Experimentation of a three-focal photogrammetric survey system as non invasive technique for analysis and monitoring of painting surfaces decay condition

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ABSTRACT: This is a contribution to the process of monitoring and evaluation of frescoes laser cleaning, quantitative pictorial material loss detection, and qualitative data acquisition, necessary to evaluate the state of conservation of pictured surfaces (decay typologies, physical characteristics, morphology, etc.), useful to manage conservation interventions. We wished to verify the efficiency of an innovative survey system, based on the acquisition and processing of multi-view high quality images sequences, as an innovative and non invasive inquiry instrument that can support traditional techniques (like visual and instrumental analysis) in collecting colorimetric and morphologic data of paintings needing restoration, and for superficial decay kinetics analysis.

1 INTRODUCTION

Laser techniques applied to frescoes cleaning in art conservation have demonstrated very promising applications for restoration purposes. Laser based methodologies have had successful results, taking advantage of the peculiar characteristics of laser radiation for elemental composition, structural defects detection, and professional restorers are being acquainted with these new instruments and methods (Appolonia, L. & Brunetto, A. 1999).

So far laser is a selective tool and the shotted beam is absorbed by dirt without affecting the substratum, as the beam power can be varied according to the operator's needs, nevertheless it is of main importance to project the restoration intervention and document the artifact before and after the restoration process. Moreover degradation patterns must be recognized, recorded, and compared with similar ones for further investigations. Monitoring of the conservation degree of art pieces is essential in Cultural Heritage management and, as it allows to detect possible degradation phenomena and their diffusion, it requires repeated measurements of relevant parameters. In the field of interest of architectural surfaces frescoes and paintings, two of the most important parameters concern geometric and colorimetric information. To enable the detection of surface changes at a given resolution (e.g. erosion, mould growth, chemical alterations), geometric and colorimetric measurements must be sufficiently accurate and strictly correlated each other.

Technologies adopted must then give accurate data during frescoes analysis and must be a useful monitoring tool, before, during and after restoring intervention.

Taking into account this purpose a trifocal digital photogrammetric-based technology has been tested for the acquisition of Quart Castle's frescoes in Aosta. Medieval Quart Castle near Aosta is formed by a set of buildings arranged within a fortified perimeter, adapting to the natural contour of a difficult rocky slope. Medieval frescoes surveyed decorate the internal walls of the *donjon*. Actually they are being restored with laser based cleaning techniques by Anna Brunetto (Brunetto, A. 2004), under direction of the Superintendence of Valle d'Aosta Region.

It has been used a laser type Nd JAG, 1064 nm wave length at different pulse time (SFR, LQS, QS).

The trifocal digital photogrammetric-based technology have been previously tested in Siena at *St. Maria della Scala*, *Cappella del Manto* (Fig. 1), for the survey of frescoes during the cleaning intervention (Brunetto, A. 2008); relevant outputs after data processing have encouraged to adopt and apply this system widely in paintings documentation and restoration intervention.

By means of the used survey technology, that is a multi image matching system, it has been possible to metrically reconstruct, at different LOD, from macro to micro scale, the all frescoes and samples of pictorial surfaces, obtaining accurate 3D scans (point

Figure 1. 3D RGB point clouds general 951000 points and detail of 2 million points

clouds including both spatial and RGB information) that show all those information needed for the complete paintings knowledge.

Establishing protocols for the acquisition and the 3D models reconstruction process (before, during and after restoration) reproducibility, within the same data collecting and processing is a preliminary condition. Results of color measurement of a test point on a painted surface may change significantly when moving the capture device position. This technology fulfill this task, for time monitoring the kinetics of individuated decay pathologies, or even for controlling the effects of executed restoration interventions. A correct approach to artworks conservation requires the identification of defects at an incipient stage.

Through the use of algorithms for surfaces comparative analysis, it has been possible to evaluate the effects of paintings laser cleaning and to register the micro variations in paintings depth in terms of amount of removed material and loss of pictorial fragments. Final precision depending on the distance between camera and object, on the type of lenses and on general photo conditions (object lighting).

2 TECHNOLOGY AND METHODOLOGY

2.1 *Technology: hardware*

Concerning the frescoes survey, the trifocal digital photogrammetry-based survey technology adopted is ZScan Survey System and ZScan Micro (manufactured by Menci Software of Arezzo): they can be used to obtain RGB point clouds and relative 3D models, at different levels of detail, starting from the treatment of a number of images, taken with a limited set of constraints, through the use of a special acquisition equipment, and processed in a specific software, through the application of image matching algorithms. The acquisition equipment consists of a calibrated aluminium bar, of 100 cm (Fig. 2) for medium scale acquisition and of 30 cm (Fig. 3) with millimetric camera step positions, computer controlled, for micro evaluation. The bar can be easily mounted on a photographic tripod, which is provided with a small trolley for supporting a digital calibrated camera. Both the bar and the digital camera calibration parameters, that have to be sent to the software for data processing, are necessary in order to allow the spatial reconstruction of camera centre position and to know the distortions due to the optics employed.

The trolley allows to move and to secure the camera in different fixed positions on the bar in order to acquire sequences of images of the same object from different angle-shot. To produce a single 3D model, a sequence of three images, has to be taken from the left to the right, shifting the camera along the bar.

The left and the right shots must be symmetric compared to the central shot, and the distance

Figure 2. ZScan calibrated bar and digital camera.

Figure 3. ZScan micro with automated bar.

between them (the baseline) has to be carefully evaluated in relation to the optimal distance of the camera from the object (1:8 - 1:10), survey accuracy and level of detail required. There is no need of

topographical support points, in order to create the single 3D model. However it is possible to make use of ground control points, during image processing, in order to geo-reference the single point clouds, in relation to a global datum system, and then to facilitate point clouds registration necessary for producing a final complete 3D model of the surveyed object.

The systems satisfies characteristics of great flexibility and ease of use and guarantees, at the same time, accuracy of the geometric data acquired; however, using an image processing algorithm for 3D reconstruction, the system has some limits of application in relation to the characteristics of measured object surfaces. It reveals some limits in the 3D point cloud reconstruction of surfaces endowed with homogeneous colors, repetitive patters or high reflective materials.

2.2 *Methodology: data acquisition*

The frescoes at Quart Castle have been surveyed in two survey campaign (July, September 2008) and in both occasions in two steps: from a distance of 1-2 m with a 24 mm calibrated lens with the 1 m bar for full coverage of the walls (a 10.2 megapixel CCD digital camera) and within a distance of 24-28 cm from the painted wall with a 80 mm calibrated macro optic (a 15.0 megapixel CCD digital camera) for details.

From a distance of 150 cm the captured field of view has been of about 70x100 cm^2 with taken images of 3872x2592 pixels (Fig. 4); from a distance of 24 cm have been framed 3,8x5 cm^2 areas of 3888x2592 pixels (Fig. 5) using the micrometric bar, for close survey of the frescoes surface.

The aim was to document wall paintings before, during and after the surface *descialbo* intervention and to evaluate the quantity of "material" removed by comparing elevation values (DEM), of correlated points before and after the restoration intervention in order to numerically and graphically describe surface's trend, or to compare surface's differences in time.

This documentation has been then mainly a test to verify ZScan technology as a valid tool to control frescoes laser cleaning, but even if a detailed decay conditions analysis and pathologies record have not been done, nevertheless results obtained encourage to use this technology also for these purposes. It is possible in fact to query the detailed point cloud with ZMap tools so to extract dimensional data and eventually to upload any post processed output (vector or raster) in dedicated GIS (Salonia, P. et al. 2005).

Frescoes status of conservation could then be periodically verified and recorded, along with the probable causes of possible future decays, taking into account the complexity of decay phenomenology on pictorial surfaces.

Wall frescoes are especially sensitive to temperature and humidity variations. Temperature and humidity act as shearing forces between layers or portions of a wall, weakening the material during the numerous cycles of these forces and causing the

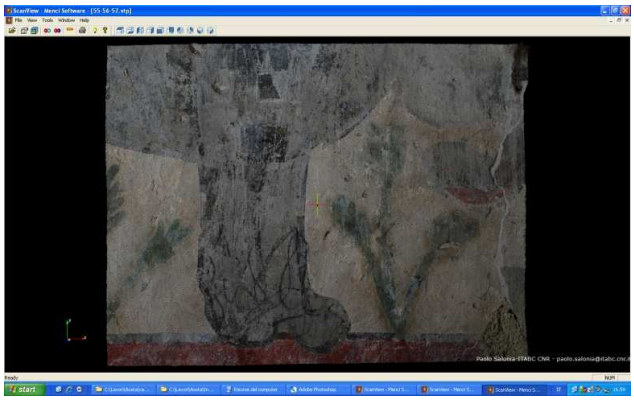


Figure 4. 70x100 cm frame.

Figure 5. 3,8x5 cm frame.

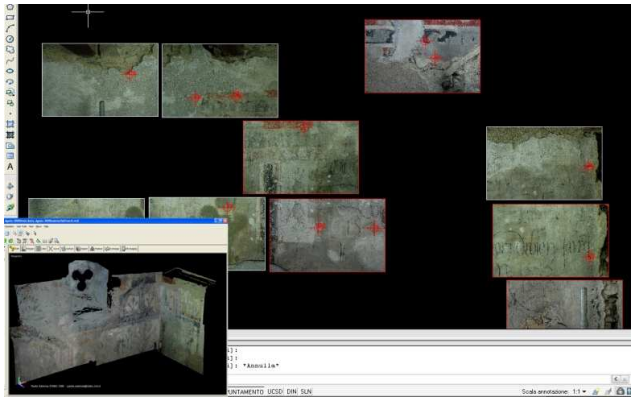


Figure 6. Topographic survey and merged 3Dmodel.

appearance of micro-cracks, debonds or anomalous strains on the surface, finally resulting in the decay of the artworks, actually Quart's frescoes are interested by cracks and fractures occurring on walls, contour scaling, mechanical damaging, salt crusts.

A painting on a wall can be considered as a layered structure with a support, coated with plasters, which serve as a base for the painting.

These layers are less thick and more fragile than the support. Expansion and contraction of the support due to daily fluctuations of ambient parameters can produce large strains and eventually cracks in the layers, as they become less flexible with age.

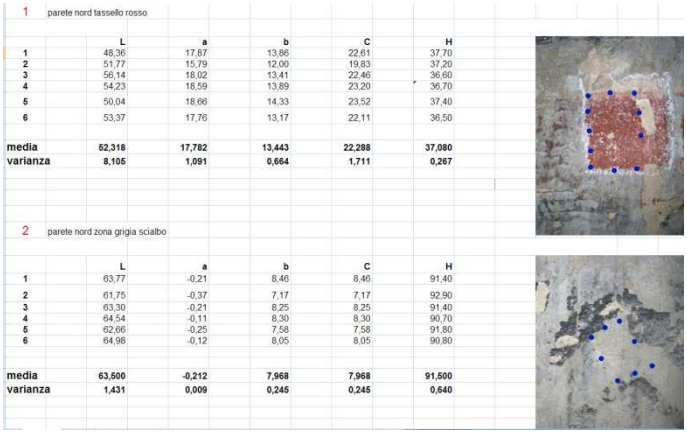
Furthermore, abrupt changes of temperature and humidity, and heat exposure may also cause unpredictable stress distributions in the heterogeneous materials of the support with consequent damage of the painted surface. All these mechanisms may lead to the formation of detachments that must be geometrically monitored.

Some GCPs have then been taken with a reflectorless total station, registered in a local coordinate system, so to fix constraints for the 3D final model reconstruction (Fig. 6) .

By means also of topographic survey it has been possible to understand how the presence of the support cracks or discontinuities alter the movements of the painted surfaces.

For what concern colorimetric measurements and comparison is of main importance to reproduce the same measurement conditions in time, test point localization, color temperature of lights (LUPO quadri-light 4x55W 5400°K) and surveying geometry, in terms of spatial position between instrument and scene, have then been recorded.

Each point of point clouds has a vertex color value that have to be eventually equalized to real colorimetric coordinates The Chemical Analysis Laboratory of the Superintendence of Aosta has taken spot colorimetric measurements (LabCH values) (Fig. 7), on some of surveyed areas, with a Minolta CR700 (technician Dario Vaudan). Those data can be used to correct images color in the 3d point clouds reconstruction.



1 parete nord tassello rosso

	L	a	b	C	H
1	48,36	17,87	13,86	22,61	37,70
2	51,77	15,79	12,00	19,83	37,20
3	56,14	18,02	13,41	22,46	36,60
4	54,23	18,59	13,89	23,20	36,70
5	50,04	18,66	14,33	23,52	37,40
6	53,37	17,76	13,17	22,11	36,50
media	**52,318**	**17,782**	**13,443**	**22,288**	**37,080**
varianza	**8,105**	**1,091**	**0,664**	**1,711**	**0,267**

2 parete nord zona grigia scalbo

	L	a	b	C	H
1	63,77	-0,21	8,46	8,46	91,40
2	61,75	-0,37	7,17	7,17	92,90
3	63,30	-0,21	8,25	8,25	91,40
4	64,54	-0,11	8,30	8,30	90,70
5	62,66	-0,25	7,58	7,58	91,80
6	64,98	-0,12	8,05	8,05	90,80
media	**63,500**	**-0,212**	**7,968**	**7,968**	**91,500**
varianza	**1,431**	**0,009**	**0,245**	**0,245**	**0,640**

Figure 7. LabCh values.

2.3 *Methodology: data processing*

Approach in the surfaces reconstruction has been a two step approach ; first the modeling of architectural structures and global frescoes, second the processing of micro details with high resolution, georeferenced to the global one.

Data processing has been carried out through the use of two dedicated software that are part of ZScan survey system.

Single point clouds models have been extracted from each triplet of acquired images (Fig. 8). after chromatic equalization between different shots through the use of an image processing commercial software (Photoshop).

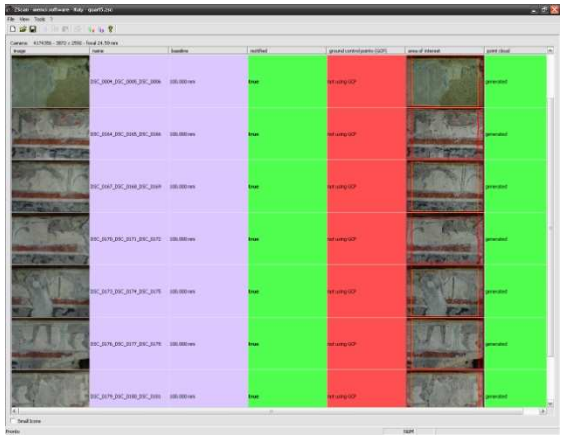


Figure 8. Triplets processing.

The procedure for RGB point clouds extraction, consists of four main steps: images rectification, through the application of trinocular rectification and feature matching, in order to eliminate geometrical and optical distortion; selection of the image areas of interest (AOI) that have to be processed; definition of the step resolution value, measured in pixel unit; production of a point cloud relevant to each group of three images, through the application of matching algorithms during image processing. Moreover, contextually to the point cloud production, the software allows to automatically create a texturized triangulated surface, through a triangulation process of the point cloud.

According to the survey precision and to the representation detail needed, a step resolution value of 3 pixel was adopted for the elaboration of each three images sequences of global and detailed paintings, corresponding respectively to 0.654 mm point to point sample spacing and 0.037 mm on the created point cloud.

Each sample of the global fresco (70x100 cm^2) is around 0.9 millions of points and each micro (3,8x5 cm^2) is about 0.74.

These high resolutions permit to easily detect and

measure features with advantages of photo-realistic visualization. For instance it has been possible to quantify fissures dimensions , superficial alterations and features induced by material loss with millimetric accuracy; fissures vary from 1 up to 7 mm of depth and 150-180 cm of length (Figs 9-9a).

Other geometric measurements, angles, radius, cross sections are easily extracted from data using dedicated tools as those in Rapidform Tm (Inus Technology) software (Fig. 10).

Figure 9. RGB point cloud.

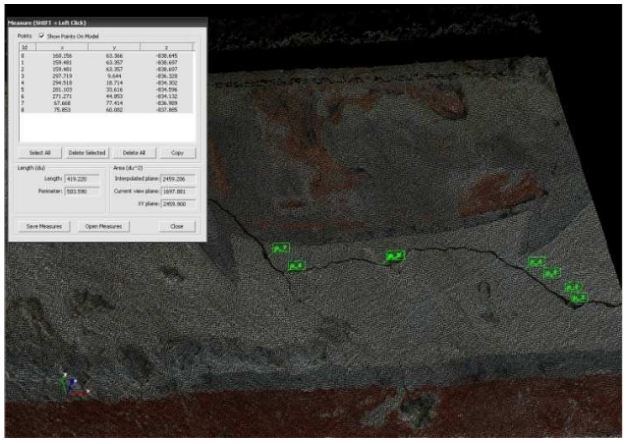


Figure 9a. Fissures measuring.

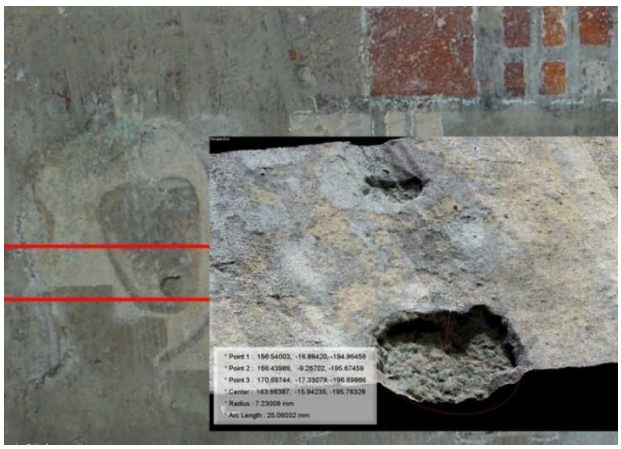


Figure 10. Erosion measuring.

The study of deterioration processes implies availability of models simulating the deterioration dynamics, DEM analysis and comparison in ZMap permits to numerically and graphically describe surface's trend, or to compare surface's differences in the time (Fig. 11).

The detection process aims at deriving both coverage and morphological measures regarding decay areas. Thus, it addresses both accurate location estimation and efficient shape segmentation.

Single areas are overlapped trough omologous non collinear points (Fig. 12). Although in a noiseless situation three points is the absolute minimum, more points must be used in practice to ensure that the match is more robust (i.e., less sensitive to uncertainty in the positions of the points). The match is then defined in the least-square sense and at least 6 GCPs have been processed with average residual values in xyz of 0.046 mm (Fig. 13).

Once matched two or more pictures, taken with Zscan micro, in different times, DEM are generated

Figure 11. Point clouds before and after *descialbo*.

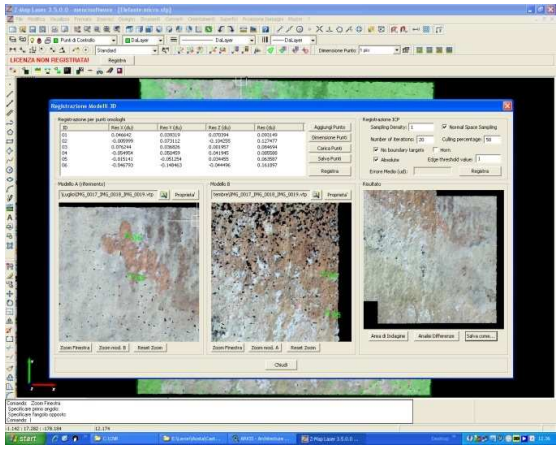


Figure 12. GCPs correlation.

and uploaded inside the comparing interface of the software. Z min, Z max, and range of values variation are automatically generated and reported (Fig. 13).

We have evaluated after *scialbo* laser cleaning an average Δz of 0.078 mm, value that represent the average *scialbo* thickness. It has been then validated the potential and the efficiency of the. cleaning method and technology adopted.

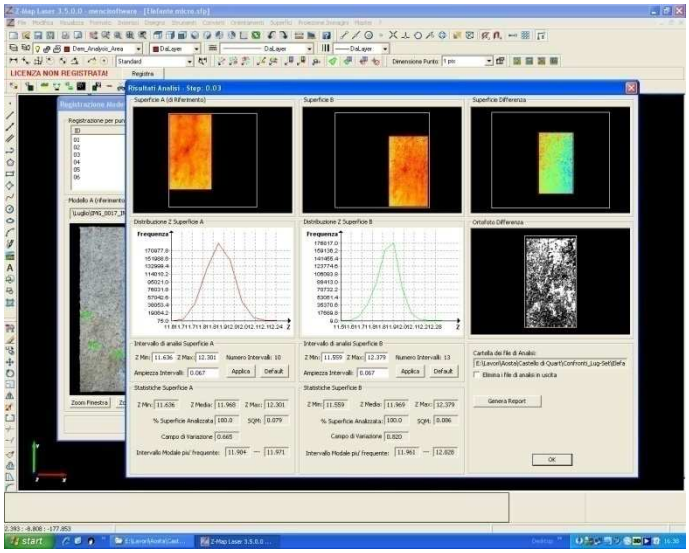


Figure 13. DEM analysis.

Moreover, as throughout the cleaning process, some parameters such as the laser pulses are modified resulting in the removal of patina layers differing in thickness, each cleaned strip should be recorded between adjacent spots in Δt. It has been also possible to evaluate the percentage of area covered by patina layer, 60%, and their average size and spatial distribution on the overall fresco.

3 CONCLUSIONS

In this article have been presented the application of digital imaging techniques and technologies in the monitoring of laser cleaning intervention on wall frescoes. The aim was to evaluate the exact quantity of removed material trough the reconstruction and comparison of 3d models of wall surfaces before, during and after restorers work.

Data extracted from 3d RGB point clouds have been extremely useful to validate laser cleaning methodology for frescoes restoration as sub-millimetric measures on 3d models can be taken due to high LOD obtained with ZScan Micro technology.

Image processing (IP) techniques can then be used for extracting information regarding the demaged areas in paintings, moreover, the proposed non-destructive approach enables measurements on the intensity distribution of decay, which is directly associated with the thickness of the patina crusts at these areas. The comparison of results derived by the monitoring of cleaning processes in time provides an overall assessment of the potential and the limitations of optical digital 3D inspections also in the reliable estimation of surfaces decay kinetics.

In future survey campaign of Quart's frescoes will be possible to go deep in ZScan application, being this a reliable non invasive technology for a wide range of different data typology acquisition.

4 AKNOWLEDGMENTS

It would not have been possible to accomplish this presented work without the remarkably intelligent and wonderful availability constantly shown by restorer Anna Brunetto. With outstanding professional far-sightedness she accepted to submit to our micrometric survey her interventions of laser cleaning for both Cappella del Manto at St. Maria della Scala Church - Siena, and Quart Castle – Aosta.

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