Uses of Reverse Engineering Technique for Tridimensional Reconstruction os Fossils Through Photographs

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Abstract

This Paper presents an exploratory study about the use of reverse engineering and 3D reconstruction applied to different areas. The results of data analysis showed that the Shape-from-silhouette 3D reconstruction technique is an alternative to more expensive 3D reconstruction techniques such as laser scanning and computer tomography scanning techniques. This paper presents the Dinosvirtuais experience with the shape-from-silhouette technique using the commercial solution software 3D Software Object Modeler.

Keywords: Virtual reality, Reverse Engineering, 3D reconstruction, Shape-from-silhouette.

Introduction

There are many different reverse engineering techniques that aim to create a 3D reconstruction of real objects for different purposes. SANSONI et al. (2009) presents a study with a comparison of many 3D reconstruction techniques and its applications. Laser triangulators, Structured light, Stereo vision, Photogrammetry, Time of Flight, Interferometry, Moiré fringe range contours, Shape from focusing, Shape from shadows, Texture gradients, Shape from shading, Shape from photometry are examples of 3D optical techniques cited in her paper.

This paper presents the use of the Shape-from-silhouette (SFS) technique (mentioned above as Stereo vision) for the 3D reconstruction of dinosaur and other
pre-historic fossils and sculptures created by paleoartists. The SFS has some advantages over other techniques and the most important of them is the cost, since there is no specific hardware necessary to generate the 3D models, only a general photograph camera. And is part of the Dinosvirtuais project, an Internet virtual exhibition of fossil vertebrates of the Museu Nacional da Universidade Federal do Rio de Janeiro (MNRJ) (see MONNERAT, et al. 2009, 2008, and ROMANO, et al. 2007, 2006 for revision). The paleontologists of the MNRJ, associated with different research groups) has been using advanced computational tools in their projects like laser scanning, computer tomography, SFS and virtual reality (e. g.: AZEVEDO et al., 1994a, b, 2000, 2004; GRILLO, 2004, 2007; HENRIQUES et al. 2005; HENRIQUES, 2006; ROMANO et al., 2006; CARVALHO, 2007; MONNERAT, et al. 2008, 2009).

The SFS 3D reconstruction technique consists in 2D photographs taken from many different angles of the object that are processed by algorithms that capture the viewpoint and the silhouette of the object in each of the photographs and from these informations the 3D model of the object is obtained. For this work, the commercial solution 3D Software Object Modeler (3D SOM) was used to obtain the 3D models of the fossils and sculptures using the SFS technique.

Materials and Methods

3D Reconstruction Techniques

There are many different techniques for the 3D reconstruction of objects. A complete comparison of optical range imaging techniques is presented by SANSONI et al. (2009, p.578). Three techniques appeared as an option for the Dinosvirtuais project because of the knowledge of the associated research groups in the project: Laser scanning; Computer tomography; and Shape-from-Silhouette.
Laser scanning

Laser scanning is a 3D reconstruction technique well developed that can be used for almost any purpose. One of the important strengths of this technique is the high resolution of the final 3D model that can be achieved. There are nowadays many different commercial models of laser scanners for different applications from small hardware for small object scanning to portable handscanners for very large objects or buildings. Two examples of the use of laser scanning technique for non engineering applications is the Digital Michelangelo Project that used a Cyberware Large Statue Scanner to create a virtual model of the Michelangelo statue (LEVOY et al. 2000) and the Statue of Liberty 3D model created with a Cyrax 2500 3D laser scanner (http://www.geomagic.com/en/solutions/liberty.php).

Computer tomography

The 3D reconstruction of objects through tomographic images is the technique with the higher potential for paleontology. The reason is because it is a technique that is able to capture internal cavities of the fossils, impossible to be obtained with other 3D reconstruction techniques. Besides that, the computer tomography technique has another advantage, which is to obtain the geometry of fossils that were not prepared, that are still within formations. SILVA et al. (2008) presents a project that uses tomographic images of a 59 years old woman spine to reconstruct a specific vertebra to assist orthopedic implants.

Shape-from-Silhouette

In this technique, the geometry of the object is captured by conventional 2D photographs obtained from different angles of the object. Algorithms were developed to obtain the viewpoints and the silhouette of the object in each 2D image. From these information the 3D model of the object is built.
The most important advantages of the SFS technique is that it is not invasive (there are no physical contact with the object), which is especially important for paleontology because of the fragility of some fossils and the low cost. Further information concerning the use of such technique in biological forms have been explored by CHIARI et al. (2008)

**The Shape-from-silhouette Technique**

According to NIEM (1999) the SFS 3D reconstruction technique can be divided in two steps: First, pyramids are generated using the viewpoint and the silhouette of the object in each image; then the pyramids are intersected, forming an approximation of the bounding volume. A third step of the process would be the projection of the object texture to the 3D model generated.

LAURENTINI (1994) presented the concept of the visual hull, that is exactly the result of the intersection of the silhouette cones of each image of the obect (called by NIEM as pyramids). All SFS algorithms developed are based on this concept and the difference between the SFS approaches is how they process the silhouette cones to achieve the representation of the visual hull.

BAUMBERG et al. (2005) observe that there are two main forms of obtaining a 3D model that represents the visual hull from 2D photographs. They are called volumetric sampling and direct intersection. The first one (volumetric sampling) uses a grid of voxels surrounding completely the object to be reconstructed producing a voxel carving. The voxels that are inside and outside of the cones of silhouettes are discarded and the voxels that are intersected by the cones of silhouettes are kept, forming the point cloud that forms the 3D geometry. The second one (direct intersection) generates the 3D representation of the visual hull intersecting the silhouette cones directly two by two until all the cones of silhouette are processed.

Independent of the approach, the SFS technique has these six phases: (1) generation of the 2D photographs from different angles; (2) determination of the
viewpoints of each image; (3) identification of the silhouettes of the object in each image; (4) generation of the silhouette cones; (5) generation of the wireframe representation of the visual hull; and (6) mapping and generation of the 3D model image texture.

The Dinosvirtuais Experience

The Dinosvirtuais project used a commercial solution software for the 3D reconstruction of fossils and sculptures of the MNRJ, the 3D Software Object Modeler (3D SOM). The software was bought for the project with the CNPq resources by less than half the price of the cheapest 3D laser scanner found – US$ 1,000.00 for the 3D SOM software (academic price) and US$2,950 for the Next Engine laser scanner – also bought for the Dinosvirtuais and other MNRJ projects).

The 3D SOM software solution showed itself very easy to learn, not needing any previous knowledge in 3D softwares or even photograph. With a few hours of training, anyone can start reconstructing the objects with satisfactory quality for internet visualization, which is the purpose of the Dinosvirtuais project. The first fossil reconstructions obtained using the 3D SOM software for the Dinosvirtuais project were a skull and a femur of the fossil turtle *Bauruemys elegans* with its results published as a abstract paper at the *Journal of Vertebrate Paleontology* (ROMANO et al. 2006).

Phases of the 3D reconstruction

For the Dinosvirtuais Project there was a previous phase before the generation of the 2D photographs from different angles phase (the first one of the six phases of the SFS 3D reconstruction technique mentioned before which is the selection of the objects to be reconstructed.
Selection of the objects to be reconstructed


Generation of the 2D photographs from different angles

The generation of the 2D images demands only two things so they can be processed by the 3D SOM: The object must not be cut in the image; and there should be a specific calibration mat so the software can identify the viewpoint of the images. Figure 1 shows the calibration mat used by the software to identify the viewpoint and examples of images used in the reconstruction of a fossil.
Considerable improvements can be made in the photographs, comparing to the examples of the figure 1, to obtain better results and a smaller processing time. Better print quality of the calibration mat and a use of a simpler background can make the software obtain a more precise viewpoint and silhouette of the object with less manual interference. Figure 2 presents examples of photographs obtained with the two improvements cited.

**Figure 1:** Image of the calibration mat (left) and examples of photographs of a skull of a *Tapejara wllhoferi* specie that fit the minimum demand of the 3D SOM software.

**Figure 2:** Photographs of a vértebra of a *Pycnonemosaurus* with a simple background and a high quality calibration mat print.

**Determination of the viewpoints of each image.**

According to BAUMBERG et al. (2005) since the calibration mat and the object are moved together for the different angles of the photographs is possible to estimate the
viewpoint of each image. The software identifies each group of four dots of the calibration mat that are visible in the image and process them with a RANSAC based algorithm, capable of identify intrinsic and extrinsic camera parameters (WAN and XU, 1996), to determine the viewpoint of each specific image taken. Figure 3 shows an example of a picture with the identification of the groups of four dots of the calibration mat.

![Identification of the groups of dots with the discrimination of the small and big ones to determine the viewpoints.](image)

**Figure 3: Identification of the groups of dots with the discrimination of the small and big ones to determine the viewpoints.**

**Identification of the silhouettes of the object in each image**

The identification of the silhouettes of the images are made using the color-key (or chroma-key) technique, that is used since the decade of 1930 and common in many applications such as movies and television weather forecast presentations (WIKIPEDIA CONTRIBUTORS, 2009). Manual identification of the silhouettes are possible to be made in the 3D SOM software and is used to refine the silhouette of the object in almost every image especially those with complex backgrounds. Figure
4 show examples of silhouette identification of the objects with complex and simple backgrounds.

Figure 4: Above, photographs of the sculpture of a Ceratosaurus nasicornis sculpture with a simple background and the automatic silhouette identification. Below a fòssil of a Tapejara wellnhoferi’s skull with a complex background and the automatic silhouette identification.

Generation of the silhouette cones

The silhouette cone of an image is determined by the vertex that represents the viewpoint of the image and the vertices of a polygon that represents the silhouette of the object in that image. Besides that, it is necessary to determine a maximum volume of the object because the cone of silhouette cannot be infinite. In the SAVANT algorithm, used in 3D SOM, an initial cube is used as a maximum volume to determine the limits of the silhouette cones.

Generation of the wireframe representation of the visual hull
In this phase, the SAVANT algorithm first subdivide the cube and the resultant cubes of this subdivision is processed and then subdivided again following this rule: (1) discarded if there is no silhouette cones crossing it; (2) subdivided again if there are silhouette cones crossing it; and (3) has its inside vertices calculated to form a point cloud that will be part of the final object geometry. The final cloud points are then triangulated to form the wireframe representation of the visual hull.

**Mapping and generation of the 3D model image texture.**

It is made, in the 3D SOM approach by using a technique called 2D image splining described by BURT et al. (1983). The algorithm uses the six orthographic views (front, left, top, right, bottom and back.) and some other parts of other views that will fit triangles not completely viewed by the orthogonal views. Each triangle of the 3D model has three different images to represent its texture. The objective is to achieve the high definition of the principal image projected to the triangle and the variation of light and shadow gave by the two other images projected. This will create a view dependent texture mapping that gives more realism to the final model.

**Results**

The Dinosvirtuais Project was officially launched at the Dinos in Rio paleoart exhibition of the MNRJ at August 25, 2009 that attracted interest of the main midia (TV, radio, internet, etc.). From August 26, 2009 the website of the Dinosvirtuais exhibition reached a considerable number of visitors with 1,000 visitors every week during the first month and 10,000 visitors until January, 2010.

The 3D models generated for the Dinosvirtuais project used 39 photographs on average and has 4,000 polygons on average. The objective of the project is to display this 3D models on the internet. That is the reason why we use a low poly mesh for the final models. The average number of polygons of the 3D models is
3,990 and the average file size of the X3D/VRML file and the texture image file are, respectively, 371 Kb and 171 Kb. The 3D SOM software is able to generate models with many more photographs and up to 300,000 polygons. For example, the fossil *Vinticfer comptoni*, reconstructed with 15 photographs, at the best quality, generated a 3D model with 209,568 polygon (3,200 polygons in the optimized version) and a texture image file with 6,289 Kb (153 Kb in the optimized version).

![Figure 6](image)

*Figure 6: Above, the optimized 3D model with the texture (left) and in wireframe (right). Below the high quality model with the texture (left) and in wireframe (right).*

It was made a performance test of the software to observe the time spent to generate the final models of the fossils and sculptures. Two different objects were chosen according to the quality of the photographs to observe the impact that the high quality images would made in the final processing time. A Notebook HP Pavilion dv6000 with an Intel Core 2 CPU T5300 1,73 GHz processor per core, 2 Gb RAM and a Mobile Intel 945 Express Chipset Family graphic card with a 256 Mb of shared memory was used running a Windows Vista Home Premium SP2. Table 1 shows the results of the performance test of the reconstruction of the 3D models of a sculpture.
of Asmithwoodwardia scotti and Ceratosaurus nasicorni proportionally to the number of photographs used for each 3D reconstruction.

Table 1. Proportional performance of the 3D reconstruction using the 3D SOM.

<table>
<thead>
<tr>
<th>Species</th>
<th>Asmithwoodwardia scotti</th>
<th>Ceratosaurus nasicornis</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td># of photographs</td>
<td>29</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Images loading time</td>
<td>6.89</td>
<td>7.76</td>
<td>Not a considerable difference.</td>
</tr>
<tr>
<td>Images generation</td>
<td>118.63</td>
<td>101.63</td>
<td>Automatic silhouette detection works a lot better with simpler backgrounds minimizing the need of a manual intervention.</td>
</tr>
<tr>
<td>Geometry time</td>
<td>125.86</td>
<td>41.82</td>
<td>The need of a manual viewpoint alignment, needed because of bad quality images increases considerably the final time of the 3D reconstruction.</td>
</tr>
<tr>
<td>Texture time</td>
<td>10.00</td>
<td>13.52</td>
<td>Not a considerable difference.</td>
</tr>
<tr>
<td>X3D/VRML</td>
<td>1.37</td>
<td>1.17</td>
<td>Not a considerable difference.</td>
</tr>
<tr>
<td>Total time</td>
<td>234.13</td>
<td>162.94</td>
<td>The total time difference between the bad quality images and the high quality images shows the importance of generating good photographs for the 3D reconstructions.</td>
</tr>
</tbody>
</table>

Conclusion

The results obtained with the 3D reconstruction of fossils using the SFS technique and the 3D SOM software was very satisfactory considering the main objective of the project that was to publish the 3D models on the internet for public visualization. The ease of use of the 3D SOM software must be highlighted also. The limits of the 3D SOM may be the size of the objects to be reconstructed since the bigger the object is, bigger must be the calibration mat used below that object, but that object size
limitation is present in most of the 3D scanners, especially the cheaper ones and even the computer tomography technique. Further tests needs to be made to see if the 3D models reconstructed using the SFS technique can have the geometry precision to be used for different purposes such as measurement of fossils and sharing data between researchers from different places. The use of 3d SOM as a tool in biological evolutionary studies seems to be unsatisfactory due to the lack of precision of the 3d reconstruction, necessary in biological comparative analysis, as morphometry. The evaluation of different SFS techniques is being performed by our research group and will be published in further works.

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References


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