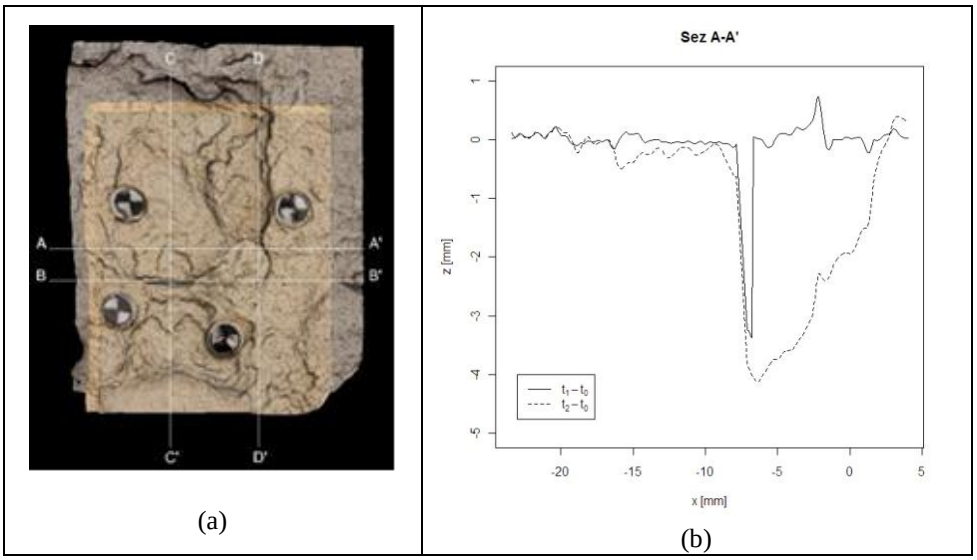
This type of representation allows visualizing the dispersion of the surface's quotes with respect to the average value; such it is possible to estimate the surface roughness. For all the treatments, the Z-variation introduced by cleaning treatments is not very appreciable with respect to the initial pattern (time zero t_0).

3.2. Assessment of the effectiveness of consolidating treatments

In this case the photogrammetry in ultra-close range configuration is used for assessing the effectiveness of some consolidating treatments applied on the

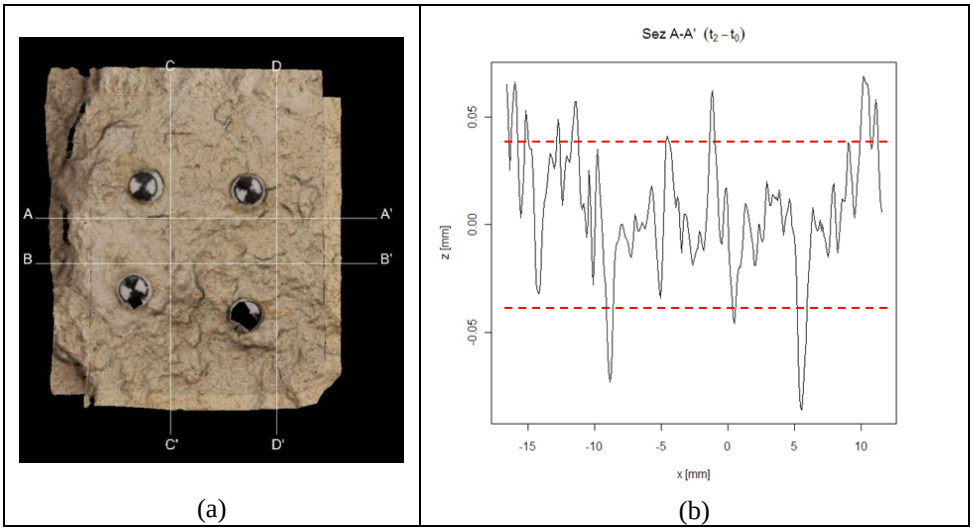
facade of Santa Croce in Lecce realized with a bioclastic limestone (Pietra di Lecce).

Several areas with similar state of conservation are selected to comparing the performance of some consolidating products respect to non-treated areas.



(a) (b)

Figure 3. (a) The reference area selected for the monitoring; (b) comparison of the elevation profile along the section AA' at different steps of monitoring respect to the initial condition (t_0).



(a) (b)

Figure 4. (a) The area treated with ammonium oxalate selected for the monitoring; (b) comparison of the elevation profile along the section AA' at different steps of monitoring respect to the initial condition (t_0).

The measures concerned the balustrade area and two different areas of the fastigium, each area was divided into three sub-area: one treated with ammonium oxalate, one treated with ammonium phosphate and a comparison of untreated.

The variations of the surface morphology were monitored at different times after the initial treatments (t_0): t_1 refers to the 8^{th} month, and t_2 refers to the 16^{th} month.

The areas of interest were acquired with Macro lens from a distance 300 and 337mm, depending on the difficulty of positioning of the system. The distance between following shoots (*step*) between 15 and 17 mm, is depending on the distance acquisition.

All the acquired images were processed for generation of 3D models, using a resolution step of 10 pixel (1 pixel generated in the space for 10 each pixel of the image).

The patterns of the surfaces acquired by means of the photogrammetry at each monitoring step have been overlapped and the pattern differences elaborated. Some illustrative profiles are plotted in Figure 3 for the non-treated area and in Figure 4 for the area treated with ammonium oxalate.

Comparing the profiles at t_1 and at t_2 respect to the initial condition (t_0) it is clear the loss of material form the surface of the non-treated area (Figure 3a). For area treated with ammonium oxalate the differences are comparable with the precision error of the measurement (Figure 4a).

4. Conclusion

The ultra-close range photogrammetry method and its possibility to be applied in monitoring surfaces of interest for the Cultural Heritage have been illustrated. The method allows, thorough the acquisition of three images by a commercial camera, to obtain metric information on the surface under investigation. The advantages due to the simplicity, the portability and its non-invasivity (no-contact measurement method), prospect this methodology to be used in usual restoration works for an easily and effective documentation of the surface pattern, for controlling and monitoring the weathering and restorations processes.

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