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THREE DIMENSIONAL IMAGING OF CULTURAL HERITAGE AS A BASIS FOR A KNOWLEDGE CULTURAL ASSETS

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Această lucrare prezintă avantajele folosirii achiziţiei 3D în conservarea bunurilor din patrimoniul cultural precum şi prezentarea unor modele digitale 3D ca rezultate a măsurărilor de scanare ce au fost efectuate în anul 2006.

Este folosită tehnica laser pentru a produce modele digitale de înaltă rezoluţie a obiectelor. Rezultatele acestei metode, urmează a fi puse în contact cu rezultatelor tehnicilor de investigaţie, fiind parte dintr-un laborator complex mobil. În funcţie de suprafaţa obiectului, rezoluţia poate lua valori începând cu 0,15 mm, timpul de scanare a unsei suprafeţe de 1m^2 la o rezoluţie medie fiind aproximativ 20 minute.

This paper presents the 3D acquisition advantages versus cultural heritage preservation and reconstruction of Romanian's cultural objectives that made the object of 3D scanning during the year 2006. It is used laser technique to produce high resolution models of the object.

The result of this method, much better than the traditional ones (i.e. photogrammetry), is followed to be used with connected investigation methods, being part of a complex mobile laboratory. Depending by the object's surface the resolution may take values from 0.15 mm. Time to scan an area of 1m^2 at a medium resolution (less than 1mm) is 20 minutes.

Keywords: 3D scanning, mesh, triangulation, time-of-flight, cultural heritage

1. Introduction

Documentation in the artifact studies using optic techniques use the properties of the light reflected from the surface of the object. Depending of the

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radiation sources these techniques may be passive (where it is use the radiation from the sun) or active, where as source of radiation it is use a laser.

Recording this reflected radiation from the object surfaces, it may be produce high resolution digital model of the (surface of the) object. This is called 3D scanning, a high quality solution, compressive and supported by expert professional and it is the answer of the architects and restorers-conservator's needs. This noninvasive technique is portable, so instead of bringing the artifact (some of then it may not be carried out – like big statues or buildings) to the measuring machine, the system it may be moved where it is needed. This method is a part of a complex mobile laboratory, including techniques for on site monitoring, investigation and intervention on cultural heritage [1]

In this paper presents validated cases in Romanian's cultural objectives in restoration and the necessity of bringing out the value of 3D scanning as a tool for restorers to elaborate a 3D data base containing the digital model of the artifact, digital model that can be accessed any time from anywhere. [2]

2. 3D measuring optical methods

One of the most known passive techniques is photogrammetry, a technique that use photo image taken from different angles and then these images are used for a volumetric representation of the object. Using some references points, it may offer some geometric details but this representation depends by the physical proprieties of the photo cameras that is used. This precisely and contact measurement method it is used on large application, from art reproducing to architecture and even engineering.

The active methods are also divided by the principles that are using. The common used technique is triangulation, a method used mainly in digitizing small and medium objects, like statues or old inscriptions.

Depending by the size of the object and the details that are wanted to be digitized the technique it is chosen. If the object is flat (and small) the Interferometric Time-of-Flight it is the proper technique. If the size of the object is less than 5 meter the right method it is triangulation. But, if the object is big, like façade buildings or even buildings the perfect method is Time-of-Flight. [3]

The name of triangulation comes from the displacement of the experimental devices: the laser source, the object and the sensor used to record the light reflected from the object's surface – like the corners of a triangle. This method use the speed of light in air, the distance between the laser head and the sensor and angular orientation of the two parts (laser and sensor) and the direction of the reflected light to register the profile of the surface object. The relief of the surface is then revealed in a mesh representation, in a continuous mode. Because it is used laser radiation, the obtained image is represented in a grey scale, variation that depends by the amount of the energy reflected in the photosensor. [4]

The monochromatic light comes usually form a laser diode, it is reflected on the object's surface and it is recorded by a photosensor. Mostly, instead of a laser dot it is used a laser line that passes over the object's surface. As the line cover the object, its reflection is registrate by the photosensor and so it is recorded the profile of the surface - resolution is controlled by software (the speed of the rotating line over the object). The resolution of this method is couple of tens of micrometers (the size of a triangle side). This kind of representation is preferred for visualization of the small objects, like statues or old writings, but, because it offers high resolution models, the result depends by the optical proprieties of the object, more, by the reflectance of the surface at the wavelength of the laser that it is used. The angle between the normal at the surface of the object (α) increase the resolution of the object., if in normal case, the resolution would be $x = d \cdot tg\delta$, the effective resolution is in this case is $x` = \left(d / \cos\alpha\right) \cdot tg\delta$ where δ is the angle between two passes of the line over the object's surfaces. [5]

T-O-F method is suitable for a large application, from large statues (over 5 meters) to buildings or even archaeological sites. The resolution may be varied with values starting 100 μm. This techniques use the speed of light value to find out the distance between the scanner and the object, within an error less than 1 μm. This technique uses both phase and amplitude modulation. If in the case of the previous techniques the distance between the source of radiation and the object must be more than 10 cm and less than 2 meters, in this method's case the distance may be varied form 1 up to 100 meters.

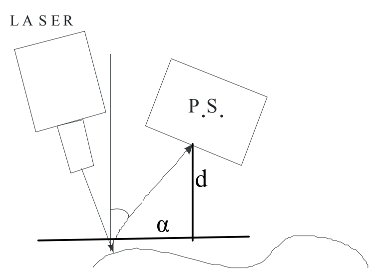

Fig. 1 Schematic of the triangulation displacement of the experimental device: laser, object and the photosensor. The parameters for digitizing the object are: the distance laser- object, object-photoseonsor, the direction of the reflected light and the angle between the laser orientation and P.S.

Because this portable technique it is used in on site measurements it is necessary to assure a compact scanner easy to manipulate. In most of the cases the laser source and the photosensor are incorporate in the same compact case, assuring a more secure handling of the scanning system.

It is used both c.w. and pulse lasers. In the case of the pulsed lasers, a beam is emitted from the laser, travels to the object and a part of the beam reflects back in the scanner and it is measured the time for the beam to make the round trip road. By this way it is measured the distance between the scanner and one point on the object's surface. This process in repeated, with the beam is focalized on another point and so on for a complete digitizing of the whole surface of the object.

In the case of the continuum wave lasers instead of the laser dot it is used a laser line that passes over the surface of the object with the beam directed to the object by a system of mirrors.

The experimental set-up is made by a 3D scanner (optical surface digitalizer) and a command laptop, with whom it may choose the resolution of the digitizing process and where it is stored the data. The 3D scanner contains a semiconductor laser diode, a beamsplitter, rotating mirrors and a photo receiver. The scanner use phase shifting principle, the radiation from the diode come to the beamsplitter (BS) and one of the 2 resulting beam travels to the object surface and a part of the beam it is reflected back to the scanner where it is measured the phase difference between this beam and the 2nd resulting beam of BS.

Knowing the speed of light in air and these phase difference it is measured the distance from the scanner and one point of the object surface with micrometer precision. With the rotating panorama stage it may be cover the 360^{o} on horizontal and with the rotating mirrors it may cover 270^{o} vertical coordinate (it may not be covered the 90^{o} under the scanner) and so it is measured the whole area of the object (or the interested area).

One of the postprocessing applications in the image matching tool, a high resolution photo can be stretched over the 3D model and so it is obtained a 3D color digital model of the object.

The scanner is control by angular units, taking values from 17 up to 180 lines per degree. Knowing the distance between the scanner and the object and this angular resolution it may determined the effective resolution of the digital model. But this parameter is a more as a rough guide, because the surface of the object is not flat and it is not placed perpendicular with the scanner, but it may offers a general idea of the accuracy of the digitizing process. Also, in the more complex model, where it is taken more than 2 scans, the resulting scans files are not exported 100%, due to the performance of the post processing computers, so instead of a high resolution complete model, which can be handled hard on PC's the general model is a medium resolution but separately it may be loaded the high resolution of each scan in part.

3. Results

The data it is stored in a 4 columns matrix, 3 containing the *(x,y,z)* coordinates and the 4th the intensity of the reflected beam, for a grey scale representation and for each point it is assigned one line. Usually the matrix contains from thousand up to millions (tens of millions) of points and the resolution may be varied form 150 µm up to couple of cm.

Although this scanner offers the result in a point's representation, it can be obtained a continuum surface representation, when 3 near points generate a triangle, points that generate other triangles, and so on. The mesh representation has a better resolution than the point's representation. This kind of representation is preferred in the case of statutes, little objects or writings.

Below results are selected because of the particular case that each of the represents:

i. a complete documentation of the special architecture in Romanian historical monuments

Bălineşti Church (Suceava County) build in second half of the XV century is one of the most representative Moldavian art from the medieval period. The stoop of the Church is made in gothic style and its architecture is a reference in the Romanian's art directors. For a proper reconstruction of the stoop it was made 5 different scans at a medium resolution, between 60 and 120 lines per degree with the distance from scanner and the surface to scan taking values from 3 up to 8 meters, effective time to scans was 4 hours, including time to position the scanner.

The digital project of the Bălineşti stoop may be reconstruct from more than 56 millions of points with a medium resolution of 1.5 mm and with a processing time of the scans files more than 20 hours.

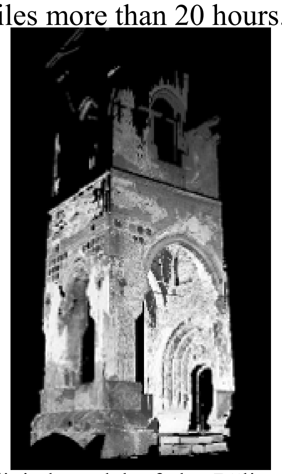

Fig 2 Screen capture of the 3D digital model of the Bălineşti stoop, a model represented by 56millions of points at a medium resolution of 1.5 mm

ii. almost flat surface on superior part of the exterior wall

Another scanning application was the right writings *pisania.* It is situated 5 meters above ground and the first scan was made with the scanner placed on the ground at a resolution of 60 lines per degree. The 3D image contains of shadowed area and a 2nd scans was inevitably. The resolution was 100 lines per degree and the distance from the *pisanie* and scanner was 2 meters (in the first case was 5 meters).

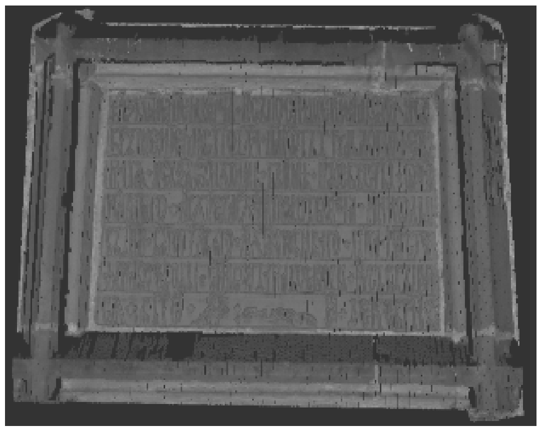

Fig. 3 The result of the first scanning of the pisania, with the scanner placed on the ground. It can be observed that there are a lot of black (shadowed) areas.

The point's representation contains 6.7 millions of points and the mesh representation 5.5 millions of triangles. The resolution of the two representations is 0.36 mm (point's representation) and 0.3 m (mesh representation).

iii. painted wooden surfaces in streaming environmental conditions

One of the Moldavia main show places is Sucevița Monastery, build in the last decades of XVI century, when Moldavian ruler was Ieremia Movila. Gothic and Byzantine elements blend in this monument that contains architectural motives of the old wood churches in one of the grates masterpieces of the Moldavian Monasteries. [6]

The iconostas of the Church sculpted in *yew wood* in baroque-rococo style is dated in 1801 was scanned in 5 hours, at a medium resolution of 70 lines per degree. There where made 5 different scans and 2 at each half of the iconostas and another one with the entrance in the grave chambers. The digital model contains 20 millions of points, at a resolution of 0.8 mm.

Fig. 4 The iconostas of the Sucevița church reconstructed by more than 20 millions of points, at a medium resolution of 0.8mm with 5 scans. On the left side of Sucevița's iconostas was a cutting on one of the icons. The distance between the slices varies from 0.3 up to 1.6 mm, image containing 1 millions of points.

iv. flat surface on floor area

One of the challenging 3D scanning applications was the digitizing of the funeral tombs from the entrance in the church. Because the tombs are placed on the ground and due to the time exposure the comprehensibility of the text lost during the time. This is the motive that the resolution used was maximum, 180 lines per degree, that corresponds at a resolution of the digital model of 150 μm, digital model that contains more than 150 millions of points.

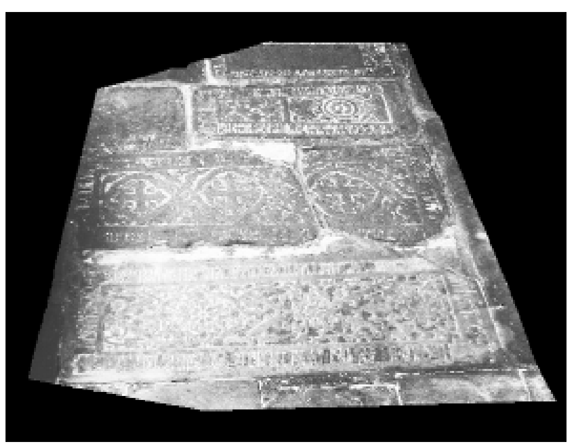

Fig. 5 A low resolution image of the digital model of the tombstones.

v. large outdoor surface with mural paintings in strong erosive process

A Byzantine inside church and with exterior paintings is Humor, dated in 1533 has some particularities from the other period churches, like the missing of the cupolas.

Another particularity is the open stoop, for the first time in a Moldavia church. Where made 11 scans to obtain the 3D model of the stoop, with minimum shadowed areas at a resolution between 60 and 100 lines per degree. The digital model contains 25 millions of points at a resolution from 1-2 mm. This is a part of a complex study regarding the shapes and the dynamic of the open stoop's degradation. [7]

Fig 6 Image containing more than 25 millions of points of the stoop of the Humor church.

The particularity of the interior of the church is represented by the *gropniță,* the funeral chamber of the church. Where made 2 scans for the each room << because of the placement of the candelabrum>>, except of the *naos* - still is in restoration. The resolution was between 50 and 150 lines per degree and the digitalizing was made during the night because of the affluence of the tourists. [2].

Because it couldn't scan all of the church, the digital model contains only the *pronaos* and *gropnița*, model containing 27 millions at a medium resolution of 1.3 mm.

a) b)

Fig 7 a) A general view of the altar from Humor church, image containing more than 17 millions of points at e medium resolution of 0.8 mm, containing 2 different scans. b) The digital model of the gropnița and pronaos part of the Humor church.

vi pulverulent surface's replica

The Basarabi Ensemble Caves of 4 Churches made in IX-XI century in a chalk hill, on a roman career and contain bower cult, grave vault, tomb. On the walls are a lot of number of incision with symbolic character and inscriptions.

The scanning process of Church ensemble from Basarabi was based on a 3D reconstruction of 3 from 4 Churches, and to observe several inscriptions on the wall, carved crosses on the column and to remark the microclimate parameters gradient versus surface's stress.

The effective scanning time was 10 hours, medium resolution of 40-80 lines per degree for the general reconstruction of the churches and 180 lines per degree for the high resolution details. Because of the dimension of the churches, the hardest part of the digitalizing of the Basarabi inscription was the location of the scanner. In one of the high resolution details that where scanned from 2 different angles, the distance between the scanner and the object was 1.5 meter, in the 1st scan and 1.8 meters in the 2nd scan. This caused an observable contrast of the luminance of the two scans.[8]

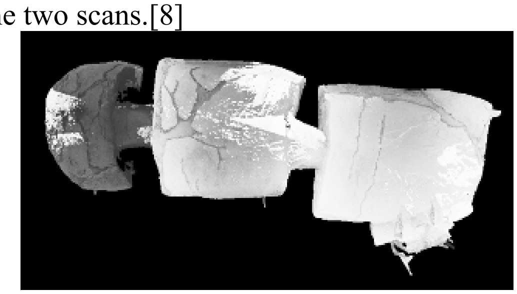

Fig. 8 An upper view of one of the Basarabi caved churches. A model containing 27 millions of points and 3 scan files.

The digital model of the churches varied from 27 millions of points up to 40 millions of points and the resolution of 1.3 up to 2.2 mm. The high resolution models contain details that can be observed from 150 μm.[2]

The painted Grave from Constanța, dating from IVth century discovered in 1988 by the architects C-tin Cherea and Virgil Lungu. There were made 4 different scans, 2 inside of the grave, 2 outside, 1 with the portal closed, the 2nd with the portal open to capture some common details with the inside of the grave.

The resolution was between 40 and 100 line per degree that correspond of a 1.2 mm of the digital model that contains 25 millions of points.[8]

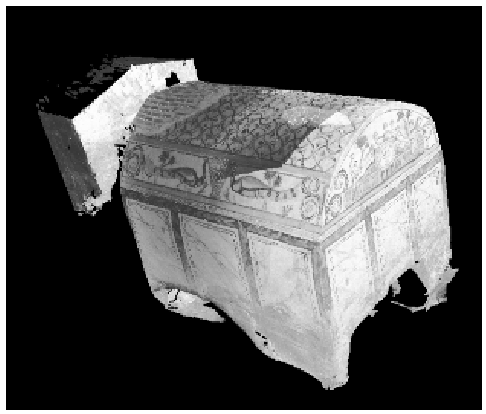

Fig. 9 General of the painted grave from Constanța, image containing more than 25 millions of points.5.

6. Conclusions

New techniques developed on the past years offer new application in more areas, areas that at the beginning weren't assumed. 3D scanning first application was in reverse engineering, to inspect the prototypes, after that it was found new application in quality product inspection for quality control purposes.

3D scanning should not be observed only as a tool to record the silhouettes of the objects but as a tool in the architects and restorers to survey the shape and the exact profile of the object for a better planning of the saving of the object for advanced studies regarding degradation mechanism and dynamics. Also may produce digital museums, which may be accessed from anywhere, without any transportation cost from the visitor but offering some hidden eye details.

The new research in this field concentrate on scanners with 3 laser wavelengths, beside recording the shape at a high resolution also to record the color of the object with laser precision.

The aim of the project, developed during the next step of research is based on the development of multi-dimensional data mining algorithms for condition monitoring and decision support in evaluating the status of cultural heritage artifacts.

Implemented sensors' data collections over a long time will be associated to the 3D model of the building in order to improve the historical records that describe the evolution of the material in time, in terms of environmental conditions and natural aging.

Development of efficient sensors network and a mathematical model for prediction of the materials dynamics are parts of the study. The predictive model will take into account the current state of the artifact and its conditions and will produce a prediction, for instance, on a part of the artifact for which there are no available observations. Next, the system will consider historical data from the actual measurements on the artifact, historical data on the environmental factors influencing the artifact, current data on both the artifact and the conditions that affect it, and the predicted future data on environmental factors. The status estimator will be implemented using neural networks; however its performance will be compared to traditional techniques such as the Kalman Filter.

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