Applied Mechanics and Materials *Online: 2014-10-08*
ISSN: 1662-7482, Vol. 657, pp 795-799
doi:10.4028/www.scientific.net/AMM.657.795

Replica Fabrication of a Greek Paleontological Find Utilising Laser Scanning and Fused Deposition Modeling

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Keywords: Computer Aided Design, Reverse Engineering, Rapid Prototyping.

Abstract. The current work demonstrates a feasibility study on the generation of a copy, having a highly complex geometry, of a Greek paleontological find utilising reverse engineering and low-cost rapid prototyping techniques. A part of the jaw bone of a cave bear (Ursus spelaeus) that lived during the Pleistocene and became extinct about 10,000 years ago was digitized using a three-dimensional laser scanner. The resulting point-cloud of the scans was treated with a series of advanced software for the creation of surfaces and ultimately for a digital model. The generated model was three-dimensionally built by the aid of a Fused Deposition Modelling (FDM) apparatus which was subsequently treated with acrylic coatings and paints in order to match the colour of the paleontological find. An analytical methodology is presented revealing the step by step approach from the scanning to the prototyping. It is believed that a variety of interested parties could benefit from such an analytical approach, including, production engineers, three-dimensional CAD users and designers, palaeontologists and museum curators.

Introduction

Reverse engineering is applied these days gradually on the field of cultural heritage more than any other method of producing digital documentation and exacting authentic copies. The generated scanned data have been used for digital archiving, virtual restoration and visualization, physical restoration as well as implementation of authentic copies. A few examples, that can be mentioned, are the facial reconstruction of an 11-year-old girl residing in Athens of the Golden Age of Pericles 430 bc whose skull was unearthed in excellent condition [1], the virtual 3D reconstruction of the east pediment of the temple of Zeus at Olympia [2], ancient pottery scanning and analysis [3], and generation of a 3D digital model of a slab found from the Middle Jurassic of Msemrir in Morocco [4].

In the current work the examined object is a paleontological find with dimensions 28 cm x 15.4 cm x 3 cm which is a part of the jaw bone, as shown in Figure 1, of a cave bear (Ursus spelaeus) which was found in 2007 in the area of Kastoria, Greece. The specific species of bear lived in Europe during the Pleistocene (2.588.000 to 11.700 years before present) and became extinct before approximately 10.000 years ago. Its name derives from the fact that fossils of this species were mainly found in caves, indicating that the cave-bear spent more time in caves than the brown bear, which only uses caves for hibernation. The purpose of this study was to examine the feasibility of reverse engineering of the aforementioned paleontological find and the use of low-cost rapid prototyping technique in order to produce its replica so to be ready for further surface coating and color painting. Parallel to the generation of a copy, the aim was to examine the data derived from the research for additional editing and manipulation so to potentially use them in the future for other applications. More specifically, the current work utilized a laser scanner in order to scan the fossil and to generate digital data so to describe the highly complex geometry of the scanned object. Advanced processing of these digital data was achieved as well as conversion to the corresponding format for modeling and prototyping by materialization of the physical model.

Fig. 1. The part of the jaw – bone of the cave bear, found in Kastoria, Greece.

Instrumentation and Software

The highly accurate NextEngine 3D laser scanner was used for the scanning procedure. The laser scanner contains two arrays of four solid state lasers, two 3.0 megapixel cameras, and two lights for image capture. The laser scanner could scan objects of field size between 129.5 mm x 96.5 mm and 343 mm x 256.5 mm. It could provide texture density of 150 DPI up to 400 DPI and its dimensional accuracy lied between, + or – 0.127 mm and + or – 0.38 mm with acquisition speed of 50,000 points per sec. For the rapid prototyping a low-cost FDM machine was used, which was capable of building up layers with dimensional accuracy of 0.1 mm from a 3 mm Acrylonitrile Butadiene Styrene (ABS) wire. The model was formed from the molten plastic using the data from the print wizard and control panel software. Primarily, the ScanStudio software was utilised for the processing of the point cloud, the CAD modeling and the conversion to STL respectively, so to be able to transfer the digital data to the FDM apparatus and thereby to build the prototype. Additionally, the Solidworks parametric CAD software has been used for the further processing of the CAD model.

Fig. 2. Laser scanning of jaw-bone and different positioning during scanning

Scanning

The setup of the scanner was set in that way that the scanned object was placed approximately 430 mm from the scanner achieving accuracy of 0.38 mm and field of view 254 mm x 330 mm. The scanned object was placed on different positions as shown in Fig. 2 in order to overcome the phenomenon of self-occlusion.

Generation of Point Clouds and Scan Data Process

The scanning generated a number point clouds indicated as scan families. Trimming was implemented by an appropriate tool of the ScanStudio software. The selection of the noise was done manually by circling or squaring the related points. The noise reduction resulted to finer and cleaner point cloud for each scan family. The alignment and trimming of the scan families were executed manually with caution. Usually prior to scanning, alignment marks are made on the scanned object to make it easier to place pins and identify locations on the object during the alignment process. In this study that was impossible to be done for obvious reasons, thus the alignment was a challenging task. The volume merging, remeshing, filling holes and simplifying have been accomplished by the use of the Scanstudio software. In this phase the overlap from multiple scans was eliminated and the scans were merged into a single mesh as shown in Fig. 3. The procedure has been repeated with different settings due to the requirement for optimal balance between simplification and number of triangles.

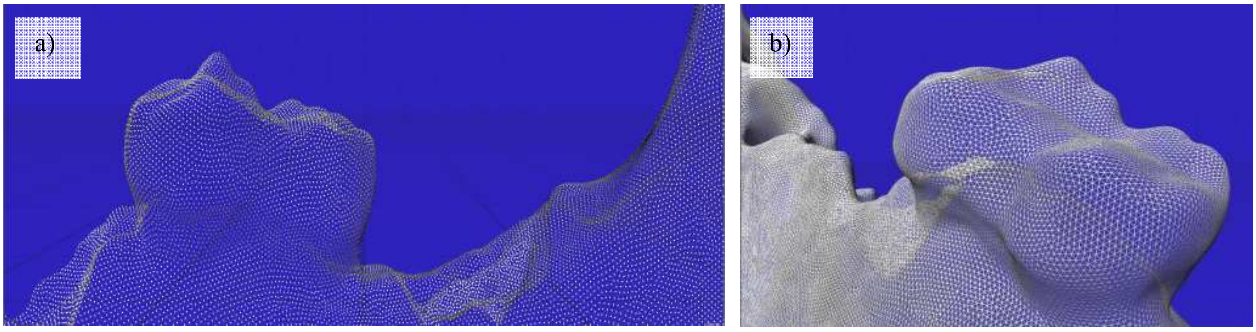

Fig. 3 a) Mesh display of tooth and b) magnification of mesh

Data Optimization

The polygon mesh was processed and was examined for non-manifold edges, self-intersections, spikes or small holes. The polygon mesh was retriangulated to produce a more uniform tessellation as shown in Fig. 4 (a,b). Multiple versions of meshes were created, with different number of triangles and with thin shells. Fig. 4 (c) demonstrates the selection of polygons of given curvature, that was increased while Fig. 4 (d) shows the selected polygons in red color that have been decreased. Additionally, polygon models with a thin shell were made as illustrated in Fig. 4 (e, f) to enrich the potential 3D printed model options. Finer polygon models have been produced and better STL files of the entire object were exported.

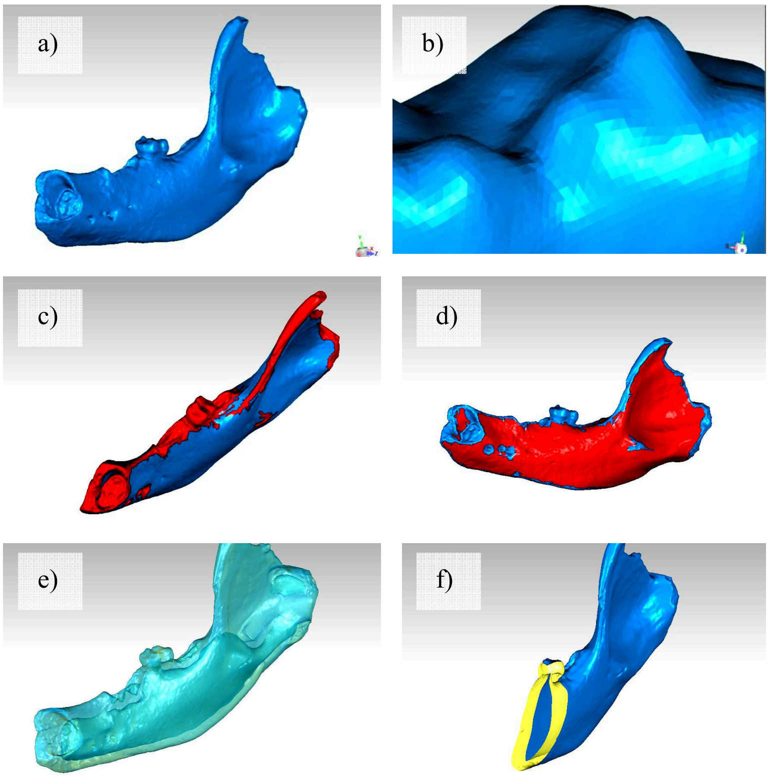

Fig. 4. a) Polygon mesh model, b) magnification of polygon mesh, c) areas with high curvature selected, d) areas with low curvature selected, e) transparent view of thin shell model, f) CAD view of thin shell model

The process of data optimization described was repeated for polygon models imported in PLY format. A variety of properties can be stored in PLY files including: color and transparency, texture coordinates and data confidence values. The generation and exporting of optimal PLY and STL files of the entire body of the jaw-bone was implemented to ensure that this kind of format was able to be achieved as a result of this study. PLY formats, as the one that is illustrated in Fig. 5, can be used in the future in highly expensive colored jet printing technology printers where multi-colored objects can be produced having almost the same color with the original object.

Generation of Surfaces, CAD, IGES Models for Further Processing

Up to this phase optimal STL files for FDM fabrication of the part were produced but the data have been further processed. This was necessary in order to examine the capability, of producing data which could be used for printing the jaw-bone in pieces and not only as an entire object. This procedure can be used for restoration purposes as well as to overcome any prototype size limitations of any FDM apparatus. In this phase the polygon models were converted to NURBS surface models and consequently to IGES and CAD models as shown in Fig. 6.

Fig. 5. View of model in PLY format displaying texture

Processing of CAD Model

The Solidworks CAD software provided the necessary tools to divide the IGES model to 4 or 5 assembling parts (Fig. 7). Rivet slots were designed to the parts to make both the virtual and physical assembly of the created models easier. Each one of the 4 or 5 parts could next be converted to STL, OBJ, WRML, or any other format requested.

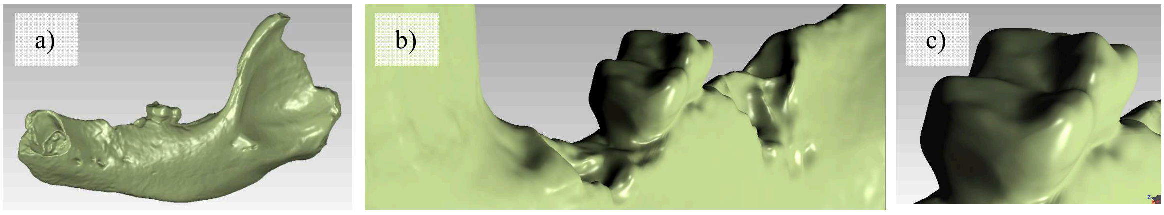

Fig. 6. a) Display of model after surfacing, b) magnification of a specific area, c) tooth magnification

Generation of Built Files for FDM Machines

The optimal STL files of the entire body and for the divided parts were then imported to the corresponding software of the FDM apparatus. The running parameters of the FDM machines were selected and the built up files were created in order to fabricate the part.

Discussion of the Results

Checking procedures were performed for data optimization, an automatic examination for non-manifold edges, self intersections, spikes or small holes were executed. At this point, there was some consideration in producing polygon models with thin shells that would provide thin shell CAD models later on. A thin shell polygon model although it has less material requirements during materialization in rapid prototyping it has more polygons- almost double the number- hence more triangles are created to geometrically describe the inner geometry. This problem has been resolved by reducing the triangles of the areas with low curvature. Thus, a polygon model of 500k triangles approximately has been edited to 350k triangles prior of shelling it, so as after the shelling, the number of shells to be again around 500k. The generation of surfaces and CAD models was obtained and next the corresponding STL files were exported. A further extension of the study has been implemented, resulting to a further edit and manipulation of the CAD model. The main target was new data to be produced enabling the materialization of the physical models in parts and not only as an entire model. This outcome could find many applications in the field of conservation, since it gives another solution of delivering copies of parts of scanned objects which can be used as accessional elements. Additionally, since the dimensions of the scanned object many times make impossible its prototyping to take place, 3D printed or FDM produced copies of parts of the object, would be a

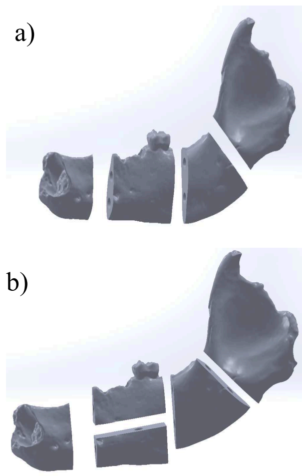

Fig. 7. CAD model divided in four and in five

solution. After the conversion to STL format and the generation of appropriate files for the FDM equipment for the prototyping process, the generated physical models made of white ABS polymer were fabricated as shown in Fig. 8 and 9. Further surface processing with acrylic coating and color paints was applied so to match exactly the color of the real paleontological find.

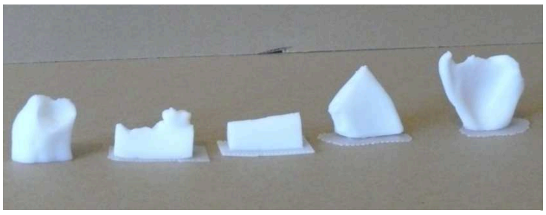

Fig. 8. Views of the five parts of the physical model made of ABS

Fig. 9. Physical model of the entire part made of ABS (top) and thereafter acrylic coatings and paints applied on the part to match the exact colour of the paleontological find.

Conclusion

The main focus of this paper was to demonstrate a step by step approach so to reproduce a fossil utilizing reverse engineering and low cost rapid prototyping procedures. The workflow comprised the scanning procedure, the generated point cloud and polygon mesh, the surface modeling and CAD modeling, and ultimately materialization of the digital copy along with subsequent coloring. In overall, the current work shows in a simplified manner the process of producing replicas and it is believed that will further encourage the use of advanced CAD procedures in the heritage protection and restoration.

Acknowledgement

The authors would like to acknowledge Ephorate of Palaeoanthropology - Speleology of Northern Greece who gave the official permission to use the specific find for research purposes. Special acknowledgments to Dr E. Maravelakis, Dept. of Environment & Natural Resources Engineering, TEI of Crete for his contribution with the model processing.

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