Developing an “Archaeological” Benchmarking Procedure

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Abstract:
The present paper reports an ongoing project aiming at developing an “archaeological” benchmarking procedure for the definition of the most suitable methodology for 3D models creation, to adopt for different research goals such as conservation, virtual restoration and web visualization of archaeological objects. The test has been carried out on some archaeological artefacts, differing in size, material, shape, texture and surface characteristics, focusing on the possible applications of the outcomes and on diverse parameters offered from the device. A low cost 3D laser scanner (NextEngine) was chosen for the test, because of its cost affordability, especially for museums and Cultural Heritage (CH) institutions. The result of the qualitative analyses performed by professionals on the scanned objects (archaeologist, ceramist, paleoanthropologist), along with issues that emerged during data acquisition and data post-processing, allowed us making recommendations useful for Cultural Heritage professionals interested in applying digital technologies in their daily work.

Key Words: *Laser Scanning, Archaeological Objects, Benchmarking*

Introduction

Three-dimensional scanning devices are increasingly adopted by CH professionals for recording archaeological sites and artefacts for documentation, conservation and dissemination purposes.

Currently there is still a lack of a well-established methodology concerning the digital acquisition of archaeological artefacts. Therefore the definition of guidelines for digital data acquisition and post-processing is strongly required in order to assess and validate the quality of the final results and adapt the 3D models creation process to the needs and aims of the users.

Furthermore it could be a waste of time and money choosing instruments not suitable for the aim of the research: for example using cheap devices providing low quality results or using improperly an expensive laser scanner without exploiting the potential of the instrument.

In approaching 3D scanning devices the first question of CH experts is always related to the choice of the most suitable device and methodology to adopt for their work, giving more attention to the correlation with the different scenarios that the technology can offer, rather than a purely metrological aspect. Unfortunately there is not a single answer to this question, because many criteria are involved in the decision making.

Usually, three-dimensional scanner benchmarking is provided mainly from an engineering perspective, without considering the particularities of the archaeological objects and archaeological tasks. Even when archaeological finds are used as samples (Guidi et al. 2007), there is little or no justification of this choice. “It would be very useful to develop customer-oriented benchmarking strategies in other contexts where 3D scanners are normally employed, such as medicine or archaeology, in order to obtain a complete and reliable description of the 3D scanner scenario” (Vezzetti 2009). Therefore on the base of the Verzetti’s ideas, we decided to develop a benchmarking procedure approaching the users’ needs, finding the optimal scanning procedures for different archaeological objects, differing for size, material, shape, texture and surface characteristics.

The next section reports on existing benchmarking applied on archaeological artefacts. The third section introduces the laser scanner used emphasizing its principle and technical specifications. The fourth describes the characteristics of the archaeological objects that have been tested, while the fifth section explains the data acquisition and post-processing workflow. The sixth section addresses the capabilities and the limitations of the used approach and illustrates the achieved results. The final section addresses our conclusions.

Existing Benchmarking Using Archaeological Objects

Benchmarking of 3D scanner is mainly provided by manufacturers and researchers which tested the various objects from an engineering perspective (Menna and Troisi 2010; Tornincasa and Verzetti 2005) reaching in this field a certain level of expertise, while there are few tests performed on archaeological material with the scope of testing the performances of a laser scanner according to different archaeological objects. For example, the test performed by Guidi and colleagues (2007) has an engineering perspective focusing on the instrumental performances in terms of precision and accuracy, although it uses as test objects some archaeological artefacts. In this work the evaluation of the performances of the low-cost NextEngine 3D laser scanner have been compared with that of other well known triangulation-based range sensors. In another case the performance evaluation of a coded structured light system for 3D documentation of cultural heritage objects has been tested (Akca et al. 2007). The NextEngine scanner was reviewed by archaeologists (Abernathy 2007) that developed a qualitative benchmarking with an archaeological perspective.

The work carried out by Tucci, based on the digital reproduction of archaeological objects aiming to implement a scholars’ archive with high resolution models and to provide content for virtual exhibitions on the Web (with geometrically simplified models at lower resolution) was an attempt to define the most effective work-flow for data acquisition and processing (Tucci et al. 2011).

Georgiadis and colleagues (2009) modelled a series of different objects spanning from prehistoric archaeological finds to contemporary art objects: in this work were used, independently from the object’s size, photogrammetric techniques for simple objects with well defined edges and simple surfaces and a series of laser scanners for objects of high complexity depending on the object’s size and material with the goal to find the optimum modelling technique.

Device Description

The device used for our testing is the Next Engine Desktop 3D scanner. This instrument was chosen because of its cost-affordability, especially for museum and CH institutions, and because an accurate methodological analysis on its technical proprieties has been already performed (Guidi et al. 2007).

The 3D scanner is based on multi-stripe laser triangulation (MLT); it projects multiple laser-stripes recorded by a CCD camera which registers the point's position. The device consists in a compact aluminium box of 22×28×9cm size, provided with twin arrays of four solid state lasers (red, 650nm) and twin 3.0 Megapixel CMOS image sensors (Hermon et al. 2010). The texture is overlapped automatically on the models by a synchronous RGB colour texture capture. The instrument is also equipped with a rotary table which in our case has been used because of the small size of the objects.

Next Engine Desktop 3D scanner has a field size of 12.95×9.65cm (Macro Mode) and 34.29×25.65 (Wide Mode). However there is no size limitation for object acquisition because objects larger than the scanner field can be composite-captured and assembled with the scan alignment software even though it makes the process more complex. The acquisition speed is 50.000 processed points/sec throughputs. Typically it takes 2min per scan of each facet and the dimension accuracy is ±0,127mm in Macro Mode and ± 0, 381mm in Wide Mode. The scanner resolution is 200DPI in Macro Mode and 75DPI in Wide Mode. Texture density on target surface is 400DPI in Macro Mode and 150DPI in Wide Mode. The Next Engine works under ordinary office lighting, so no darkroom or special backgrounds are required.

Archaeological Artefacts Description

Besides the criteria related to the instrument, the operating condition and the nature of the objects to be scanned may influence the outcomes. As part of the testing procedure, a set of typical archaeological finds and replicas have been scanned in order to verify the different response from the laser to the various materials, texture and shape of the tested objects. The criteria chosen for the comparison are related both to the characteristics of the objects and to the different scan parameters of the used software (ScanStudio). In the table below are listed the characteristics of the objects used for the test (Table 1):

Material	Reflectance	Colour	Texture
Bronze	High	Dark brown-green	Fine compact
Flint	Medium	Light brown	Fine compact
Bone	Low	Beige/light brown	Porous
Tooth	Medium	Light	Partially porous
Ceramic	Low	Light brown	Porous

Table 1. Artefacts characteristics.

In particular the artefacts analyzed have different light scattering characteristics. Below the list of the tested objects:

- a bronze statue (replica),
- a flint tool both (replica),
- an ancient human vertebra,
- an ancient human tooth,
- a potsherd.

The bronze statue measures 13.15×4.43×2.57cm. The contours are smooth and rounded; the colour is dark with green traces of oxidation. The object has a surface with high reflectance and a fine and compact texture.

The flint tool is a hand axe, measuring 11×6.26×2.73cm. It is light brown, presenting some traces of the original cortex that make the texture not homogeneous. The surface is compact with many planar faces due to the chipping and the contours are sharp and retouched.

The ancient vertebra has a complex shape with low reflectance texture with size 9.13×2.56×5.06cm. The bone analyzed here is the last human lumbar vertebra (L5), from the Early Bronze Age site of Karmi-Palealona, Kyrenia district, Cyprus (Lorentz 2009). The bone is badly preserved showing a lot of spongy parts as well as missing surfaces and the colour is beige/light brown with a porous and opaque surface.

The ancient human tooth has a regular shape with a partially porous surface. The colour is light with a low reflectance and the maximum dimensions of the tooth are 1.67×1.06×0.82cm.

The potsherd is a fragment of a ceramic vase that measures 6.97×6.71×1.33cm and it has one face decorated. The fragment's surface is porous with a light brown colour.

Adopted Methodology

Digital data acquisition

Before starting the digital acquisition process, some parameters were defined in order to evaluate the potential offered by laser scanner according to the different objects. The scans were performed in a controlled environment in order to minimize the ambient lighting in the room and to reduce shadows, improving the textures appearance. The software used for data acquisition is ScanStudio, produced by NextEngine. It allows defining the scan parameters, aligning multiple scans and post-processing aligned scans data.

The tested objects were all acquired in Wide and Macro Mode, both with low and high resolution acquisition in order to test the various options offered by the software. The objects were placed on the rotary table and for the smallest ones we used the part gripper. A positioning of 360 degrees was adopted and the whole surface of the objects was scanned with a number of scans varying from 5 at first, 7 and then 9 scans, as this number should preferably be odd in order to overlap the last scan with the first. We decided to test the acquisition of the object intentionally with a low number of scans in order to test the efficiency of the instrument in terms of time and cost while other tests have been performed with an average of 20 scan for each object (Tucci et al. 2011).

Using the Wide Mode, the artefacts were acquired with a distance of 46cm from the scanner (the manufacturer estimates 0.38mm of accuracy with a maximum of ~6 points per mm), while using Macro Mode the distance was of 16.5cm (estimate 127 micron of accuracy with a maximum of ~16 points/mm). The camera inside the laser scanner takes a picture of the object, saved as .jpg file format. The pictures are overlaid on the 3D scans, making the alignment process easier. The same digital acquisition procedure has been repeated for the five objects and for each scenario.

Data post-processing

After the digital acquisition of the artefacts was completed the range maps were exported to MeshLab, the open source software for mesh processing developed at the Visual Computing Lab of ISTI - CNR. The single scans were saved in .ply file format and seamlessly exported. We decided to adopt MeshLab software because it is user friendly, open source and because it has been tested already on archaeological objects with optimal results (3D-COFORM 2011).

Once imported in MeshLab the single scans were cleaned applying several filters, commonly used for meshes optimization: '*remove duplicated faces*', '*remove unreferenced vertex*', '*remove duplicated vertex*', '*remove non manifold vertex*' and '*remove non manifold faces*'. The cleaned range maps, saved as .ply, were then aligned using an ICP algorithm to obtain the complete model. The registration was done manually by comparison of the 3D geometry choosing at least four common points.

The range maps were then flattened in order to create a merged file containing all the scans aligned in the previous steps. A continuous surface was reconstructed by fusing the single scans and applying the *Poisson Surface Reconstruction* algorithm provided by Meshlab (using Octree depth: 12, Solver Divide: 12). The texture was transferred to the model applying *Sampling/Vertex Attribute Transfer/Transfer Colour* filter.

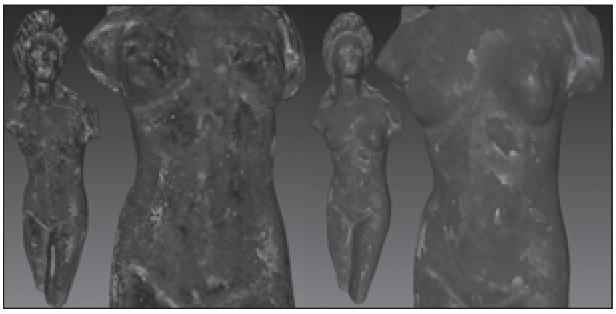

Figure 1. Bronze statue in Macro Mode (left) and Wide Mode (right) with 9 scans.

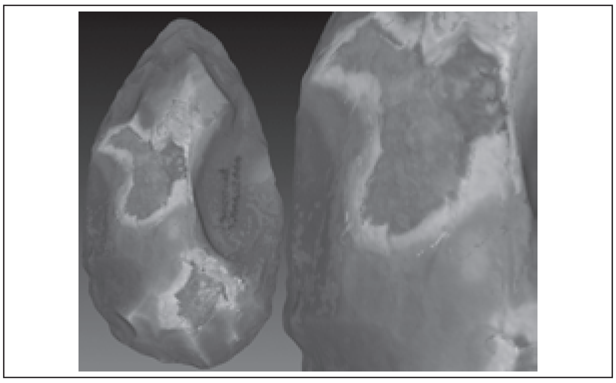

Figure 2. 3D Model of the flint tool.

Results and Interpretation

The various ScanStudio parameters allowed us to simulate different scenarios for the digital acquisition of the artefacts and evaluating the corresponding outcomes.

The main factors that influenced the results of the digital acquisition and post processing are related to acquisition range (Wide/Macro), resolution (low/high), shape and material of the tested objects.

A qualitative analysis of the results of the scanned objects, supported by professionals (archaeologist, ceramist, paleoanthropologist) shows that the scans acquired using Macro Mode with high resolution give a more detailed geometry of the object and a very realistic texture, obviously more accurate than the low resolution acquisition as in the case of the bronze statue. The geometry of the statue, rounded and not very complex, was not affected by the resolution acquisition, while the texture shows a considerable loss of details varying from high to low resolution (Fig. 1).

In particular all the scans with Wide acquisition range at low resolution did not allow completing the alignment process because of the lack of common points due to the gaps in some parts of the range maps. On the contrary the scans acquired in Macro Mode, both low and high resolution, gave satisfactory results, allowing the alignment of all the objects. The ones acquired in Macro high resolution gave an outcome with a very detailed geometry and a realistic texture. The accuracy of the geometry is affected by using the low resolution, with the loss of details, as in the case of the flint tool where the surface of the final model was smoother than the real object losing the characteristics of the chipping traces (Fig. 2).

Through the process of digital acquisition and post-processing, a number of common scanning issues concerning the geometry of the model and the texture emerged. These are related to the number of scans and the shape of the objects.

In the specific case of the flint tool, a low number of scans (5 scans) and its narrow shape made the post processing easier. In fact, the digital acquisition of the object with five scans gave a range map with a cover of the surface that allowed an easy individuation of the common points necessary for the alignment process. On the other hand, for the range map resulting from 7 and 9 scans the lining up of the match points was less intuitive due to the lack of points on the surface of some scans.

For the specific case of the vertebra (Fig. 3) and the human tooth (Fig. 4) the obtained models have been examined by a paleoanthropologist who performed qualitative analysis. The analysis demonstrated that the models are suitable for educational purposes or comparative studies because the geometry is fully comprehensible. Concerning the texture of the 3D model of the vertebra, the final result was quite realistic while for the tooth, due to its small size and the low resolution of the camera, the result was not satisfactory. However, it is not advised to use those models for specific studies, such as pathology analysis since the essential features are not detailed enough. The models obtained with low resolution scans, streamlined geometry and a not accurate texture can be used, due to their low file size, for visualization through the web.

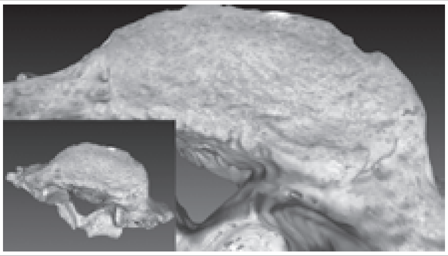

Figure 3. 3D model of the human vertebra with the particular of the textured mesh.

Figure 4. 3D model of the human tooth without texture.

Figure 5: 3D model of the textured potsherd.

In the specific case of the potsherd, its regular geometry and its medium size, allowed us to obtain satisfactory results by applying the various parameters (Macro/Wide, high/ low resolution) and simulating the various scenarios applied to the other objects (Fig. 5).

Conclusions

The objects used for the benchmarking were chosen because they represent some of the typical and most commonly studied archaeological finds. From the results achieved with the test we can assume that the scanning was generally very successful. The result of qualitative analyses of the scanned objects performed by professionals (archaeologist, ceramist, paleoanthropologist), along with issues that emerged during data acquisition and data post-processing allowed us to start making recommendations useful for Cultural Heritage professionals interested in applying digital technologies in their routine work.

For this reason we decided to test only a low cost laser scanner in order to simulate the normal scenario of an organisation responsible for the conservation and the study of Cultural Heritage (museums, research institutions, etc.)

that usually deals with scarce availability of funding for purchasing high cost instruments.

Many criteria are involved in the decision of the most suitable methodology to adopt for the creation of 3D models; therefore there is not a single answer. This work can be considered as a good starting point for the activities providing the definition of some guidelines derived from issues on the data acquisition and post processing that emerged during the test.

This is an ongoing project: the main idea is to proceed with the testing of other archaeological objects, trying to cover the variety of categories such as marbles, small architectonic decorations, coins, jewellery, and possibly also replicas produced by experimental archaeology. This will allow manipulating even the most delicate items in order to perform the test.

Experimental archaeology can be useful also to perform tests on the reliability of the methodology, evaluating the accuracy of the outcome in the case of virtual reconstruction application. A valid way could be to start an inverse process: for example, a test can be done on a replica of a ceramic vase. It can be broken and the pieces digitally acquired with the scanner. After applying the complete procedure, from data acquisition to post-processing, the outcome will be compared with the original, previously measured, in order to evaluate the accuracy of the obtained model.

Another further development of the research could also be the test of this instrumentation not only in laboratory but also as a support of the archaeological excavation documentation in order to evaluate the performances of the laser scanner with different conditions (light, wind, dust and so forth).

Acknowledgements

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