INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 4, Special Issue, 2013: 525-534 www.ijcs.uaic.ro

ULTRA CLOSE-RANGE PHOTOGRAMMETRY TO ASSESS THE ROUGHNESS OF THE WALL PAINTING SURFACES AFTER CLEANING TREATMENTS

Ilaria BARBETTI[1], Alberto FELICI[2], Donata MAGRINI[3], Rachele MANGANELLI DEL FA'[3], Cristiano RIMINESI[3*]

[1] Freelance conservator/restorer V.le F. Strozzi, no.1, 50122, Firenze, Italy
[2] Opificio delle Pietre Dure di Firenze, V.le F. Strozzi, no.1, 50122, Firenze, Italy
[3] CNR-ICVBC, Via Madonna del Piano, no.10, 50019, Sesto Fiorentino, Italy

Abstract

In the present work authors show the results obtained by means of the application of ultra close-range photogrammetry for assessing the pattern of a detached wall painting's surface during/after cleaning treatments. The cleaning treatments are critical operations in conservation so the choice of the method and the definition of the protocol require preliminary activities and studies for the optimization of the procedure. Since the removal of the material is an irreversible operation, an extremely selective method is needed. The criteria traditionally chosen for the selection of the adequate cleaning procedure are the evaluation of the amount of material removed during the treatment and the surface variations (roughness) before and after the treatment. A non-destructive technique could be particularly highlighted as an assessment tool; to this aim the authors propose the photogrammetry method in ultra close-range mode. The ultra close-range photogrammetry is a total non-invasive method, fully portable, and easy to use. The cleaning treatments studied in this work are chemical cleaning, and laser cleaning. The obtained information on the third dimension of the surface by means of ultra close-range photogrammetry was compared with results performed by 3D optical microscope (only on selected single points). The colorimetric information on selected areas during and after the cleaning completes the surviving activity. The performed tests on the case study demonstrate the ability of the proposed approach to control the effectiveness of the cleaning procedures applied on wall paintings during conservation interventions. The advantages due to the portability and to the non-destructivity of photogrammetry (no-contact measurement method) with regard to others techniques candidates, led this methodology to be used in wider restoration works.

Keywords: *Ultra close-range photogrammetry; Cleaning treatments; Surface pattern surviving; Colorimetric analysis; Monitoring.*

Introduction

The state of conservation of artistic surfaces, as wall paintings, is usually investigated by means of several diagnostic tools and methods. The set of scientific and technical examination is usually carried out in order to give information about the structure of the object and the identification of constituent materials. These studies are traditionally performed by micro-sampling for chemical-physical analysis or by non-invasive punctual methods such as X-ray fluorescence (XRF), laser-induced breakdown spectroscopy (LIBS), and reflectance and Raman spectroscopy. Imaging techniques are also applied in several regions of electromagnetic spectrum such as microwave dielectrometry, ultraviolet-induced (UV-induced) visible fluorescence, IR thermography, visible,

* Corresponding author: c.riminesi@icvbc.cnr.it

near infrared, and X-rays spectroscopy [1-3]. All these techniques examine paintings only as two-dimensional objects, neglecting the information on the third dimension (depth or elevation). This last information is however an important factor to establish the state of conservation of the paintings, in particular with respect to the monitoring of the surface pattern, and to control and verify the effectiveness of restoration. The analysis of deformations of the wooden and canvas supports in relation to possible changes of environmental conditions (such as humidity and temperature) were performed by a digital 3D surveying methods [4, 5]. 3D data can provide essential information for an early detection of any structural change, which is crucial to prevent irreversible damage. The accuracy required for this surveying application is less than 1 mm; highest precision (1 to 100 μm) is required for a proper investigation of surface changes due to conservation operations, in particular cleaning treatments. A recent work has been focused on the 3D digital microscopy tool based on the "shape-from-focus" technique for assessing micro-morphological features during laser cleaning treatments of artworks [8]. The system has been used for the optimization of the operative parameters of the laser during the restoration work; indeed, the correct choice of the cleaning treatment protocol is fundamental for the success of the entire restoration [7].

The painted surface cleaning is one of the most important and sometimes controversial stages of the restoration: it is an irreversible procedure that results in substantial physical changes of the object surface, raising thus a series of questions regarding aesthetics, the loss of historical information, and the ability to control the cleaning process adequately [7]. This is one of the issue on which scientists and restorers today are focusing their efforts.

During the cleaning intervention, the restores have to decide regarding partial and complete removal of the patina (dirty, varnish etc.) which involves the selection of a treatment that allows a control of the cleaning process, so that undesired layers can be removed without damaging the underlying ones [7, 8].

In this framework, the advantages due to the use of the photogrammetric technique in ultra close-range modality are the safeguard of the painting surface, since the measurement is completely non-destructive, and the possibility to investigate large areas.

This paper describes the research activity, carried out by scientists and restorers, aimed to evaluating the effectiveness of cleaning treatments (chemical and physical methods) by means of ultra close-range photogrammetry, and to define an application protocol. The investigated surface is a detached wall painting dated from the 16th century. The painting is covered by a thick patina of calcium oxalate of a brownish yellow color. The target of the cleaning procedure was to remove the patina without altering the pictorial surface; additionally, the aims of the ultra close-range photogrammetry were the assessment of the amount of patina removed during the treatment tests, and the control of the surface's roughness variation after the treatment.

Materials and Methods

Setup and case study description

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 16th century, 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 di Firenze.

By means of diagnostic investigations has been known the painting technique: on a basis of "buon fresco" have been applied whitewash finishes. The pigments, mainly consisting of earth and iron oxides based pigments (hematite), were diluted in water or lime painting with several paint layers overlapped.

It was also possible to characterize the materials arising from the previous restorations: on the top of the surface is present a layer of calcium oxalate of a brownish color due to a previous treatment based on organic compounds. There are also traces of oxen bone glue used to detach the fresco. The painted film has been joined on a cotton canvas by using PVA based glue charged by powdered calcium carbonate and placed on a masonite support (size 149x169x2.5cm).

The aim of the cleaning was to remove the patina of calcium oxalate “without affecting” the painted layer. The patina alters the color of the painting but also a hard cleaning can have an undesirable effect; so the choice of the cleaning treatment and its proper application are crucial to the success of the intervention.

The cleaning treatments tested in this work are described in **Error! Reference source not found.**. The operating conditions for the laser and the characteristic of the chemical cleaning have been chosen by the restorer within the cleaning methods traditionally used [9-13].

Table 1. Cleaning treatments selected. (Note: Laser equipment was supplied by El.En Group)

Cleaning treatments	Description
Chemical cleaning	Carbogel (4%) and EDTA tetrasodium (5%), poultice, contact time 30 min.
SFR laser (Short Free Running modality)	@1064 nm, 200 mJ, 3 Hz, Spot Ø 2.75 mm, Fluence 3,3 J/cm^2, 40 μs, dry mode
LQS laser (Long-Q Switched modality)	@1064 nm, 130 mJ, 3 Hz, Spot Ø 3.10 mm, Fluence 1,7 J/cm^2, 100ns, dry mode

The tests were performed on selected areas as uniform as possible. In **Error! Reference source not found.**a, the area selected for the test is shown. In this area three sub-areas were dedicated for each test (chemical, LQS laser, and SFR laser). Each sub-area was divided in other four smaller areas performing a progressive cleaning as listed below:

A – not cleaned area (t_0)
B – after 1 cleaning step (t_1)
C – after 2 cleaning steps (t_2)
D – after 3 cleaning steps (t_3)

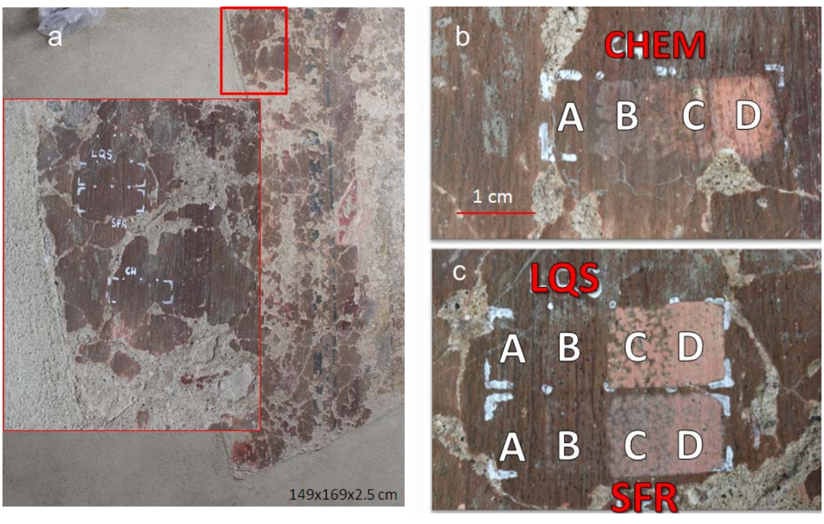


Fig. 1. (a) General view of the selected area for the cleaning tests and its magnification.
In (b) the detail of the area for the chemical tests, (c) the areas for the LQS and SFR laser tests.

Color measurements

The colorimetric measurements were performed using a tristimulus colorimeter (Minolta Chroma Meter CR-200) on three areas of the painting. An acetate mask (with holes of 1.5 cm x 1.5 cm) was used for each (Fig. 2.), in order to be able to repositioning the mask in the subsequent field surveys. To calculate the color parameters was adopted the color space CIEL*a*b* 1976 [14-17].

For each area, results were given as average of 3 measurements, in order to avoid the mistakes introduced by the repositioning of the measuring head. The measurement was made with standard illuminant C, 10° observer, and the measured area had a diameter of 8 mm

Fig. 2. Detail of the color measurement during the acquisition (detail of the head of the colorimeter) on one selected area using the acetate mask.

Microscopic investigation

Some micro-fragments have been sampled from the cleaned/not cleaned boundary to observe the thickness of the patina to remove and the samples were embedded in epoxy resin to obtain a cross section (Fig. 3).

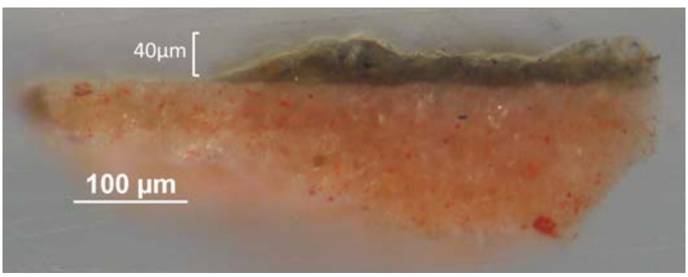


Fig. 3. Cross section of the sample taken from the boundary from a cleaned (SFR laser) and not cleaned surface

Measurements on the samples have been performed using a traditional optical microscope (mod. Eclipse E600 from Nikon), coupled with a high resolution camera and a motorized *Märzhäuser Tango* stage. The acquisition software used is NIS-Elements D Microscope Imaging Software, with EDF (Extended Depth of Focus) module that allows combining images that have been captured at different Z-axis values to create a single all-in-focus image. Once the all-in-focus image has been created, it can be viewed and rotated as a virtual 3D image as well as displayed as a stereovision image. A vector image is obtained and starting from this, it is possible to extract the elevation/depth profile by selecting a capture line.

Ultra close-range photogrammetry technique

This method is very useful for monitoring of surfaces after/during restoration and for controlling the geometric or morphological variations, as cracks, fissures and detachments or parts of clay in unstable equilibrium. The proposed technique is a totally non-destructive technique, and it is based on the same principles of classic photogrammetry but it is applied to a different scale. An RGB point cloud of the surface of interest is generated by acquiring three images (or more if it is necessary). The dimensions of the acquired area can vary from 2 cm^2 to a maximum of 20 cm^2 with regard to the distance of the shot and to the lens of the camera; so it is possible to investigate larger areas, without mosaicking approach.

The system (Fig. 4) is composed by a motorized bar 260 mm long and a digital reflex camera (Canon 7D) equipped with calibrated Canon EFS 60 mm macro lens or 28 mm lens. Software controls the process of acquisition, and allows the elaboration of the acquired images [6, 18].

Fig. 4. Micro-photogrammetry system (by Menci Software Srl, Arezzo, Italy).

After the selection of the shot's parameters, the software acquires the image of the area of interest with three shots of the same area (from the left to the right, symmetrical regarding the central shot, shifting the camera along the bar).

The point cloud related to the acquired images is generated following the classical steps [6]. On the 3D model can be applied a texture that allows a better overview of the surface. The metric information can be obtained from the Digital Elevation Model (DEM), generated by selecting a reference plane through seeding points. It is possible to export *xyz* data and evaluate the surface pattern parameters, as the geometry, morphology or roughness. The accuracy of the measurement in the plane is about ±40 μm, and along the direction perpendicular to the surface it is about ±30 μm [6]. These high precisions are obtained with a subsequent elaboration procedure by Matlab subroutine that aligns the target surface – interpolated by a plane – with the reference plane on the camera [6].

Results

Colorimetric results

The colorimetric results, obtained as the average of three measurements, are resumed in the histograms reported in Fig. 5, in which are reported for each area, the values of the CIEL*a*b* parameters. The main colour alteration factor was due to the ageing of the patina, which produced a diffuse browning of the painting and, after its removal the differences in the colorimetric parameters are, as expected, very high. Colorimetric parameters have been acquired for each area. The color difference (*ΔE)* has been calculated referring each single cleaning step (t_1, t_2 and t_3) to the initial not-treated area (t_0). The calculated *ΔE* for LQS, SFR and chemical cleaning treatment, are very similar. Indeed, the efficacy of the treatment, in term of colour change, seems comparable.

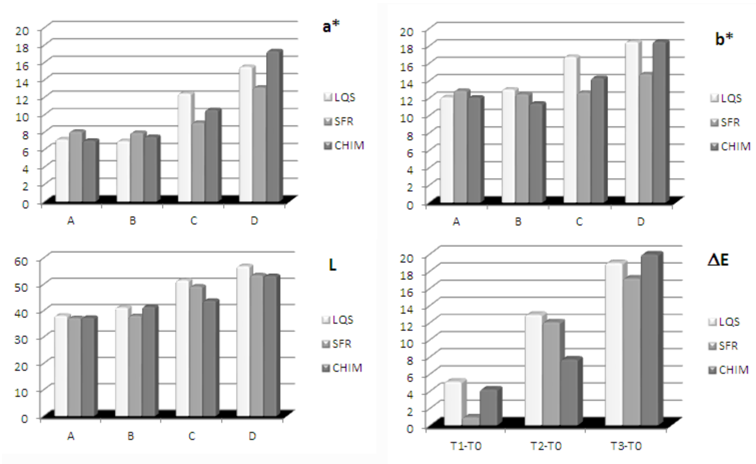


Fig. 5. Colorimetric values for each area (A - not cleaned, B - after 1 cleaning step, C - after 2 cleaning step, D - after 3 cleaning step) and colorimetric variation for the area D at each treatment step.

Microscopic results

In order to evaluate the thickness of the removed patina, a micro-sample was taken from SFR laser cleaned area and not cleaned boundary (Fig. 6a). By means of the microscope, it was possible to create an all-in-focus image from a series of Z-axis images, using the Extended Depth of Focus (EDF) module (Fig. 6b).

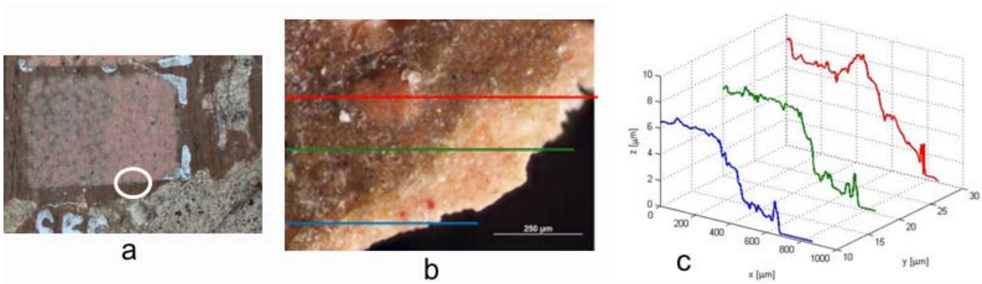


Fig. 6. (a) Detail of the SFR laser cleaned/not cleaned area; (b) Microscope image obtained by EDF module and lines reference for the profiles extraction; (c) 3D representation of the profiles.

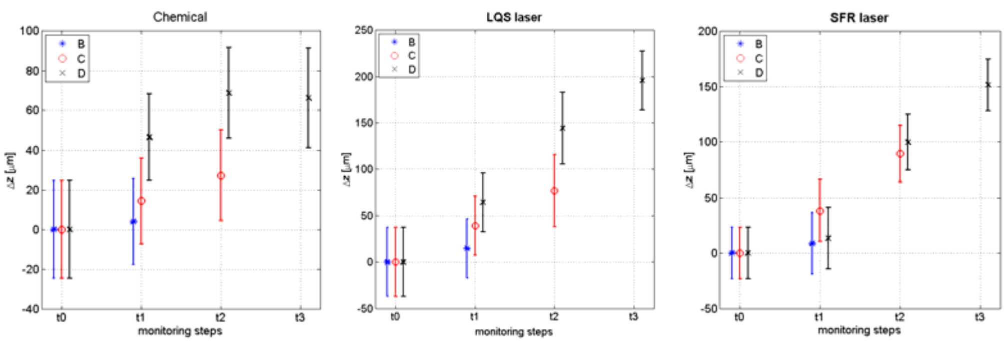
The EDF module allows to acquire the Z-profile on the captured image of the sample. By means of a properly selection of directional reference lines on the surface (see lines in Fig. 6b), has been possible to re-built the elevation profile and to evaluate the Z-value of the step on the edge between cleaned and not cleaned area (Fig. 6c). The profile’s features, in terms of shape and trend, look reproducible and totally comparable with the sample's roughness. However, concerning the quantitative information, problems regarding the real scale have been observed. In fact, the thickness of the patina, evaluated by observing the cross section's picture, is around 40 µm (Fig.3), instead of 10 µm as reported in the elaborated graphs.

Ultra close-range photogrammetry results

The shooting conditions were defined in order to obtain the required accuracy on the basis to previous measurement campaigns [6]. The motorized bar was positioned at a distance of 320 mm from the painting, and the acquisition step was fixed to 16 mm. Five shots were needed to cover an area of 4x1 cm and three 3D sub-model were arranged forming a single model (Fig. 7).

Fig. 7. Example of an arrangement of three 3D sub-models for LQS laser working area to obtain a single model

For each treatment area (chemical, LQS laser, and SFR laser) a single model is 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) are used to create an interpolation plane (reference plane) to which are 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 is known. By evaluating the distance of each points of the treated sub-area from its reference plane, it is possible to determine the thickness of the material removed by each cleaning treatment step. In **Error! Reference source not found.** the thickness (Δz) of the material removed is shown as a function of the monitoring step (the error bar is equal to the root mean square). For the sub-area B, only one step of cleaning treatment was performed after the time t_0. In the case of sub-area C two steps of cleaning treatment were performed; the first one after the time t_0, and the second one after the time t_1. For this instance the measurement of Δz at t_1 allows to evaluate the thickness of the patina removed by the first cleaning treatment step, and the measurement of Δz at t_2 allows evaluating of the removed thickness at the second step of the cleaning treatment. For the sub-area D three steps of cleaning treatment were performed and the patina's thickness was measured at t_1, t_2, and t_3, respectively.



(a) (b) (c)

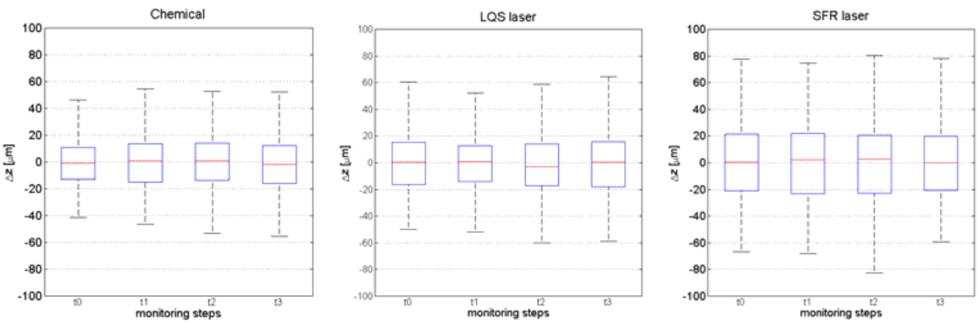
Fig. 8. Thickness of the material removed at each treatment step (average values).

(a) Chemical cleaning, (b) LQS laser cleaning and (c) SFR laser cleaning.

The roughness is an indicative parameter of the characteristic of the surface and its control can help in the selection of the cleaning treatment. In Fig. 9 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 [18].

This type of representation allows to visualize the dispersion of the surface's quotes with respect to the average value, so it is possible representing 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).



(a) (b) (c)

Fig. 9. Comparison of the surface's roughness of the sub-area D evaluated during each treatment step.
(a) Chemical cleaning, (b) LQS laser cleaning and (c) SFR laser cleaning.

Conclusions

In this paper, a new application of photogrammetry to assess the cleaning treatment of artistic surfaces, in particular wall paintings, was presented. The methodology is based on classic photogrammetry applied in ultra-close range for 3D reconstruction of the surface pattern. The setup consists of two fundamental parts: a commercial photogrammetric system used for image acquisition and for generation of DEM, and a subroutine in Matlab dedicated to the elaboration and the analysis of *xyz* data. The reliability and the accuracy of the method allowed to characterize the surface pattern by statistical quantities (mean, root mean square, standard deviation). The mean value of the thickness of the material removed during the treatment can be estimated and the trend observed is in agreement with the depth profile obtained by means of optical microscopy on the samples taken from the boundaries between the cleaned/not-cleaned areas. However, the control of the effectiveness of the cleaning treatment can't be always evaluated by sampling, due to the invasiveness of this operation. Otherwise, sample's observations under the microscope and the relative acquisition of the depth profiles present some difficulties due to the reproducibility and to the loss of any quantitative information. The proposed approach, as well as being completely non-destructive, is more suitable than others, and it is particularly suitable for in situ applications. The setup is very simple and completely portable (motorized bar, digital camera), and the data elaboration is relatively fast and reliable.

Forthcoming works will be dedicated to further methodological improvements of the proposed approach, extending the application to other supports and materials.

Acknowledgments

This work has been partially founded by Region Tuscany in the framework of the project Tecon@BC (POR-CReO/FESR 2007-2013). The authors wish to thank Dr. A. Zanini of El.En Spa for technical support with laser equipment.

References

[1] R. Olmi, M. Bini, A. Ignesti, S. Priori, C. Riminesi, A. Felici, *Diagnostics and monitoring of frescoes using evanescent-field dielectrometry*, **Measurement Science and Technology 17**(8), 2006, p.2281

[2] H. Liang, D. Saunders, J. Cupitt, *A new multispectral imaging system for examining paintings*, **Journal of Imaging Science and Technology, 49**(6), 2005, pp.551–562.

[3] C. Bonifazzi, P. Carcagni, R. Fontana, M. Greco, M. Mastroianni, M. Materazzi, E. Pampaloni, L. Pezzati, D. Bencini, *A scanning device for VIS–NIR multispectral imaging of paintings*, **Journal of Optics A: Pure and Applied Optics, 10**(6), 2008, 064011. p. 9.

[4] F. Remondino, et al., *Review of geometric and radiometric analyses of paintings*, **The Photogrammetric Record, 26**(136), 2011, pp.439–461.

[5] S. Robson, S. Bucklow, N. Woodhouse, and H. Papadaki. *Periodic photogrammetric monitoring and surface reconstruction of a historical wood panel painting for restoration purposes*, **International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 35**(5), 2004, pp.395–400.

[6] P. Tiano, D. Tapete, M. Matteini, F. Ceccaroni, *The micro-photogrammetry: a new diagnostic tool for on site monitoring of monumental surfaces*, **The Proceedings of the International Workshop SMW08 "In situ Monitoring of Monumental Surfaces",** (Firenze 27-29 October 2008). 2008. Published by EDIFIR Edizioni Firenze.

[7] I.C.A. Sandu, S. Bracci, M. Lobefaro, I. Sandu, *Integrated Methodology for the Evaluation of Cleaning Effectiveness in Two Russian Icons (16th-17th Centuries),* **Microscopy Research and Technique, 73**(8), 2010, pp. 752-760.

[8] I. Cacciari, D., Ciofini, M., Mascalchi, A. Mencaglia, S. Siano, *Novel approach to the microscopic inspection during laser cleaning treatments of artworks*, **Analytical and Bioanalytical Chemistry, 402**(4), 2012, pp. 1585-1591.

[9] M. Rizzi, M. Matteini, *L'azione solvente dell'EDTA bi e tetra-sodico verso il gesso e l'ossalato di calcio nella pulitura dei manufatti calcarei / Solvent action of Bi and Tetra-sodic EDTA towards gypsum and calcium oxalate in the cleaning of calcareous artefacts*, **OPD Restauro, 11**, 1999, pp. 97-115.

[10] R.S. Lanigan et al., *Final report on the safety assessment of EDTA, calcium disodium EDTA*, **International Journal Toxicological, 21** Suppl. 2:95-142, 2002.

[11] S. Siano, R. Salimbeni, *Advances in laser cleaning of artworks and objects of historical interest: the optimized pulse duration approach*, **Accounts of Chemical Research, 43**, 2010, pp.739–750

[12] P. Pouli, A. Selimis, S. Georgiou, C. Fotakis, *Recent studies of laser science in paintings conservation and research*, **Accounts of Chemical Research**, **43**, 2010, pp.771–781.

[13] I. Barbetti, A. Felici, *L'uso dei sistemi laser Nd:YAG per la pulitura dei dipinti murali. Integrazioni con altre metodologie, confronti e valutazioni sulla loro efficacia*, **OPD Restauro**, **22**, 2010, pp.203-212
[14] * * *, CIELAB 1976, Commission Internationale de l'Eclairage, http://www.cie.co.at/
[15] * * *, EN15886 – Conservation of Cultural Property – Test Method – Colour Measurements of Surfaces, 2010, http://esearch.cen.eu/esearch/Details.aspx?id=16469545
[16] A.M. Saviuc-Paval, A.V. Sandu, I.M. Popa, I.C.A. Sandu, A.P. Bertea, I. Sandu, *Colorimetric and microscopic study of the thermal behavior of new ceramic pigments,* **Microscopy Research and Technique, 76**(6), 2013, pp. 564-571.
[17] A.M. Saviuc-Paval, I. Sandu, I.M. Popa, I.C.A. Sandu, V. Vasilache, I.G. Sandu, *Obtaining and Characterization of Ceramic Pigments for Polychrome Artistic Elements II. Microscopic and colorimetric analysis,* **Revista de Chimie (Bucharest), 63**(2), 2012, pp. 170-178.
[18] R. Manganelli Del Fà, C. Riminesi, *Sistema ultra-close range photogrammetry per la conservazione dei Beni Culturali: principi di base, prestazioni e possibili applicazioni / Ultra-close range photogrammetry tool for the conservation of Cultural Heritage assets: basic principle, performance and possible applications*, **IFAC-CNR TSRR, 5**, 2013, *(in press).*
[19] * * *, The R Manuals, URL: http://www.r-project.org/

Received: October, 11, 2013
Accepted: December, 10, 2013