

CLOSE RANGE PHOTOGRAMMETRY FOR MEASUREMENT OF PAINTINGS SURFACE DEFORMATIONS

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ABSTRACT:

The paper describes the first results about a study on the measurement of paintings surface deformation. The study was carried out using one ancient painting model made in a restoration laboratory and consolidated with the materials and dilutions most frequently used in the field of conservation. The restorers suppose deformations of the paintings surface from 0.1 mm to some millimetre when the painting model is keeping in environment with the presence of humidity and temperature fluctuations. The main purpose of the study is to evaluate the relative accuracy and the reliability of multi-images photogrammetric techniques related to the camera stations network and to the commercial software used. The tests were carried out with two commercial software (i-Witness and CDW) and a digital Canon EOS 1 Ds Mark II camera measuring more than once the coordinates of 143 targets on the painting model. The tests have showed a relative accuracy of about 0.1÷0.2 mm. Some preliminary tests were carried out with the short range laser scanner Minolta Vivid 9i too. The laser scanner techniques, even though having notable potential, demonstrated, however, a series of problems which require further study.

1. INTRODUCTION

The work can be placed in the area of more general research conducted by a group of restorers who are employed in studying the processes and techniques of restoration and painting on canvas.

The restorers study the typology of the products to use for the work of restoration and the effects that such products could produce with paint on canvas. The experimental tests are generally conducted on historically painted models made specially for the purpose of research.

A particularly interesting aspect for restorers is represented by the study of deformation that the surface undergoes after the treatment of restoration with regard also to possible changes in environmental conditions of conservation. In particular variations in humidity and temperature are considered. Generally the process includes the following steps:

- the realization of some models of painting.
- the treatment of the models of painting with different products;
- conservation of the models of painting inside locations where values of humidity and temperature are modified artificially in a controlled way;
- measurement of the deformation of the surface.

Measurement of the deformation of the surface is particularly important for a correct evaluation of the restoration interventions. Excessive deformation of the canvas could in fact damage the work of art undergoing restoration.

The problem of measurement comes into the area of application of topography and photogrammetry.

The aspect which interests the authors of the current work regards the study of the procedures of measurement suitable to determine possible deformation of the surface of the paintings.

The restorers suppose deformations of the paintings surface from 0.1 mm to some millimetres. Such *range* of measurement can be obtained with photogrammetric techniques and with laser scanner short range device. The procedures of measurement can be carried out with the purpose of:

- determining the position of displacements of the targets positioned on the surface of the canvas;
- reconstructing and comparing the surfaces of the paintings.

The evaluation of the displacement of the targets can be carried out using stereoscopic and multi-image photogrammetric techniques.

The activity carried out focused mainly on checking the possible use of digital multi-image photogrammetric techniques for the measurement of deformation of the surface in painting models.

The test was carried out using one ancient painting model made in a restoration laboratory; the model had dimensions equal to 52 cm x 67 cm. The painting model reproducing the layering of 17th century canvas paintings with typical Venetian red preparation; the painting model was consolidated with the materials and dilutions most frequently used in the field of conservation. During the experimentation conducted it was not possible to submit the model to environmental variations in humidity and temperature. For this reason, the first stage of the work was focused only to evaluate the relative accuracy of photogrammetric techniques related to the camera stations network and to the commercial software used. The camera stations network was carried out in order to define a proper configuration for the images to be taken. Two commercial software (i-Witness and CDW) were tested to evaluate their accuracy in the measurement of the paintings surface deformations. The measurements were executed using 143 targets on the painting model.

Two different project of close range photogrammetry were carried out at a distance of 1.8 metres and 1.2 metres respectively. For every project, two independent surveys were performed in the same environmental conditions and in a very short time. The images were acquired with a digital non metric camera and a self-calibration was performed to define the interior orientation parameters for each survey. After every test, the comparison of the two independent photogrammetric surveys was done to estimate the relative accuracy and the repeatability of the survey.

Furthermore, some preliminary tests were conducted also using a short range laser scanner. The laser scanner techniques, even though having notable potential, demonstrated, however, a series of problems which require further study.

2. PHOTOGRAMMETRY SURVEY

2.1 Camera stations network

Multi-image techniques are widely used in the application of close range photogrammetry. Their use, above all in architectural surveys, is due to the simplicity of use, the availability of numerous commercial software and the possibility of generating 3D photorealistic models. Such techniques allow:

- great redundancy in photogrammetric measurement;
- the images orientation without the use of ground control points;
- the calibration of non metric cameras.

These aspects are particularly important for applications where it is necessary to obtain high precision in photogrammetric measurement.

In the case of monoscopic multi-image restitution, the accuracy of the three dimensional coordinates (σ_{xyz}) can be considered by the following formula (Fraser, 1996):

$$\sigma_{xyz} = \frac{q}{\sqrt{n}} S_f \sigma_{xy}$$

where q is a coefficient that depends from the strength of the photogrammetric network geometry and varies from 0.4 to 0.8 per well configured network, n the number of images taken from every position, S_f is the denominator of the average scale of images and σ_{xy} represents the accuracy of the measure of the coordinate images.

To estimate the accuracy of the survey it was decided to plan the photogrammetric survey with different geometry of network considering:

- a reduction in the object-camera distance;
- a gradual increase in number of images.

A first photogrammetric survey was planned with 5 convergent images taken at an average object-camera distance of 1.8 metres. In these conditions it is possible to photograph the whole painted model from all positions. The camera stations network provides a central image, two convergent images with the angles between the optical axis of about 30° and another two convergent images more externally of about 50° (Figure 1). The accuracy in determining the three dimensional coordinates, according the previous report is equal to 0.15 mm.

A second survey was planned with 10 images taken from an average object-camera distance of 1.2 metres. In this case it was necessary to carry out 5 images on the top part of the model and 5 for the bottom. The camera stations network repeats the order of images planned at a distance of 1.8 metres (Figure 2). The accuracy is equal to 0.10 mm.

The values of accuracy were calculated in both cases considering an image recorded with a camera with a focal distance equal to 50 mm and pixel on the sensor of 0.0072 mm. Furthermore, the parameter q was placed equal to 0.6 and the parameter n equal to 1.

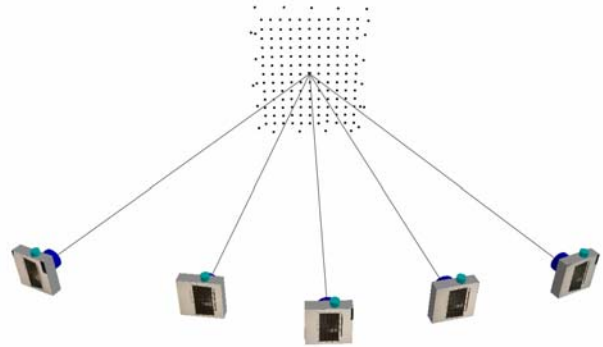


Figure 1. Camera stations network for test T1

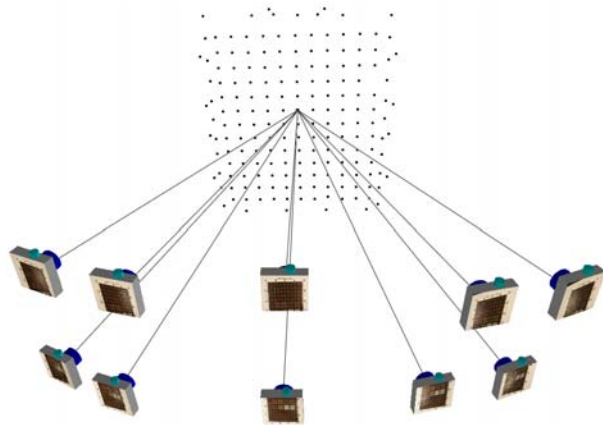


Figure 2. Camera stations network for test T2

2.2 Image acquisition

The images were recorded with a non metric Canon EOS 1Ds Mark II camera with a resolution of 16.7 megapixels, equipped with a CMOS sensor of a dimension equal to 36 mm x 24 mm. The images were recorded inside the Laboratory of Geomatics of the University of Palermo, by hanging the painted model on the wall and providing a good widespread system of lighting (Figure 3).

The images recorded from 1.8 metres turned out on an average photogrammetric scale of 1/35 and a pixel-size on object equal to 0.25 millimetres (Figure 4); those recorded from 1.2 metres have an average photogrammetric scale of 1/23 and a pixel-size on object equal to 0.16 millimetres (Figure 5).

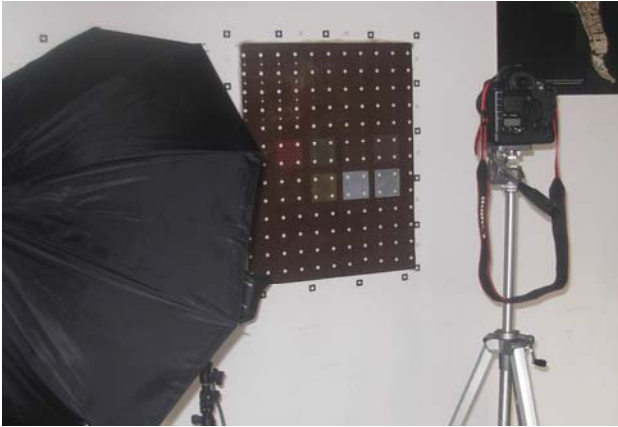


Figure 3. Images acquisition

For every survey project 2 images were also taken with the camera turned $\pm 90^\circ$ to better estimate the internal parameters of orientation calculated during the phase of external orientation.

On the surface of the painted model 143 adhesive targets were placed made specially to allow both the manual location of the centre of the target and its recognition with automatic techniques. The targets have a circular form with a diameter equal to 1 cm and a central point of 2 mm in diameter. The targets were arranged according to a grid which covers the entire surface of the painted model in an even way. Furthermore, 30 targets, to be used as an external reference in the procedure of measurement, were placed on the wall around the model.

The experimental checks envisaged the carrying out of two takes both from the plan carried out at a distance of 1.8 metres (T1) and the one carried out at a distance of 1.2 metres (T2). For every single project, two tests (R1 and R2) were carried out at a reduced time interval and in the same environmental conditions. In this way, for the project carried out from 1.8 metres and the one carried out from 1.2 metres it was possible to determine the value of the three dimensional coordinates of every single target. Going from the hypothesis that the surface

of the canvas during the whole period of photogrammetric survey does not undergo any change, it is possible to establish relative experimental accuracy through comparison of the values of the coordinates reported for each target. The differences found in the coordinates are in this case attributed only to the intrinsic precision of the system of measurement and not to eventual changes in form of the object. Furthermore, the results obtained provide us with an indication of the repeatability of the procedures adopted.

2.3 Image orientation

The external orientation of the images was calculated in an arbitrary reference system defined with original regard for a target of the wall, with the plane XZ coinciding with the wall itself and the axis Y perpendicular to the plane XZ. In this reference system the coordinate Y represents the direction of altitude variations. To determine the scale of photogrammetric model in project T1 four distances were measured with a vernier caliper between the targets on the wall; in project T2 5 calibrated bars were placed on the wall (Figure 6). The calibrated bars were made on a non-deformable support on which were placed two photogrammetric targets; the distance between these two targets was measured with a laboratory microscope with a precision of ± 10 microns.

The orientation procedures were conducted using the two commercial software iWitness by Photometrix and CDW by RolleiMetric. The measurement of the targets was carried out in a semi-automatic way with the iWitness software using the centroiding marking/referencing tool (Figure 7). With CDW software the measurement was done in an automatic way (Figure 8).

The interior orientation parameters of the camera were estimated with self-calibration carried out contextually to bundle-adjustment for every test.

The results obtained in the orientation phase are compatible with the estimated precision during the phase of planning of photogrammetric survey. However, it is interesting to note that the iWitness software supplied better results, in particular for the residuals of the coordinate Y which works out to be inferior

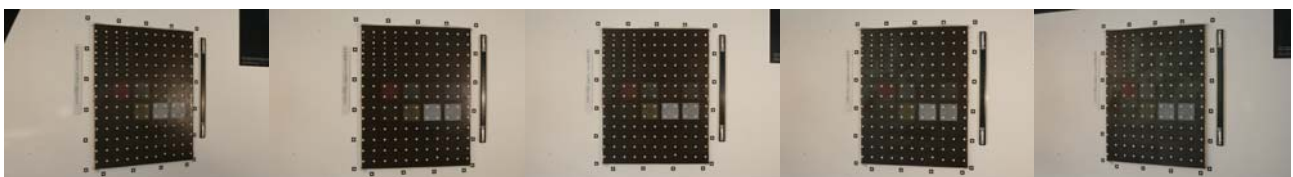


Figure 4. Images recorded from 1.8 metres (T1)

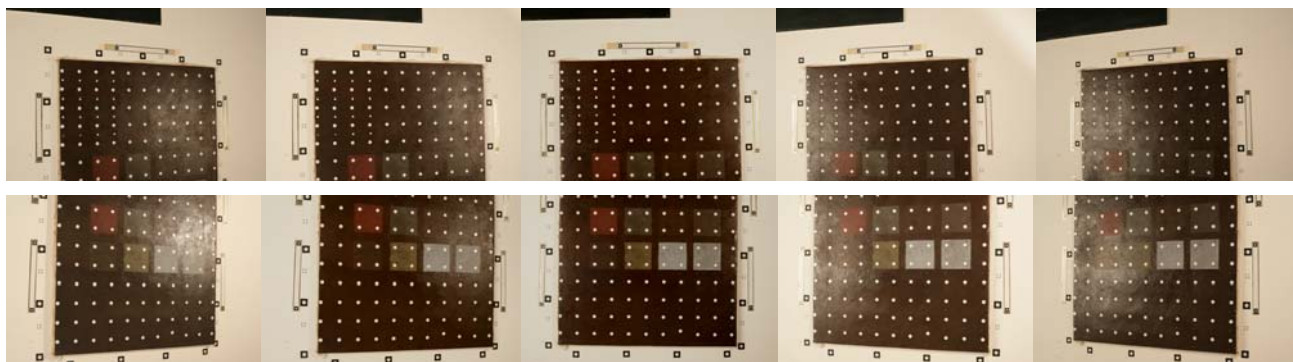


Figure 5. Images recorded from 1.2 metres (T2)

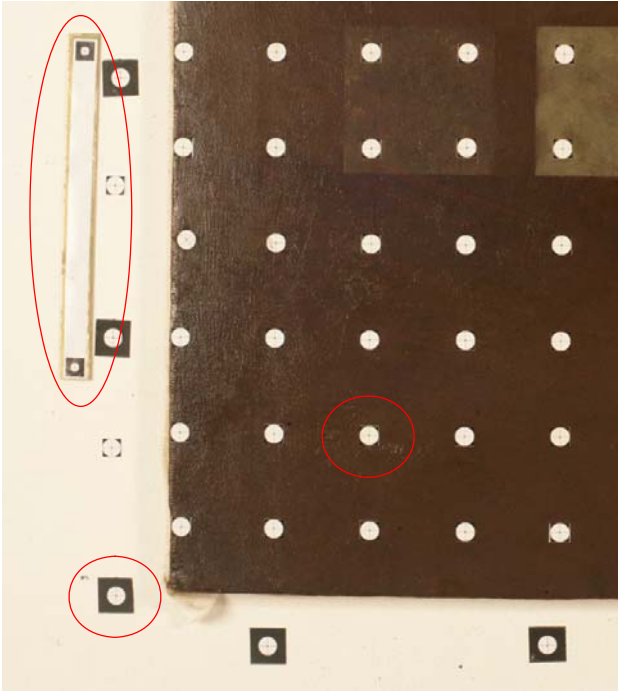


Figure 6. Targets and calibrated scale bar

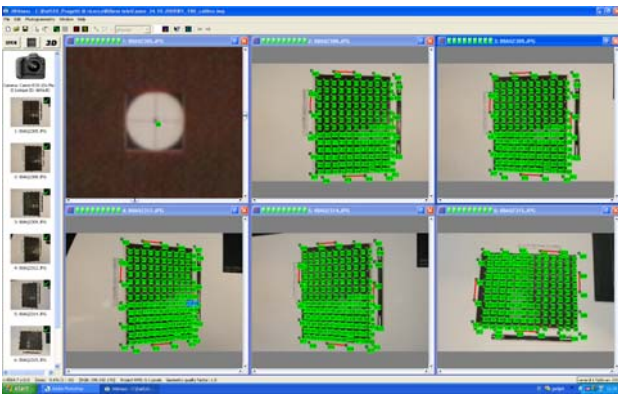


Figure 7. iWitness screenshot

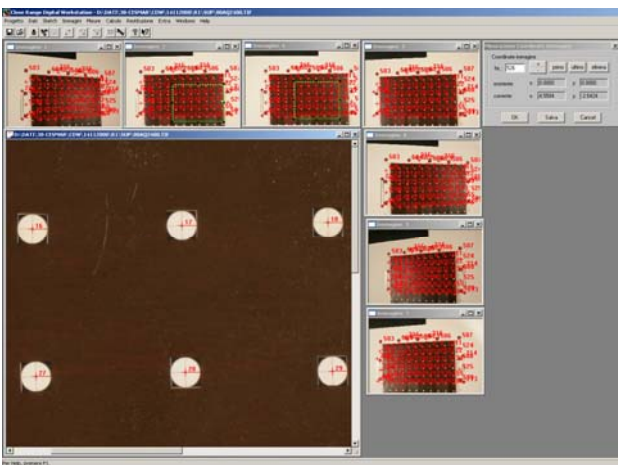


Figure 7. CDW screenshot

in size with regards to those calculated with the CDW software. The table 1 show residuals relative to the different tests carried out.

| | | | <i>RMS X</i> | <i>RMS Y</i> | <i>RMS Z</i> | <i>RMS XYZ</i> |
|----|----------|----|--------------|--------------|--------------|----------------|
| T1 | CDW | R1 | 0.033 | 0.111 | 0.024 | 0.118 |
| | | R2 | 0.039 | 0.152 | 0.028 | 0.159 |
| | iWitness | R1 | 0.012 | 0.035 | 0.012 | 0.039 |
| | | R2 | 0.012 | 0.046 | 0.012 | 0.049 |
| T2 | CDW | R1 | 0.030 | 0.115 | 0.021 | 0.121 |
| | | R2 | 0.036 | 0.128 | 0.025 | 0.136 |
| | iWitness | R1 | 0.008 | 0.019 | 0.007 | 0.022 |
| | | R2 | 0.007 | 0.018 | 0.007 | 0.021 |

Table 1. Residuals of the external orientation in millimetre

3. TEST RESULTS

The deformations hypothesised by the restorers in the painted models subjected to variations in temperature and humidity varying in range from 0.1 mm and some millimetres. The fundamental supposition for the correct determination of the deformations of the surface of the painted models is the execution of different test measurements always under the same conditions.

As far as the use of photogrammetric techniques is concerned it works out, therefore, necessary to carry out the measurements using the same camera stations network, the same software and possibly the same camera.

The tests carried out aimed to check the relative accuracy and repeatability of the measurements. The evaluation was conducted considering T1 and T2 projects separately, distinguishing the results according to the software used.

The check was carried out comparing the positions of the targets on the surface of the painted model for each project and evaluating the most significant statistical parameters. In particular, the standard deviation of the differences between the coordinates of the targets obtained from a comparison between test R1 and R2 in the project T1 worked out to be equal to:

- ± 0.026 mm in X, ± 0.057 mm in Y e ± 0.028 mm in Z for the software iWitness;
- ± 0.044 mm in X, ± 0.210 mm in Y e ± 0.044 mm in Z for the software CDW.

The standard deviation between tests R1 and R2 in the project T2 works out equal to:

- ± 0.015 mm in X, ± 0.028 mm in Y e ± 0.015 mm in Z for the software iWitness;
- ± 0.018 mm in X, ± 0.133 mm in Y e ± 0.029 mm in Z for the software CDW.

The results obtained in project T2, as foreseen, show lower values of standard deviation compared to those obtained in project T1. However, some aspects should be pointed out:

- the results achieved with iWitness software are always compatible with the precise requests for the operations of measurement of deformation;
- the results achieved with CDW software supply compatible values as far as the evaluation of possible planimetric displacements (plane XZ). They, however, show less accurate precision in the evaluation of altimetrical displacements (axis Y).

4. LASER SCANNER SURVEY

During the course of the research some reconstruction tests of the surface of the painting with a laser scanner were carried out. Scans of the canvas were carried out with a Minolta Vivid 9i short range laser scanner. This kind of system uses a low power source laser through an appropriate optic, produces a monochromatic blade of light which is measured by a CCD sensor. The reconstruction of the surface comes through the principle of the optic triangulation.

The instrument work in a range of distances from the object which go from 0.6 metres to 2.5 metres and is equipped with three lenses (Tele, Middle and Wide). The choice of the type of lens is correlated to the distance from the object and the accuracy requested (Table 2).

| Light-Receiving Lenses | Focal distance | Accuracy (X,Y,Z) |
|------------------------|----------------|-------------------------------|
| Tele | 25 mm | ± 0.05 mm / ± 0.10 mm |
| Middle | 14 mm | ± 0.10 mm / ± 0.20 mm |
| Wide | 8 mm | ± 0.20 mm / ± 0.40 mm |

Table 2. Minolta Vivid 9i accuracy

To carry out a first check of the use of the Minolta Vivid 9i laser scanner a test was carried out on a limited area of the painted model. In the test conducted the Tele lens from a distance of 0.6 m was used. In this way it is theoretically possible to reconstruct the surface with an accuracy of ± 0.1 mm compatible with the precision sought.

Also in this case, two sets of scans at a brief interval were acquired maintaining the painted model in the same environmental conditions.

The objective of this test was to evaluate possible problems connected with the Minolta Vivid 9i laser scanner and to carry out a first evaluation on the relative accuracy of the measurements.

A first problem regarded the typology of the painted model; the surface was treated with a dark slightly light varnish. This has caused during the scanning an absence of metric information in some areas of the painting. The problem was resolved optimising conditions of lighting.

A second problem regarded the high number of scans necessary to cover the surface. Even having chosen a reduced area as a test of the painted model it was necessary to carry out a high number of scans, in part superimposed to allow registering (Figure 8). With regard to the type of lens used and the scanning distance every single scan covered a small surface of dimensions equal to 12 cm x 10 cm.. This caused an increase in data to manage and notable redundancy of metric information.

Furthermore, the registration of the scans, because of the geometrical characteristics of the object, can represent a critical step in the maintenance of the initial accuracy. The scans were initially registered with Minolta Polygon Editing Tool software

and subsequently imported into the Rapidform software of Inus Technology to carry out fine registration (Figure 9). The procedures used provide the connection of single mesh through correlation techniques through the surfaces. These procedures can cause errors in the case of surfaces devoid of morphological discontinuity as those of the paintings.

The results obtained comparing the two meshes from the two scans show differences in the order of 0.3÷0.4 millimetres. Such results can be considered acceptable only in the case where the deformation of the surface of the paintings is in the order of some millimetres. The results are provisory in as much as further tests are in the process of taking place to obtain a more accurate test even through the use of different instruments.

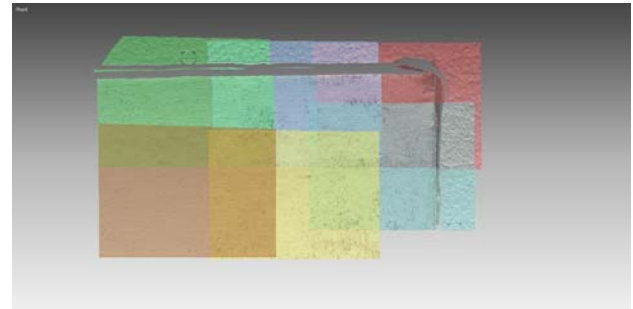


Figure 8. Scans of the area test



Figure 9. Mesh of the area test

5. CONCLUSIONS

The results obtained represent a first check of the use of multi-image photogrammetric techniques for the evaluation of the deformation of the painted surface of the canvas. The results are on the whole good. We can suppose the application of such techniques on models actually submitted to consolidation treatments and variations in temperature and humidity.

The tests have demonstrated the possibility of evaluating deformation in the order of a tenth of a millimetre for the tests carried out at a distance of 1.2 metres. In case the deformation results as about ± 1 millimetre it is possible to use camera stations network at a greater distance (1.8 metre) with a consequent reduction in the number of images.

Furthermore, the photogrammetric techniques allow the operations of surveying to be conducted in a relatively brief time; about 20 minutes for the images takes and about 3 hours for data processing

The tests carried out cannot be considered exhaustive of all possible technical solutions that the photogrammetric survey allows. For example the procedure adopted is limited to analysis of a single point of the surface. Theoretically the number of targets to check can be increased also considering

the availability of other commercial software (iWitness Pro, Photomodeler, ShapeCapture) or scientifically software which allows effective automatic measurement.

A further advancement of the research could be aimed at the application of the procedure of image matching for the reconstruction of the surface. In this way a check without the use of target could be used and therefore the methodology also in the case of restorations of real paintings could be applicable. Such conditions could be obtained using laser scanner techniques. The tests conducted with these instruments up until now showed some problematic aspects which require further studies.

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