

ACCURATE 3D TEXTURED MODELS OF VESSELS FOR THE IMPROVEMENT OF THE EDUCATIONAL TOOLS OF A MUSEUM

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ABSTRACT:

Besides the demonstration of the findings, modern museums organize educational programs which aim to experience and knowledge sharing combined with entertainment rather than to pure learning. Toward that effort, 2D and 3D digital representations are gradually replacing the traditional recording of the findings through photos or drawings. The present paper refers to a project that aims to create 3D textured models of two lekythoi that are exhibited in the National Archaeological Museum of Athens in Greece; on the surfaces of these lekythoi scenes of the adventures of Odysseus are depicted. The project is expected to support the production of an educational movie and some other relevant interactive educational programs for the museum. The creation of accurate developments of the paintings and of accurate 3D models is the basis for the visualization of the adventures of the mythical hero. The data collection was made by using a structured light scanner consisting of two machine vision cameras that are used for the determination of geometry of the object, a high resolution camera for the recording of the texture, and a DLP projector. The creation of the final accurate 3D textured model is a complicated and tiring procedure which includes the collection of geometric data, the creation of the surface, the noise filtering, the merging of individual surfaces, the creation of a c-mesh, the creation of the UV map, the provision of the texture and, finally, the general processing of the 3D textured object. For a better result a combination of commercial and in-house software made for the automation of various steps of the procedure was used. The results derived from the above procedure were especially satisfactory in terms of accuracy and quality of the model. However, the procedure was proved to be time consuming while the use of various software packages presumes the services of a specialist.

1. INTRODUCTION

1.1 3D models as educational tool of a museum

It is well known and documented through several studies and research, that the museums are not just buildings that provide space for preservation, study and exhibition of collections of objects and specimens of the natural world, but they also have to play a significant educational role. It is recognized that museums give people the opportunity to draw inspiration, knowledge and pleasure using critical thinking and developing a "dialogue" between the artifacts and the visitors (American Association of Museums, 1992; Mouliou and Bunia, 1999; Liakou, 2009). The positive experience of educational programs can contribute to the realization of the value of the museum as an area of non-formal learning, as the goal is not so much the acquisition of knowledge but also gaining experience and combining learning with entertainment.

Worldwide all large archaeological museums have developed educational programs for pupils of primary and secondary schools, families and adults. However, the majority of training programs are currently limited to touring the exhibition halls, observing artifacts in special show cases where they are stored and displaying in a two-dimensional projection the archaeological findings and specimens through visual media (photo, video). This recording of archaeological findings does not meet the needs of the quality of the exhibit. The object is projected from one point of view. Another way of recording by archaeologists and art historians is drawing and painting. The

designs generated by these methods have two main disadvantages (<http://www.ipet.gr/digitech2>):

- The long time required in the effort to achieve great accuracy in recording the object
- The lack of accuracy in the representation of the exhibit.

In recent years new techniques are being developed giving answers to the problem of recording and projecting cultural treasures. The digital reconstruction of the surface of complex 3D objects with real texture and then the visual representation and dissemination of digital information allow the institutions dealing with culture to view the results of their work in multiple new and dynamic ways, such as the use of photorealistic three-dimensional models and presentation through virtual reality on the internet. In the fields of photogrammetry and computer vision a major object of research has been the reconstruction of the complex surface of three-dimensional objects, which is covered with real texture. These three-dimensional models due to the continuous advancement of technology and research are now obtained faster, easier and with increasingly reliable methods, thus providing not only optically perfect but also geometrically accurate textured representations of the objects. The problem is more complex in archaeological applications due to the diversity in size, irregularity of shapes and complexity of the objects' surfaces. For this reason various methodologies have been developed, offering various solutions. All these techniques not only make an important contribution to the recording of cultural heritage, but also have the ability to make museums more attractive to audiences of all ages.

1.2 3D data collection methods

A basic classification between these approaches may depend on the way the object is lighted. Passive methods take advantage of the recorded, ambient radiation while active methods employ radiation emitted on the object surface. Among the well-known methods that fall into the first category are shape from silhouettes, shape from shading and also stereovision. These approaches offer satisfactory results for objects with a clearly defined outline, with sharp texture. On the other hand, the most common approaches of active methods include laser scanning, single-image slit scanning and structured light scanning.

The technique followed here belongs to the latter of the above mentioned methods. The calculation of the 3D point coordinates lies on the principle of triangulation. The system consists of a projector, which projects a sequence of specific patterns on the object and a digital, high resolution camera that records not only the object but also the deformation of the pattern, due to the geometry of the object. Triangulation between the optical ray and the plane that comes through the principal point of the projector and the pattern, leads to the computation of 3D coordinates for each point and eventually to the acquisition of a point cloud (Teutsch, 2007; Zhang and Huang, 2006). In order for the triangulation principle to be feasible, the interior orientation (focal length, principal point, lens distortion parameters) of the projector, according to the model of central projection, and of the camera have to be computed. Also, the relative orientation, with known scale factor, between the projector and the camera needs to be calculated through the calibration procedure (Aliaga and Xu, 2008; Rocchini et al, 2002). Another important issue is the establishment of correspondence between the camera and the projector pixels. Thus, a suitable encoding of the pattern is necessary. The most common is the binary Gray coded pattern; a sequence of vertical stripes or combination of vertical and horizontal stripes in order to accelerate the procedure of scanning (Kalisperakis et al, 2011).

This paper describes the creation of three-dimensional models of two lekythoi, one black-figured and one red-figured, and the texture development which depict the adventures of Odysseus. Black or red figures characterize the ancient Greek pottery painting and give the figurative and decorative motifs in black or red on the surface of the clay and etched incised details. This is one of the most important expressions of ancient Greek art and was the main technique for decorating pottery in the archaic period (Beazley, 1986). The vessels dealt with in this study are exhibited in the Archaeological Museum of Athens, Greece. The data collection was performed using an XYZRGB® structured light scanner. It consists of two machine vision cameras, used for the determination of the geometry of the object and of a high resolution camera, used for the recording of the texture, plus a DLP projector. The use of two cameras for the determination of the geometry of the object facilitates the procedure since neither the correlation of the pixels of the projector with the pixels of the camera nor the knowledge of interior orientation is required.

In the next chapters the steps of a 3D textured model creation process, which includes the collection of geometric data, the creation of the surface, the noise filtering, the merging of the individual surfaces, the creation of a simplified surface (c-mesh), the creation of the UV map, the provision of the texture, and the final processing of the three-dimensional textured object are described.

2. DATA ACQUISITION

2.1 Description of the objects

The objective of the project presented in this paper is to achieve high accuracy in 3D recording of small size archaeological exhibits, so that their representations (in 3D or 2D products) will become the fundamental tools for developing attractive educational courses in the museums, especially for students. The representations need to be of good quality and the data need to be of high accuracy to facilitate the production of further products-representations (e.g., developments), which help in a better understanding of the story that is painted or carved on a finding (e.g., a vessel or a decorative part of an object).

Two lekythoi (cosmetic vessels), exhibited at the National Archaeological Museum of Athens were selected: a bigger one with height approximately up to 30cm (Fig. 1 left) and a smaller one with height approximately up to 20cm. (Fig. 1 right). A lekythos is a ceramic vessel, a type of Greek pottery used to store olive oil. It has a narrow body and one handle attached to the neck of the vessel; its geometry is characterised by a great degree of complexity. On the surface of these two vessels scenes of the adventures of Odysseus are carved. Odysseus, a mythical hero of Odyssey by Homer, was the king of Ithaka and one of the Greek leaders during the Trojan War, which lasted about ten years. During his long journey back to home he had to encounter many difficulties and adventures, which are depicted on the lekythos. These vessels are dated back to 5th century BC and were discovered in the region of Athens, Greece. They are painted in dull red and black colours. They obey the rules of decoration imposed by the Archaic period, when sketches and motives with dull colours were engraved on light coloured clay. It is fascinating that the dull colours do not come from the usage of colorants, but from a special, complicated procedure of treating the surface of the vessel. First of all, the whole surface was covered by a fine-grained clay overcoat. All the sketches when then drawn and covered by a thinner layer of clay mixed with alkali and potash, while the inner details of the sketches where carved by a sharp tool. Implementing a combination of specific conditions during the procedure of firing, the acquirement of desired colours was accomplished.



Fig. 1. Photos of the two lekythoi, with the adventures of Odysseus carved on their surface

The 3D recording and digital processing of the two lekythoi aim to support the production of an educational movie and some other relevant interactive educational programs for the Museum. The creation of accurate developments of the carvings

and of accurate 3D models is the basis for the visualization of the adventures of the mythical hero.

2.2 Structured light scanner

For the acquisition of the 3D data the SL2 model of XYZRGB structured light scanner was used (Fig. 2). It consists of the following components:

- a Canon 450D digital SLR 12MP high definition camera
- two uEye 5MP machine vision cameras
- an Infocus IN35W DLP projector

and, also:

- a laptop running the appropriate software
- a calibration board, with known dimensions.

The three cameras are mounted on a rigid base. The distance between the cameras may vary according to the object scanned and it is usually set up to the 1/3 of the scanning distance. The maximum density capability equals to $150\mu\text{m}$ and the maximum precision to $50\mu\text{m}$, according to the manufacturer.

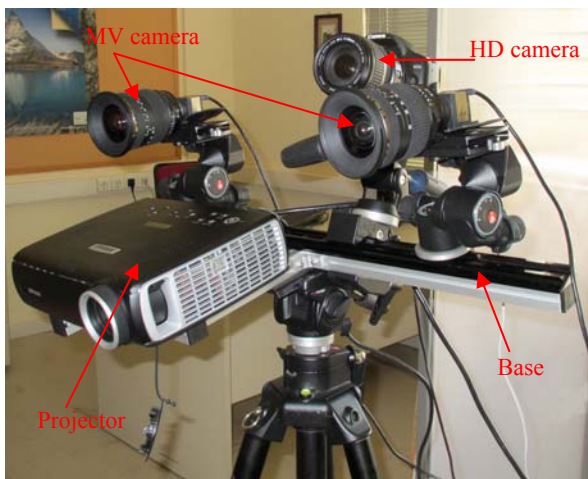


Fig. 2. The SL2 model of XYZRGB structured light scanner

This specific model of structured light scanner, though, is slightly differentiated from the traditional structured light approach, mentioned above, as it consists of two cameras; the 3D coordinates are computed by triangulation between corresponding optical rays (from the two machine vision cameras) and not by triangulation between a ray and a plane. The high definition camera records the texture of the object, in order to extract a textured point cloud (Valanis et al, 2010).

The calibration is the first and necessary step for the scanning procedure; it affects the precision of the extracted point cloud. The calibration board is set at approximately 11 different positions, including change in position and rotation. Performing plane based calibration, the interior orientations of the three cameras and the relative (scaled) orientations between them are computed.

During the procedure of scanning the relative position between the three cameras has to remain unchanged. The scanning procedure is fast and reliable. However, for a successful result, the imaging parameters of the cameras have to be set correctly in the scanning software, according to object's colour, material and lighting conditions.

2.3 Data acquisition software

The uEye software is responsible for the determination of the suitable imaging parameters of the cameras, so as to acquire data with best quality. Some of these well-known parameters are pixel clock and exposure, which are related to the refresh rate of the pixels on the screen and the amount of light allowed falling on the photographic sensor.

For the scanning procedure the software provided by the company XYZRGB[®] is used. The ideal number of scans varies according to the size and complexity of the object and also according to the desirable accuracy and density of the final product. Attention should be paid, so that the scans will have adequate overlap. In this application, 41 scans were necessary for the first vessel and 39 scans for the second one. The result of each scan is a point cloud. The software gives the opportunity to test the quality of the data that will be acquired, before each scan. Each point cloud is triangulated into a mesh, which is easier to handle, using Delaunay triangulation (Fig. 3 left). The image from the high resolution camera ensures that the mesh is textured (Fig. 3 right).

The results from each individual scan are the mesh, which is exported in OBJ format for further processing, and an image in JPG format, which is responsible for the texture information.

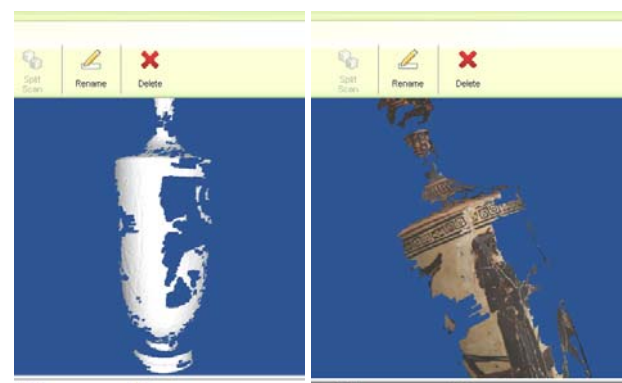


Fig. 3. Creation of the mesh (left) and the texture model (right) of a scan using XYZRGB software

3. DATA PROCESSING

The products of the scanning procedure were processed using various software packages, for the production of the final accurate 3D textured model of the vessel. For a better result and automation of various steps of the procedure a combination of (commercial and in some cases in-house) software made. In the following the individual steps of this procedure and the used software are given.

First the meshes were inserted in Geomagic Studio v12[®] for the hole filling and the registration (merging) of the individual meshes for the creation of the final surface, as each mesh refers to a different local system. The most popular algorithm for the registration of the meshes, which was also used here, is the ICP (Chen and Medioni, 1991). Selecting at least three common points between the two meshes, initial values are calculated for the transformation, which are then optimised (Fig. 4). Having completed the registration of all meshes, the final surface is processed as a whole and all the individual meshes are extracted

separately in OBJ format (http://en.wikipedia.org/wiki/Wavefront_obj_file), so as to be georeferenced (Fig. 5).

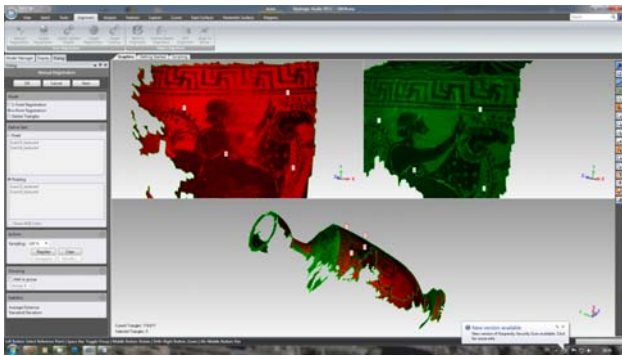


Fig. 4. Registration of two meshes using ICP algorithm procedure in Geomagic Studio software

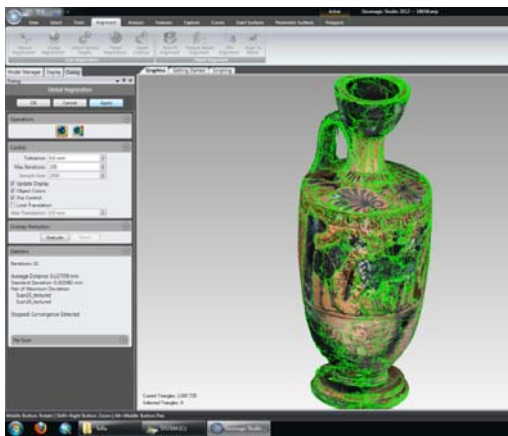


Fig. 5. The surface of a lekythos after the registration of all individual meshes

The texture of the final 3D model relies on the procedure of texture mapping. To generate a texture map, the 3D model has to be simple enough due to restrictions imposed by computer memory limitations. As the surface of the lekythos is really complex and the 3D model is detailed and precise, it is absolutely necessary to be simplified. Thus, a new surface is created, called constrained mesh (c-mesh). This surface is composed by quadrangles or triangles. The specific procedure was implemented in GSI Studio[®] software (a product of the XYZRGB Company).

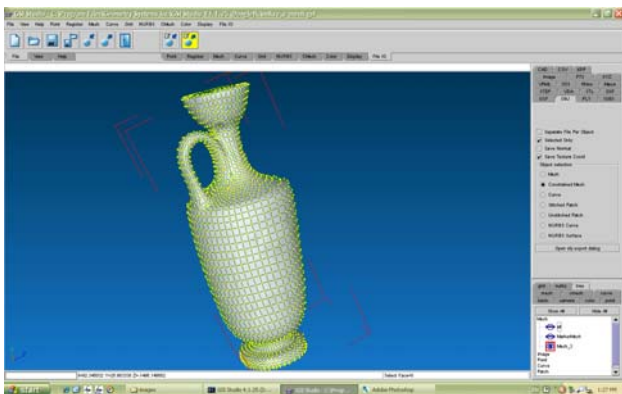


Fig. 6. Creation of the c-mesh surface

The simplified surface shall be extracted automatically; however the user, in this case, is not able to supervise the

procedure and control the result. Hence, in the presented project, it was decided to follow a manual procedure. The quadrangles forming the constrained mesh were denser where the geometry of the surface was more complicated (Fig. 6).

The UV-map, that is actually offering the texture to the 3D model, is a kind of development of the created constrained mesh. Each vertex of the 3D model, defined by X,Y,Z coordinates is projected onto this two dimensional image (texture map) and is now defined by U,V coordinates (http://en.wikipedia.org/wiki/UV_mapping). The creation of the UV-map was performed in the DeepUV software of Right Hemisphere[®]. This procedure may be done either automatically or manually. The shape of the vessels does not comply with any developable surface thus the automated procedure has created a complicated texture map hard to use (Fig. 7). Thus, the texture map was extracted manually, by selecting parts of the surface with common characteristics (complexity, curvature) and deciding in which developable surface it adjusts better (cone, cylinder) (Fig. 8).

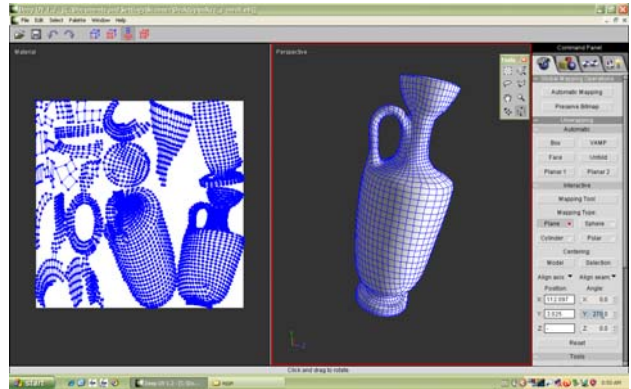


Fig. 7. Automated creation of UV-map (2D texture map) through the algorithms of the DeepUV software

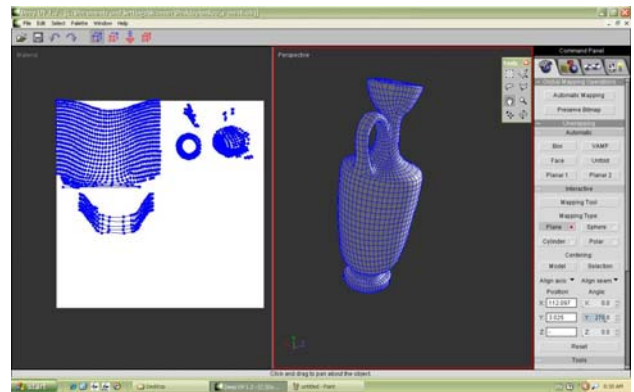


Fig. 8. Manually selected parts of the surface for the incremental creation of the 2D texture map

The next step is to provide the texture map with the right colours. For this procedure, the georeferenced meshes and the image of each scan and the constrained mesh were inserted in the 3D Studio Max software by Autodesk[®]. The result is a texture map with colour, containing the information from the each scan. This step results in many texture maps; the number of texture maps equals the number of individual scans, acquired during the field work. However, for the texture of the final surface, only one texture map must be used. Thus, all the individual texture maps are composed and turned into the final texture map using the Photoshop CSS[®] software (Fig. 9).



Fig. 9. The final texture map of the smaller lekythos

For the visualisation of the final product in any software capable of managing 3D information, the OBJ file of the constrained mesh, the final texture map (a JPG file) and an MTL file are needed. The MTL file contains the name of the material (in this case the texture map) and its properties (<http://people.sc.fsu.edu/~jburkardt/data/mtl/mtl.html>). In this project the final optimisation of the 3D textured model was implemented in 3D Studio Max software, where radiometric and smoothing interventions were made (Fig. 10).

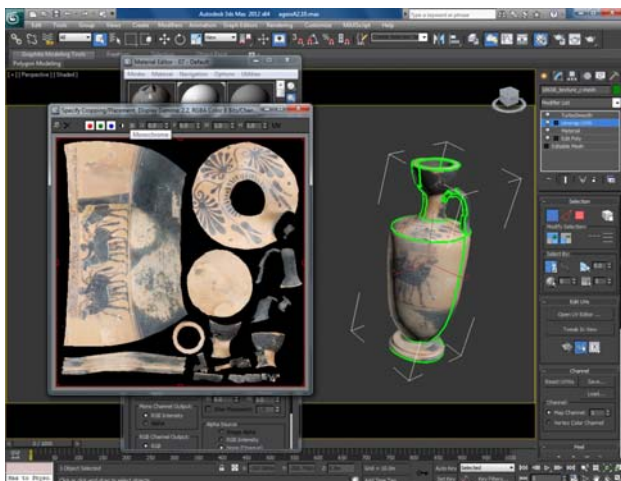


Fig. 10. Final processing of the 3D textured model of the bigger lekythos

In the upper part of Figures 11 and 12 the 3D views of the final textured models of both lekythoi are shown. The quality of the results is especially satisfactory, representing accurately all the details of the geometry of the complex surfaces of the vessels.

In addition, as a by-product of the processing, the development of the main body of each lekythos is created, the surface of which is close to a cylinder and it shows the representation of an adventure of Odysseus. The developments are shown at the lower part of Figures 11 and 12 for both lekythos. This product is very useful for the visualization of the story of each myth as it represents in an easily understandable way (2D image) the scene that decorates all the (almost cylindrical) surface of the vessel.



Fig. 11. The final 3D model (up) and the development of the texture map of the carving (bottom) of the bigger lekythos



Fig. 12. The final 3D model (up) and the development of the texture map of the carving (bottom) of the smaller lekythos

4. EVALUATION OF THE RESULTS AND THE METHOD

4.1 Procedure and Results

For the processing of the scanned data a combination of software was used; each step of the procedure was done using different software (XYZRGB, Geomagic Studio, GSI Studio, DeepUV, Photoshop, 3D Studio Max). The selection was made after several and thorough trials using various software that can execute each individual step of the process and by determining the appropriate parameters for their best operation. Many of the above procedures were repeated several times in order to have acceptable result. That way some very good results have been acquired in terms of accuracy and quality of the final products (developments and 3D textured models), but the process is time consuming and the quality of the results is up to the user's experience. In addition, particular attention should be given to field work, where the definition of the scan parameters play a crucial role for proper collection of data, which facilitates continuity and correct processing and workflow.

In general the hardware and the processing of the selected 3D data provides satisfactory results regarding the geometry of the final product, making good use of the capabilities of the structured light scanner.

A disadvantage of the used method is the step of simplifying the surface, so as a suitable texture can be attributed to the 3D model. It is advisable that this step be carried out manually, so the user can decide the rate of simplification. The final results seem to depict the object with high fidelity, but a problem is the lack of a quantitative criterion for checking the rendering texture.

4.2 Comparison with automated procedures

For the creation of the 3D textured model of small size objects, automated methods may be used, some of which do not require any user involvement and give fast results. The use of such methods is free in the internet and it just requires the entry of data. However such facilities in terms of time and cost saving have an impact on the accuracy and the quality of the produced 3D models; they cannot provide as satisfactory results as the semi-automated procedures. In the following, some examples and comparisons with the results of the used in this project procedure are given.

An alternative semi-automated solution is the use of a pulse scanner, for the collection of the point clouds, and a digital camera, for the image acquisition, so that the creation of the 3D textured model will be produced using a commercial software, like the 3DReshaper[®] or ImageMaster[®]. A drawback of the first software is that it can not process large images, and, in addition, the produced 3D models are very large in volume and not easily manageable. The disadvantage of both methods is that areas that are not visible in the images are not modeled and textured properly. Another disadvantage of the texturing procedure of the ImageMaster is the need for control points.

The automated approaches use only images as data and they create the surface of the object (mesh) using dense matching algorithms; then provide texture to the 3D model from the color information provided by the images. Examples of such software packages are: 123catch[®], Photosynth[®] and Insight3D[®]. The first of these applied for the production of the 3D models of the two

lekythos, using images taken by the high resolution camera of the SL2 structured light scanner. The results are shown at Figures 13 and 14. Significant problems at the 3D model are shown, which cannot be corrected (since the user cannot interfere), such as holes in the model and distortions of the surface, especially at the places where the curvatures changes. A significant disadvantage in the use of such software is the fact that developments of the object's surface cannot be produced as an additional product of the creation procedure of the 3D textured model.



Fig. 13. Texture map of the bigger lekythos, as it is derived from the 123catch software

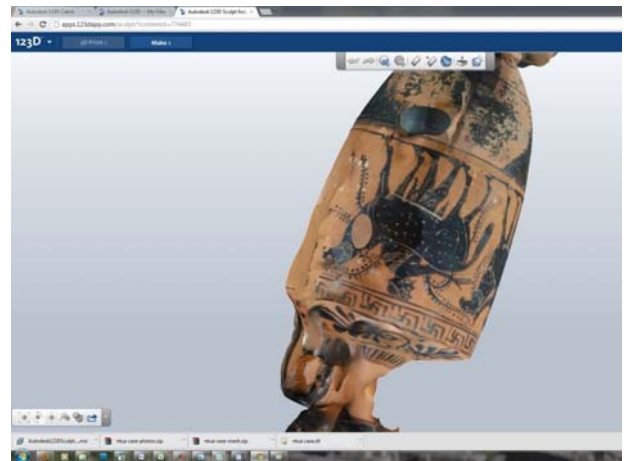


Fig. 14. Final 3D textured model created by the 123catch software

5. CONCLUSIONS

The procedure followed in this project proved to be the most appropriate method for the creation of the 3D textured models of archaeological findings. Its application on the two lekythoi gave very good results both in terms of accuracy and quality. However the low degree of automation of the process may create problem as the final product depends on the experience and the knowledge of the user.

Also, a general conclusion is that each geometric documentation process of an archaeological object has different requirements and the most appropriate method to be followed must be studied examining numerous factors. The creation of accurate 3D texture models is a field with many opportunities for future research.

However the three-dimensional textured models and their 2D developments are an attractive solution to the presentation of archaeological findings in an effort to create an attractive educational tool, which may help kids and students to

participate actively during their visit to an archaeological museum. The museum becomes a cozy and intimate space, a place of learning through play. Children are encouraged to observe, to think, to express themselves and act. Also the ability to view 3D models via Internet is another important area of action to be developed in Museums. An interactive museum visit converts visitors to active participants of the museum process. The hidden information that is the additional material that is stored on the computer, which is revealed and activated through an interactive application, stimulates interest and activates the processes of participation and guest's choice.

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