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THE MICROPHOTOGRAMMETRY: A NEW DIAGNOSTIC TOOL FOR ON SITE MONITORING OF MONUMENTAL SURFACES

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Abstract

The digital photogrammetry is a modern image-based 3D rendering technology currently in use in the field of the conservation and documentation of monumental buildings, architectural surfaces and historical objects.

The development of the photogrammetry for documenting and analyzing limited portions of monumental surfaces, objects of small size and laboratory samples, i.e. microphotogrammetry, has been proposed. The great effort in improving the matching and elaboration software, made by Menci company, for correlate images of the same area taken at different time steps let us to use this methodology for on site monitoring campaigns. The new methodology has been validated in laboratory investigations and experiments and its sensitivity and reliability as measuring tool for qualify the “surface pattern” (colour and geometry) of an historic asset has been verified. A first successful on site application was made monitoring the evolution of crack placed along the cross in the fresco of *San Domenico adorante la Croce* by Beato Angelico, at Museum of S. Marco in Florence.

1. Type of technology/methodology

Digital photogrammetry (1, 2), as one of the modern image-based and 3D rendering technology, is currently in use in the field of the conservation and study of built cultural heritage and monumental surfaces. It usually represents a practical documentation instrument to obtain 3D models used for architectural surveys and mapping of surface conservation state at fixed times.

Microphotogrammetry technology has been developed in a close collaboration with Menci Software company as a portable and practical diagnostic technique for on site characterisation of surface geometry and chromatic changes.

This 3D sampling technology is based on the acquisition, by a Canon EOS 400D digital camera (10M pixel) equipped with a Canon EFS 60mm macro lens, of a set of at least three shots (called ‘triplet’), from which a 3D model of an object is generated by ZScan software. The camera is positioned on a motorized bar (Fig. 1), which allows very precise camera movements during acquisition phase (selected steps for selected number of shots). The test management (setting of digital camera, acquisition parameters, movements and shots) is controlled by the dedicated software using a notebook. All hardware is battery operated and can be used on site without any electrical source.

Figure 1. The microphotogrammetry system.

The validation of the new methodology is based on the evaluation of the following features:

- Reproducibility
- Sensibility
- Reliability

The *reproducibility*, and consequently the comparisons between data acquired at different times, is an essential requirement to establishing common on site monitoring recommended protocols and is guaranteed by definition of fixed and not movable space references on the surface, such as opaque markers solidly anchored on surface. Regardless of available space references, the phase of 3D model registration is extremely relevant, in particular during matching of correspondent points directly on 3D models, generated at different steps and to be compared. Clearly the overlapping will be better, if the taken area contains morphological elements which could be used like space references, as for the case of painted surfaces. Moreover if acquired surface isn't completely flat, the registration can be refined by a sophisticated ICP (Iterative Closest Point) algorithm, that automatically find the best 3D model fitting (3).

The illumination in outdoor contexts could be a critical factor as can interfere on reliability of chromatic change evaluations.

The use of the annular flash could provide a repeatable illumination, but there's the risk of flattening of the surface and, consequently, influencing the surface pattern measurements. As general rule it's recommended to acquire the triplet sequence with a constant low intensity artificial light.

In relation to *sensibility*, the microphotogrammetry was tested in laboratory on simulations of degradation phenomena on stone surfaces in order to assess surface pattern changes on scale of tenth to hundredth of a millimetre.

3d reconstruction method:

3d surface reconstruction from images is a great study subject by the international scientific community. Many solutions are proposed differing on number and kind of images, and on reconstruction algorithm. Most of the methods described in literature is based on use on a pair of images and epipolare geometry. The results obtained by a pair of frames are very dependent on surface texture and morphology of reconstruction.

Some good results were obtained using algorithms reconstruction of predictive type: these, knowing in advance some approximate morphological information, take benefit to pre-filter and then choose the most likely among the candidates for stereo correlation. The validity of these methods, however, is restricted to the specialist field for which they were created.

For this reason the use of stereo correlation for instrumental purposes in the past has had so far fewer applications than could have it.

The system described, developed by Menci software, get over many limits that normally the stereo correlation presents, enabling the reconstruction of morphological areas with few restrictions. So it is usable as a real instrument for the three-dimensional surface reconstruction.

The proposed approach is based on the use of three or more frames taken from aligned positions with same direction and orientation axis. The easier condition is to make shoots from a translating camera along a straight axis and orthogonal to the subject. In this way it’s possible to use only one camera and a calibrated slider bar, in a simple hardware setup (Fig. 1). Particular attention must be paid to camera calibration.

Shoots can be three or more and with different baseline, but same studies on economy and process efficiency lead us to the choice of just three symmetric frames. The reconstruction algorithm (4). is quite complex and is based on the elaboration of images for the elimination of optical geometric aberrations. The images are then analysed by an operator of interest in finding a number of features depending on their size, but that is usually not less than 1500. Features position can influence the later stages of calculation.

A features search algorithm based on epipolar geometry constraint, leads to obtain the orientation of frames with high accuracy.

Attitude angles are close to zero, and their magnitude depends on the tolerance of slider bar mechanical construction and same small structural obscillation (tripod, head, etc.). A good orientation is the prerequisite for the success of the reconstruction process. When orientation is done a trinocular rectification is performed so that vertical parallax is simultaneously eliminated on images. Surface reconstruction is based on dynamic programming least squares image matching.

Cross-correlation is simultaneously computed on three images using RGB colour components.

2. Type of parameter that is preferentially measured and of material monitored

The microphotogrammetry method has been developed for the "surface pattern analysis": In fact the 3D image contains, for each pixel (with 60mm lens it can be equivalent to an area of 0.1 x 0.1 mm) the RGB and X,Y,Z values. The precision of the system, taking into consideration the type of lens used, the shift (step) among the 3 shots and the distance from the subject, is typically comprised between 5/100 and 50/100 of mm. These features let us to use the method for measuring the topography of the area investigated and its colour. Furthermore, the digital camera does not have the usual drawbacks of the laser scanner and the texture of the 3D model is exactly that one of the original. The 3D model can be derived from any kind of cultural assets.

The development of specific software able to match two 3D model (and related orthophotos) on overlapped area taken after some time lets us to put in evidence the differences, if any, of the surface pattern and in such way effectively monitoring its evolution in time.

A – Surface Topography

The 3D modelling of surface represents an efficient and practical tool to verify the conservation state and degradation phenomena of cultural heritage objects. The *reliability* to detect morphological features and measure thickness on small and limited portions of architectural decorative apparatus by microphotogrammetry system was verified on a block taken from a column of the Florence's cathedral. In the examined case it was possible to detect thickness of black crusts and corrosion effects on marble (Fig. 2).

Naturally it would be possible to follow on site the evolution of such black crust due to the action of natural ageing and effects of interactions with environmental and climatic factors.

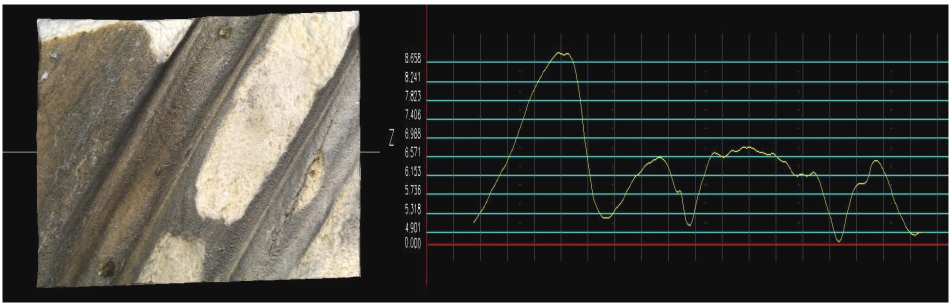

Figure 2. The topographic analysis of the surface of a marble piece coming from a column of the Florence's cathedral.

Grains of fine sifted sand (Ø < 0.5 mm) were anchored on the surface of a marble specimen simulating a particulate deposit effects (Fig. 3 a-b).

After the analysis of the surface pattern differences, it appeared clear that the instrument consider deposited particulates as changes of Z coordinate inside the (X, Y, Z) space. This is visible in the image obtained by the difference (Fig. 3c), i.e. the map of Z-differences between before and after the modification event. Through an appropriate selection of the amplitude of analysis range and the number of frequency classes, the areas characterized by positioned grains are clearly delimited and detected using a filter by-pass (Fig. 3d).

The elements added on surface could also be highlighted on the map of chromatic differences.

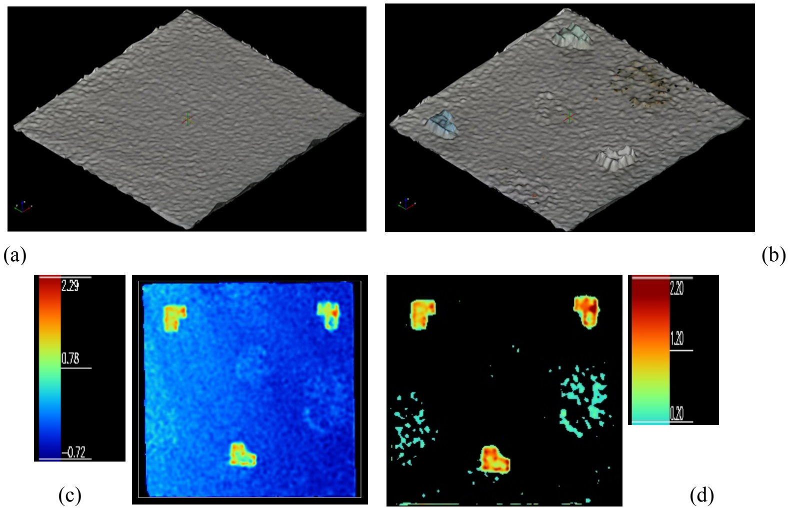

Figure 3. 3D images (south-west view)of the marble specimen before (a) and after (b) the deposition of small particles; subtraction DEM with total Z-differences (c) and with selected range of Z (d).

B – Measuring tool

The microphotogrammetry can be used just as measuring device. The DRMS (5) is a very useful diagnostic instrument for evaluate the "hardness" of monumental stones but has severe limitations for very soft or very hard and abrasive materials. In order to test such kind of materials we are developing the use of the micro sandblasting method. In this case the microphotogrammetry system can be used for evaluate their "abrasion resistance".

Five holes were realized by blowing aluminium oxide (Al_2O_3) abrasive powder (size of particles 80 µm) using a handset equipped with a nozzle (Ø = 0.8 mm), at constant pressure (4 atm) but with different time of action: 5, 10, 20, 30 and 60 seconds, respectively (Fig. 4).

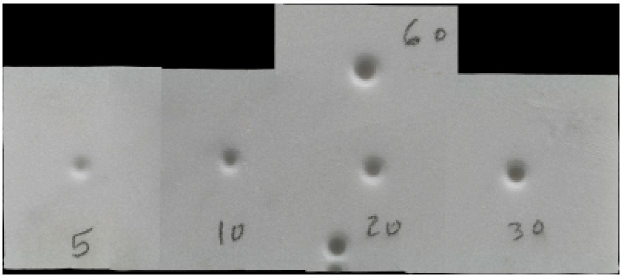

Figure 4. 3D image of the marble specimen with the sequence of holes due to the action of the abrasive powder impacting at 4atm pressure for 5, 10, 20, 30, 60 sec.

We can observe increased abrasion efficiency with the time of action, with a linear correlation between the two variables (Fig. 5). The elaboration of depth measurements on 3D models generated by the triplet (Fig. 6) is indicated as the Z value measured between the bottom of the hole and the average value of surface (considered the zero level). The marble specimen was lightened with an artificial source positioned in front of the surface, allowing a homogeneous and complete illumination of the hole bottoms.

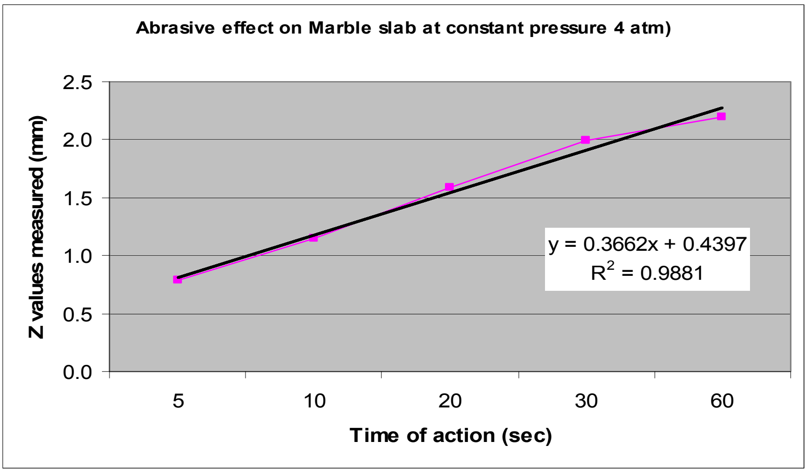

Figure 5. Behaviour of the abrasive action as a function of the time on marble slice.

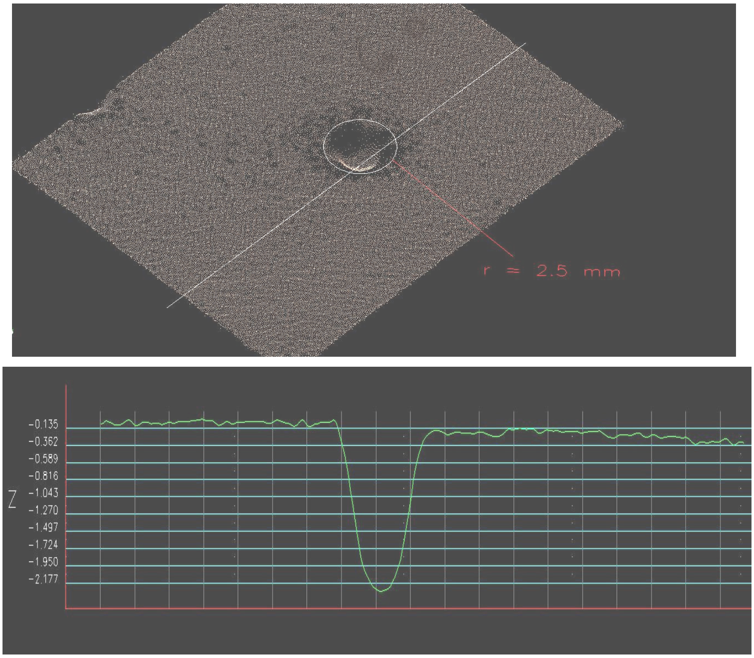

Figure 6. Point clouds of the last hole (4 atm for 60 sec) with the measurement of the radius and the line of the Z-profile.

B – RGB analysis

This technology can be also used for the evaluation of chromatic changes being registered for each pixel its RGB values. Furthermore, the color acquisition can be managed without any contact with the object. The output of the analysis of chromatic differences on selected areas is a mapping of RGB coordinates associated to the points of 3D models. These can be elaborated in many color formats: Lab, xyz.

The validation of this methodology is under work on laboratory samples, using constant lighting and a reference chromatic standard palette. The results will be correlated with the classical Minolta Chromameter data determined on the same sample under the same exposure conditions.

3. The on site application

Every type of material and typology of artefact, can be analyzed and monitored by the microphotogrammetry system.

The complex and accurate phase of development and validation of the microphotogrammetry technology was aimed to establishing smart on site monitoring protocols and proposing this image-based and 3D sampling technique as one of the main future diagnostic technologies for on site monitoring of monumental surfaces.

The necessity of a stable and fixed position of the measurement apparatus during the acquisition phase represents one of the main practical problems in outdoor contexts, especially on restoration scaffoldings. Any small movements or instability could create artificial shifts of the X,Y,Z coordinates between acquisition shots and consequently a wrong 3D-model difference could be generated.

The monitoring of surface pattern modifications consists of evaluation of progress or temporarily or permanent state of degradation phenomena, such as salt efflorescence, humidity effects, corrosion, biodegradation activities, geo-mechanical displacements(fissures and creeps) and chromatic changes.

The fresco of *San Domenico adorante la Croce* by Beato Angelico, at Museum of S. Marco in Florence, was selected as case study to test the microphotogrammetry in an on site context (Fig. 7 left). This monumental mural painting represents one of the masterpieces of the Museum and, according to new approach to conservation and maintenance of cultural heritage, a long-term monitoring would be useful to control the conservation state and create a diagnostic database about this mural painting.

During the first survey which took place at Complex of S. Marco on March 3rd 2008, it was established to start a long-term monitoring of the fresco and, in particular, of the visible fissure along the cross of the painting. According to its extension, a set of acquisitions was carried on to create a digital mosaic covering the entire area of interest (Fig. 7 right).

Figure 7. 3D model of fresco *San Domenico adorante la Croce* by Beato Angelico (left) with indicated monitored area, whose ortophoto is displayed (right).

The successive step was made on May 26th 2008 providing the first data to start the comparative assessment of any changes on the conservation state of the selected area.

A map of Z-differences was obtained from the comparison of the collected data, whereas RGB analysis was considered not convenient because of the absence of reproducible conditions of illumination between the two surveys.

The comparison carried on by couples of correspondent triplets, seems not to reveal particular geometric changes of the monitored crack placed long the cross in the fresco of Beato Angelico (Fig. 8).

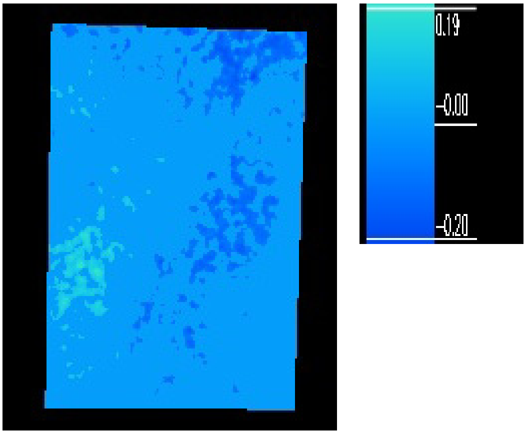

Figure 8. Comparison of subtraction DEMs: one shows no Z-differences between two steps of monitoring campaigns.

4. Evaluation of results and further advances

The evaluation of the surface pattern modifications represents one of the main methodology to monitor the conservation state of cultural heritage and degradation phenomena. Statistic analyses of data obtained from the elaboration of 3D models allow the quantification of surface patterns in a long period of time and provide an immediate evaluation of the changes through maps of differences.

The application of a non-contact measurement methodology for monitoring of chromatic changes would provide an efficient tool alternative to other colorimetric techniques, which are based on the direct contact of the colorimeter with the analyzed surface and shows some practical limits, especially when conservation issues make the colorimeter contact not convenient.

The microphotogrammetry technology needs more progress to be completely developed for on site monitoring, first of all the assessment of reproducible lighting conditions during the acquisition phase. In fact, an appropriate light source would allow a better and more reliable evaluation of chromatic changes at different times.

It also would be possible to increase the sensibility of the measurement apparatus to reveal degradation phenomena and morphological changes at the scale of tens of micrometer.

REFERENCES

1. N. Yastikli, 2007, *Documentation of cultural heritage using digital photogrammetry and laser scanning*, Journal of Cultural Heritage, 8(4), 423-427.
2. H.M. Yilmaz, M. Yakar, S.A. Gulec, O.N. Dulgerler, 2007, *Importance of digital close-range photogrammetry in documentation of cultural heritage*, Journal of Cultural Heritage, 8(4), 428-433.
3. G. Impoco, P. Cignoni, R. Scopigno, 2005, *A six-degrees-of-freedom planning algorithm for the acquisition of complex surfaces*, International Journal of Shape Modeling, 11(1), 1-23.
4. B. Van Genechten, H. Neuckermans, 2005, *Fusing laser scanning and photogrammetry creating close range architectural orthoimages*, Augmented Heritage, proceedings of the 10th European International Conference, p. 35-44, ISBN 2-909285-32-4, Damascus, Syria, 13-15/09/2005.
5. F. Fratini, S. Rescic, P. Tiano, 2006, *A new portable system for determining the state of conservation of monumental stones*, Materials and Structures, 39(2), 139-147.