

3D LASER SCANNING, NUMERICAL SURFACE DEFINITION AND FAST PROTOTYPING OF THE "BASEL BRONZE HEAD"

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Abstract

Starting from the experiences and results deriving from the cooperation between the Istituto Centrale del Restauro, Fox Bit srl and certain academic institutions, a study is presented which is aimed at using and adapting reverse engineering (RE) and fast prototyping (FR) industrial techniques to cultural property conservation.

1. Introduction

The degradation of an artifact is usually measured by the extent of the changes of the main chemical and physical characteristics of its material. Since each control parameter needs its own diagnostic technique, this approach may only provide a partial overview of the state of conservation of the artifact.

The resulting data relate to a particular feature of the material, investigated through the relevant technique (capillary absorption, grain size, elasticity modulus, porosity, ultrasonic propagation velocity, color, etc.); furthermore, in most cases, diagnostics must be limited to a few critical variables, due to cost reduction requirements, and the true essence of the measured parameters relates rather to the chemical and physical characteristics of the material than to the state of conservation of the artifact.

In fact, the state of conservation may be expressed in a more direct and significant manner by measuring the loss of material, or even better, the changes endured by the surface delimiting it, in terms of morphologic and chromatic variation. This involves the scanning of the geometrical shape of the artifact, and the numerical definition of its surface at a certain instant, the latter also including color measurement.

Numerical coding of information is independent, at least theoretically, from the instability of the physical medium containing such information and provides the best possibility to transpose the "artistic shape" into a steady state.

So, any technical process being able to perform such operation with a satisfactory resolution and

definition would generally solve the problem to control, define and keep the "shape".

The solution of this problem in sculpture, and for any sculpted or modeled surface, currently is the best answer that can be given as a concrete support to cultural property protection.

So, starting from the experiences and results deriving from the cooperation between the Istituto Centrale del Restauro, Fox Bit srl and certain academic institutions, a study is presented which is aimed at using and adapting reverse engineering (RE) and fast prototyping (FR) industrial techniques to the above mentioned issues of cultural property conservation.

The subject of this study was the "Basel Bronze Head", which is currently exposed at the National Archeologic Museum of Reggio Calabria.

In strictly industrial terms, the expression RE is often used to define a process aiming at virtually reproducing a product (mechanical parts, die inserts, etc.), in order to develop a variant, an improvement or a real implementation of it.

The logical steps of the technique consist in acquiring the starting shape, processing it, and forming a virtual model and/or reproducing the parts by fast prototyping.

In short, by using RE technique, the mathematical model is developed directly through the product's digital electronic recognition.

The most widespread methods for 3D digitizing of the physical model involve the virtual

reconstruction of the object from point clouds obtained by using special tracers (contact scanning techniques), or by photogrammetry, interferometry, triangulation, etc. (non-contact devices).

Hence, the material sensor (contact-operated, optical, etc.) is the core of the virtual reconstruction system.

At present, an optimal virtual reconstruction of an object often depends on the experience and skill of the operator. This because:

- as the distance from the scanning position to the object under examination increases, or other parameters are altered, the position of the detected point does not always coincide with the spatial position in the reference system, that is the position of the digital point does not coincide with the material point;
- the ambient brightness conditions, the moisture level, the surface state of the detected object, etc., cause refraction and/or reflection of coherent light, which often cause triangulation errors
- the scanning system collects more points than necessary for reconstruction (redundant data, that must be rejected).

So the geometrical shape of the Basel Bronze Head could only be defined by improving the currently available equipment in terms of resolution and dimensional accuracy of the virtual image.

In the above technical and operational conditions, the 3D scanning system used in the research project was a Laser Mapping System (LMS) with a triangulation laser, and integrated digital camera, and equipped with controlling PC and appropriate software.

As outlined above, since the features and performance of the sensor greatly influence the acquisition results, the study was intended to reduce, from the point acquisition step, the technical and economic weight in post-processing (point optimization and noise reduction) to ensure high quality of the virtual model (dimensional accuracy, irregularity of the reconstructed surfaces, etc.).

So, the purpose was to restrict the dispersion error range from the scanning step, in order to limit any expectable amplification and interference between the resulting morphogeometric data when these are manipulated and processed by the graphic file consolidation algorithm.

The laser scanning system that was used in the macromorphological scanning step gave an output

of a huge number (millions) of points, identified by their cartesian coordinates, which describe the shape of the art work.

In the following step the data derived from the different scanning points of view were assembled into a single reference (see systems' initial setup).

The system used in this study comes with proprietary software enabling shape reconstruction in the form of a point cloud. Hence, generally speaking, the object acquisition steps may be structured as follows:

- identifying a comparative base (known points system)
- scanning from several points of view (n-POV - number of points of view)

Therefore, in particular, the resulting point clouds, identified by n-POV must be integrated into a single model. This involves:

- segmenting the reference points detected on site
- consolidating point clouds from different n-POV
- integrating the n-POV

With an object of this particular type and dimensions, 1.500.000 points were obtained, with an average error of less than 0,15 mm



Figure 1: Cloud of points

From this moment on, surface reconstruction was started, which involved the following:

- smoothing the point cloud, by averaging the spatial coordinates through analytical models (e.g. average standard deviation)
- appropriately redefining the point density (resolution) by processed surface unit and find a primitive basic geometry (plane, cylinder, cone, etc.) approximating the model section.

After post-processing of the cloud, a surface consisting of a patch union of basic surfaces (faceting) is obtained, which approximates the real model (reconstruction step).

Faceting provided a very big model in terms of computing weight/Mb, and files having a size of about 100 Mb were to be handled.



Figure 2: *Rendering*

To obtain a better quality of the reconstructed model, the faceted model had to be converted (by using appropriate interfaces, such as IGES, ASCII, BINARY, etc.) into a common CAD-readable format.

The advantage of this conversion consisted in the possibility that approximate geometric elements (e.g. facets) could be standardized and modeled through surfaces (boundary, sweep blend, advanced, etc.) to improve the morphological and geometric definition of the scanning result.

Further, the current potential of graphic software allowed to generate outputs fit for a number of different uses (dimensional and qualitative analysis, structural analysis, rendering, prototyping, etc.) .

As test for the scanning quality, our graphic source file was converted into the .stl standard and, by fast prototyping techniques, directly passed from the 3D project to the finished product, with no intermediate steps.

To this end, .stl files (RP machines format) obtained by automatic procedures of the CAD system are actually used.

.stl files include a discretized model which has to be sectioned by parallel planes (slices) to obtain the boundary coordinates of each of the sections, forming the object by superposition (slicing).

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The object is reconstructed through direct forming of the material according to the coordinates contained in the .stl file.

Current software systems are able to automatically trace trajectories for each slice from the source format, and the operator only has to control information, while the machine ensures an independent operation.

This method imposes a new approach to production, transforming the subtractive fabrication (e.g. removal) or forming (e.g. molding) concept, into a self-fabrication concept.

All intermediate steps from conception to production are drastically eliminated, allowing to pass from concept to product in short times, with the help of machines that do not "process" the material, but materialize shapes.

In this step of our experimentation, a solid model made of an epoxy resin could be fabricated, by using the most up-to-date fast prototyping techniques, stereolithography, with appropriate dimensional tolerances, that is:

- positioning accuracy: +/- 0,09mm



(X,Y,Z axes)

Figure 3: *Original artifact and stereolithographic prototype*

The open horizons of this experimentation, the first of this type in Italy, are easily perceivable.

Science, as well as the above mentioned tools can propose new and innovative solutions to the problem of cultural property conservation and valorization.

By using them appropriately, it will be possible to:

- log mathematical models of artifacts, hence steadily keeping the *shape memory*
- monitor the degradation caused in years by weather or traumatic events, in a numerically measurable manner
- provide multimedia and interactive tools useful for study and/or educational purposes
- reproduce the artifact accurately, in accordance with the original.