

Three-Dimensional Models of Archaeological Objects: From Laser Scanners to Interactive PDF Documents

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ABSTRACT

Three-dimensional (3-D) laser scanners build 3-D models of objects and have direct application in the cataloging of artifacts and in archaeological documentation. Certain low-cost scanners are suitable for small objects because the scanners have high accuracy and the ability to capture color and textures. This paper provides the workflow and the steps needed to scan small objects using a low-cost scanner, to build textured 3-D models, and to transmit these models embedded in portable document format (PDF) files. The proposed procedure permits interaction with objects in various ways, including making measurements and building sections. The results enable the dissemination of high-precision interactive models, readable with free software, thereby facilitating the study of the metric and morphological features of archaeological objects.

Introduction

In recent years, several devices for acquiring 3-D information have been developed, including affordable desktop laser scanners. This type of scanner is generally designed to scan small objects with great precision and is used in numerous applications, from forensic science to industrial quality control. The archaeological application of such scanners has focused mainly on cataloging and imaging small pieces (Slizewski and Semal 2009; Tucci et al. 2011; Kuzminsky and Gardiner 2012).

All laser scanners generate point clouds in a 3-D local coordinate reference system. Some scanners are provided with image sensors for texture; it is possible to obtain color values for each point in space defined by its XYZ coordinates. Generating 3-D models allows us to measure an object without handling it and to execute difficult operations such as making sections in different planes or at different orientations or collecting data from complex surfaces.

Generating 3-D models of archaeological objects to build a database is a worthy undertaking. The value of the

models is significantly increased when they can be shared in a universally readable, digital format. The diffusion of this information is a very important task in support of both metric studies (e.g., shape, color, and dimensions) and visualization/illustration (e.g., virtual catalogs and heritage dissemination).

The goals of this paper are to explore the potential of a low-cost desktop laser scanner as a method of capturing high-resolution spatial data, consider the advantages and problems associated with this type of device, and propose a specific workflow to disseminate 3-D models embedded in PDF documents.

Case Study

The scanned object used in this study is a gabbro adze with double-bevel polished edge that was found at the dolmen of Guadancil 1, Garrovillas de Alconétar (Cáceres, Spain) (Figure 1). This study was conducted using a NextEngine Desktop 3D Scanner, a portable device with external dimensions of 277 mm × 223 mm × 91 mm and a weight



Figure 1. Two views of gabbro adze with double-bevel polished edge from the dolmen of Guadancil 1, Garrovillas de Alconétar (Cáceres, Spain), 2012 season. Scale in centimeters. (Photo by Ángel M. Felicísimo, 2013.)

of 3.2 kg (NextEngine 2008). This scanner uses a new technology called multistriple laser triangulation, which collects measurements using twin arrays of four solid-state lasers. The device can capture photographic information with twin 3.0 megapixel image sensors. The scanner is managed using ScanStudio HD PRO, owner software that manages the data acquisition and processes the point cloud using various functions such as merging scans, meshing, filling holes, and simplifying. The NextEngine scanner works in two basic modes (macro and wide) according to the distance between the scanner and the object. A more detailed explication about the performance of this scanner and its advantages and disadvantages can be found in Means et al. (2013).

The gabbro adze was scanned using the 360° rotation option with standard density and, due to its morphology, in a single position with the maximum coverage (Figure 2).



Figure 2. NextEngine Desktop 3D Scanner working in wide mode with the adze on the turntable. (Photo by Ángel M. Felicísimo, 2013.)

The authors recommend using the macro mode whenever possible, even with the lower resolution, because the final error is smaller (Polo and Felicísimo 2012). In this case study, the object was scanned in the wide mode because of its size.

Models can be exported from ScanStudio in several formats (e.g., OBJ by Wavefront Technologies), but not in a format useful for our purposes such as Universal 3D (U3D). Although ScanStudio software is necessary to manage the scanning process, some authors do not recommend it in the post-processing steps (Abate et al. 2011) and suggest other open-source options such as MeshLab (Gignoni et al. 2008).

Displaying 3-D Models in PDF Documents

The display of 3-D models remains problematic, especially for publishing on the Internet. After studying several ideas, the authors propose a solution that allows the dissemination of 3-D models using a known format: PDF by Adobe.

The ability to embed 3-D models in PDF documents has been available since version 7 of Adobe Reader, released in January 2005. There are several museums that use PDFs to display 3-D models, including the Virtual Hampson Museum (<<http://hampson.cast.uark.edu/>>) and the Amarna Virtual Museum (<<http://amarna.cast.uark.edu/>>). The U3D format can be used to embed 3-D models in PDF documents. The specifications of U3D are the Standard ECMA-363 (Ecma-International 2007). The direct transformation of output files from ScanStudio to the U3D format is not possible in the current version of ScanStudio, so additional software is needed. No special problem arises in working with geometry-only models without texture, but addressing photographic information produces problems in some circumstances.

The recommended workflow from image capture to publication is as follows:

1. Scan object with NextEngine scanner according to the methods explained above. The resulting output file will be in the native format of ScanStudio (i.e., SCN).
2. Using ScanStudio software, export the SCN format output file to OBJ format.
3. Transform the OBJ format file to U3D format. At this point, there are two paths depending on if one is working without texture or with texture.

- a) The generation of a U3D file without texture can be accomplished using the free open-source application MeshLab (<<http://meshlab.sourceforge.net/>>). It is sufficient to import the OBJ file and export to U3D.
 - b) The generation of a U3D file with texture is not possible using free software at this time. The best solution the authors have found is the application SimLab 3D PDF (<<http://www.simlab-soft.com/>>).
4. Embed the U3D file in Adobe Acrobat Pro to generate the PDF document. U3D files can be managed with any version of Adobe Acrobat Pro later than version 7. Embedding a U3D file in a PDF document can be performed directly from SimLab 3D PDF by exporting to U3D format. However, this process generates only a PDF page with the 3-D model. If the user wants to include any complementary elements such as titles or text, it is necessary to do the following:
- a) Create a page with the desired configuration using a word processor and maintain a region in which the 3-D model will be placed. Save the file as a PDF document.
 - b) Open the PDF file with Adobe Acrobat Pro, and, depending on the version, select between the following options:
 - (1) Version X: View→Tools→Interactive objects→Add 3-D
 - (2) Version XI: View→Tools→Content→Multi-media→3-D
 - c) Define in the PDF page a rectangle for the 3-D area.
 - d) Select the U3D file to insert and save the PDF file.

The obtained PDF file can be opened using Acrobat Reader (which is free). A toolbar will appear after clicking on the model to activate it (Figure 3). The activation can take several seconds depending on the complexity of the object and the size of the file. The toolbar presents several options such as rotating the object around any axis, zooming, measuring lengths, including comments, defining views from camera positions, viewing the object in parallel or perspective views, simulating different light sources, and creating section planes.

SimLab Composer is used to generate a PDF document with an embedded 3-D model. This software allows for the creation of several effects that can be exported into

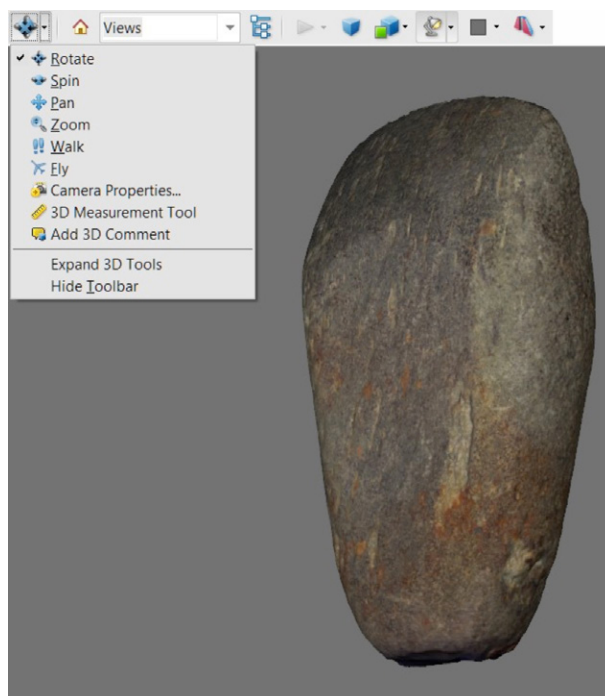


Figure 3. 3-D embedded object in PDF document. The tools are located in the upper bar. (Image by Ángel M. Felicísimo, 2013.)

the PDF document. The user can design a template with options such as adding background music, inserting a company logo or text, or applying animations (i.e., camera, light, or material) to the 3-D model. Most of these effects work when only a PDF page is generated, not in the case of using a word processor to insert complementary elements, as explained in step 4, above.

When using Adobe Acrobat Pro, the defined views and sections can be saved in the PDF file in a hierarchical structure. These options are varied enough to allow basic operations on the models, and therefore, the real object will need not undergo direct manipulation.

Results

Figure 3 shows the 3-D model in the interactive PDF document with a toolbar. The object was scanned in a single position using seven planes in wide mode. The scan required 15 minutes and generated a 23-megabyte file.

Figure 4 displays examples of model sections perpendicular to the vertical axis of the adze. On the left, a perspective view of the model with its upper end hidden is shown. On the top right, a one-dimensional sec-

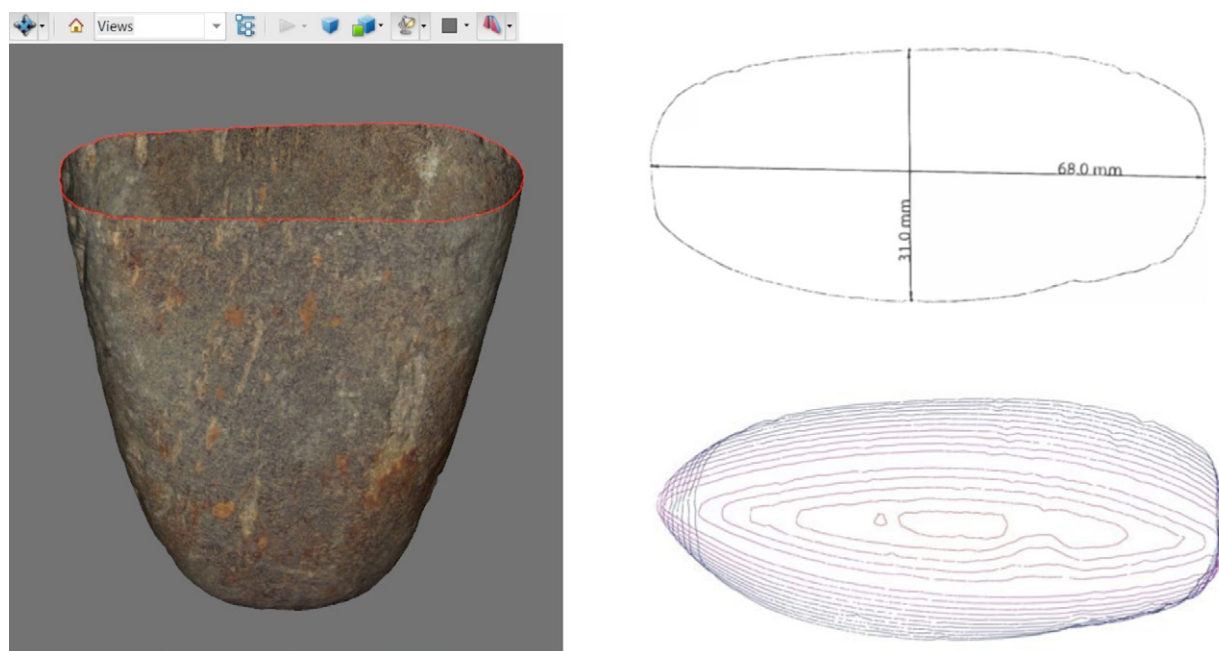


Figure 4. Model sections created in the PDF file. Left, perspective view of the model with the object's upper end hidden; top right, one-dimensional section drawing; bottom right, stacked sections, with blue lines indicating the middle of the object and red lines the end. (Image by Ángel M. Felicísimo, 2013.)

tion using the measuring tool is displayed. The units were obtained from the scanner output, and the measurements were taken between points on the external surface of the object. On the bottom right, stacked sections reveal the object's changing shape, with the central portion wider than the end.

The authors have tested the behavior of other applications in reading and managing 3-D objects embedded in PDF documents. The tests with Foxit Reader, Sumatra PDF, Nitro PDF Reader and PDF-XChange Viewer indicate that none of them correctly manage the 3-D objects, which are displayed as static images. It is necessary to use Adobe Acrobat Reader to realize the potential of these documents. As for Internet browsers, 3-D objects are correctly managed using Mozilla Firefox and Internet Explorer with the installation of the Adobe PDF plug-in. By default, Chrome uses its own interpreter (Chrome PDF Viewer), which does not recognize 3-D models. It is necessary to disable the Chrome interpreter and use the Adobe Acrobat Reader in order to correctly read 3-D models.

The PDF document (22.3 megabytes) corresponding to the gabbro adze illustrated herein can be downloaded

to explore the interactive options (<<https://www.box.com/s/33sk34nwmu7bfy3poq48>>).

Discussion

The procedures explained in this article focus on documentation using generated 3-D interactive models. It is argued that desktop scanners such as NextEngine Desktop 3D Scanner are suitable to create models of small objects. The creation of such models can serve a range of applications, from documentation to analytical studies, because of their ability to facilitate measurements and the creation of sections.

The advantages of this scanner are that it is a low-cost device, is easy to handle and learn, and is portable. Moreover, the scanner can capture texture information from the object and automatically align the scan planes.

One problem is that the automatic adjustment is based on point clouds rather than on color. As a result, the fusion of the planes in smooth objects can be difficult and is usually wrong, regardless of the color pattern. This problem becomes serious in the case of cylindrical objects, but less so in the case of objects with apparent vertices (such as

cubes) since the vertices can be used as “tie” points for the fusion of scanning planes. The problem disappears in the case of rough objects. A possible procedure to overcome this problem is to add small elements to the surface, which the scanner can use as tie points.

Furthermore, when two or more scans are fused, degradation of the color (texture) is perceived, and thus, some graphic details of the object (but not its shape or dimensions) are blurred. As the number of scans to be fused increases, so too does the severity of the blurring. Because of this issue, scanning from only two locations is recommended for objects with detailed decoration.

Another problem is that it is difficult to scan an object larger than perhaps 25 cm. This problem is due to the characteristics of the scanner because the scanned area is limited both in distance and field of view angles. There is also a limit of 9 kg in weight for the turntable provided with the scanner. Obviously, these restrictions can be avoided by using different scanners.

For most archaeological and museum applications, 3-D models presented in a PDF file are satisfactory. Off-line viewing, after downloading the file, is simple, and the interactive tools offer a comprehensive means of manipulating the model. Viewing on the Internet can be a problem due to the large size of the PDF files (between 23 and 70 megabytes in our tests). However, when the user has a fast connection, on-line viewing is feasible. As this case study has demonstrated, the outlined procedure for the dissemination of 3-D models in PDF documents offers greater functionality than traditional catalogs and non-interactive files. This procedure offers considerable advantages for transmitting and disseminating information on valuable and fragile objects. The defined process offers a solution for digital-age sharing of important artifact data, and the authors believe that such a process is a significant step forward in the study of historical archaeological artifacts.

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