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Nota Técnica

Comments on the paper *Modelagem 3D e suas aplicações na pesquisa paleontológica* (*3D Modeling and its application in paleontological research*)

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ABSTRACT
Three dimensional virtual reconstructions are powerful tools for paleontological research and edutainment. The available methods and technologies were reviewed by Dardon *et al.* (2010), providing an introduction to most existing 3D acquisition technologies, but some dubious or incomplete information were provided in that paper, which are discussed here.

Key words: paleontology, 3D virtual models, Shape-from-silhouette, 3D scanner, scientific education.

RESUMO
COMENTÁRIOS SOBRE O ARTIGO *MODELAGEM 3D E SUAS APLICAÇÕES NA PESQUISA PALEONTOLÓGICA*. Reconstruções virtuais tridimensionais são uma ponderosa ferramenta para pesquisa paleontológica e para entretenimento em educação. Os métodos e tecnologias disponíveis foram revisados por Dardon *et al.* (2010), fornecendo uma introdução às técnicas de obtenção de imagens 3D. Entretanto, algumas informações apresentadas no referido trabalho apresentam inconsistências que são discutidas aqui.

Palavras-chave: paleontologia, modelos 3D, Shape-from-silhouette, scanner 3D, divulgação científica.

INTRODUCTION

Paleontological research worldwide is implementing the use of three dimensional virtual reconstructions for several purposes, including research (e.g.: Rowe and Frank, 2011) and edutainment (e.g.: Monnerat *et al.*, 2010). The equipment and software necessary for such reconstructions are often expensive and each research group explores different possibilities in order to attain its specific goals. Hence, review papers that compare different methodologies and equipment, indicating their advantages and weaknesses, are essential for other researchers interested in implementing such methods in their projects. In this context, Dardon *et al.* (2010) provided a detailed introduction to most existing 3D acquisition technologies, based on the experience with the equipment and software that they had available. However, as they had limited access to some of the technologies that they described and compared (especially 3D laser scanners), some of their comments and conclusions may be equivocal.

As pointed by Dardon *et al.* (2010), since 1994 our research team is conducting a pioneer work in Brazil with respect to the use of 3D acquisition (Computed Tomography, different models of 3D Laser Scanners, Shape-from-silhouette digitization, 3D virtual modeling) and prototyping technologies in paleontological research (Azevedo *et al.* 1994, 2000, 2004; Azevedo and Carvalho, 2009; Belmonte, 2009; Rodrigues, 2010). Besides, in the project entitled *Dinos Virtuais*, the group was a worldwide pioneer in the use of *3D Software Object Modeller PRO* (3D SOM) to construct virtual 3D models of fossil vertebrates and in the implementation a 3D virtual vertebrate paleontological exhibition based on virtual reality technology (Romano *et al.*, 2007; Monnerat *et al.*, 2008, 2010; not Grillo *et al.*, 2009, as mistakenly given by Dardon *et al.*, 2010).

In this note we aim to complement the valuable information provided by Dardon *et al.* (2010) and also discuss some aspects not tackled by them. In order to improve the reading, our comments will be presented following the same ordering provided by Dardon *et al.* (2010).

DISCUSSION

Photogrammetry and Shape-from-silhouette

Dardon *et al.* (2010) use the term Photogrammetry in order to refer to 3D reconstruction from 2D photographic images using 3D SOM. In fact, photogrammetry is the acquisition of accurate measurements and geometric properties from 2D photographic images that allows 3D reconstructions, and the software used to produce 3D models from 2D photographs (3D SOM) employs a methodology known as *Shape-from-silhouette* (or *2D to 3D*). The algorithms used to determine the position of the camera and of each picture is photogrammetry, but the reconstruction of the 3D model from the silhouettes should be referenced as *Shape-from-silhouette*. Moreover, Dardon *et al.* (2010) were confused when referencing to Grillo (2004) as an example of work that employed photogrammetry and 3D SOM. Grillo (2004) used 3D laser scanning and virtual 3D modeling, but shape-from-silhouette (and 3D SOM) was not used. Indeed, the *Dinos Virtuais* team started using 3D SOM in 2006 (Romano *et al.*, 2006).

The extensive use of 3D SOM in following works of our team (Romano *et al.*, 2007; Monnerat *et al.*, 2008, 2010) allowed the establishment of an optimized protocol to make the most of the batch processing options of the software (Romano *et al.*, 2007; Monnerat *et al.*, 2010). As Dardon *et al.* (2010) pointed, it is extremely important to avoid shadows from the object over the calibration math. They also pointed that it is necessary to use a neutral background with a color antagonistic to the predominant color of the fossil. Our experience shows that the ideal color is always white, even for light colored objects. If flash lights are pointed to the background to eliminate shadows, the background can be homogenized by slightly overexposing the picture. Because the white background is continuous with the calibration math, the software processing algorithm will automatically recognize and isolate the object from the background. Yet, it is also necessary to assure that all parts of the object are properly focused and that it is not excessively overexposed. The use of color background for light colored objects is not recommended because the color of the background will reflect on the object, what may affect its final texture (the term *texture* in computer graphics refers to the bitmap image that is applied on the surface of the 3D virtual model to reproduce the original colors of each part of the digitized object).

Dardon *et al.* (2010) provide the average number of photographs per object that are necessary to generate a 3D model, but they do not specify how this number relates to the complexity of the object. Based in our experience, simple pieces, such as a long bone, can be easily modeled with 20-30 photos, but a complex structure such as the skull of the pterosaur *Tapejara wellnhoferi* required 60 photos. In some cases it is also necessary to produce two series of photos (with a 180º angle difference) of the same object in order to capture the silhouettes of all its parts. The two sections can be combined in 3D SOM.

Dardon *et al.* (2010) also did not mention two important aspects of this methodology:

(i) Lens distortion: All camera lenses have some type of spherical distortion and it is strongly recommended to remove this distortion in order to produce more accurate models. 3D SOM has specific tools to estimate and eliminate distortions for specific lenses and focal lengths. It is recommended to use a fixed focal length for all photos of the object, so that the correction can be batched processed.

(ii) Shape-from-silhouette works better great for objects that do not have cavities, depressions, and other deep structures that do not appear as silhouettes on photographs. On the contrary, the concavity of a seashell, for example, will not be noticed, and will appear as filled. For this reason, models produced using this technique has very limited utility to research projects. They are mostly intended for edutainment projects, as *Dinos Virtuais* (Monnerat *et al.*, 2010). For research work, we strongly recommend the use of 3D laser scanners and Computed Tomography instead of 3D SOM.

A final conclusion regarding the use of 3D SOM: it is adequate to generate precise and high quality textures in 3D models. It is possible to import a high quality 3D model generated with more precise technologies, such as 3D laser scanning, and align this model to some (minimum of six) orthographic pictures of the object, and generate a textured 3D model.

Videogrammetry with line laser and webcam

The David 3D laser scanner (David Laserscanner 3D, 2009) employs a calibration math, a laser line, and a webcam to generate 3D models. This setup is highly portable and produces reasonably good results. Yet, *contra* Dardon *et al.* (2010), the quality of the 3D model is not solely related to the processing capability of the computer. Mesh quality and resolution may be increased with the use of: (i) a high resolution low noise webcam with high frame per second processing; (ii) a green line laser (532 nm) instead of the red line laser (650 nm) provided in the basic David 3D kit. The best resolution achieved on an ideal situation using the basic setup of the David 3D is 0.4 mm. This resolution is two to four times smaller than that achieved with the use of conventional 3D Laser scanners. This compromise may be relevant when digitizing small objects. Non-ideal situations require extra care. The main advantage of David 3D is its portability, which allows its use during visits to museum collections. Yet, ideal conditions are more difficult to attain in such situations and the noise and distortions likelihood reduce the possibility to obtain resolutions as good as in ideal conditions. In any case, we believe that this technology is, at the moment, the best cost/benefit option to generate 3D during collection visits. Free hand scanners may provide a better alternative in the future, but current technology is too expansive and still not as portable as necessary.

3D laser scanning

We have employed three different models of 3D Laser Scanners – Roland Picza 3D Laser Scanner LPX-250 (Table scanner), Nextengine 3D Scanner HD (Table scanner) and Handyscan 3D VIUscan (Free Hand Scanner) – all of which show some limitations:

(i) Dark objects or object with dark and light colors: The laser beam is reflected differently by dark surfaces, and these parts appear with noise in the generated model. The Nextengine scanner allows adjusting its sensibility to the overall darkness of the object, but very dark structures (such as the collection number labeling) will appear as if it were extruding from the surface and light parts will not be digitized under this setting. This problem can be reduced or even eliminated if the fossil is covered with a thin layer of talc powder. The problem with this procedure is that it modifies the texture of the object. An alternative is to produce the 3D model without texture and generate a texture using 3D SOM. This problem is minimized in the handyscan that has better capability to deal with these difficult subjects.

(ii) Shine objects: The laser beam is scattered by shine parts and produces a lot of noise (aberrant spikes) in the model. Fossils are usually protected with some kind of polymer, such as paraloid acrylic resin, which frequently produces bright surfaces. A layer of talk can also eliminate this problem.

(iii) Trepidation: It is a major problem for all 3D laser scanners. Most equipment is capable of capturing details as small as 0.1 mm. In such a high resolution, any movement of the object or equipment may generate discrepancies and the trepidation of an unstable working surface will inevitably create noise. Accordingly, the working surface needs to be very stable and the fossil needs to be well positioned and stabilized. Thin structures are the most affected by trepidation and a proper alignment between scan parts is most important.

(iv) Thin structures: This is a problem for most 3D capturing methodologies and there is no straightforward solution. The use of the highest resolution available is the only way to guarantee that most of the original shape will be captured, but the alignment of the scan parts may be difficult and the edition of the model can take longer than usual. Thin bones such as scapula and vertebral neural arcs of small animals are examples of structures that may be difficult to digitalize.

On each different types of 3D laser scanner, Dardon *et al.* (2010) made some observations that must be further discussed. The specific free hand scanner used in our research (which is similar to that mentioned by Dardon *et al.*, 2010), i. e., Handyscan 3D VIUscan, has several advantages over table scanners, which are shared by other hand scanners:

(i) *Contra* Dardon *et al.* (2010), Handyscanners do not produce a high number of scans that are difficult to align. All other 3D scanners (table scanners and David 3D) split the object in sections in order to capture the entire perimeter of the object, as well as surfaces inside cavities and of complex structures. Additional scans are necessary to digitize top and bottom parts of the object and parts that were not captured in the other scans. This procedure results in a minimum of 12 scan parts that need to be properly aligned and fused together to generate a complete model. This will inevitably have several small holes, which correspond to areas that were not correctly directed to the laser beam in any of the several scan positions. In this respect, the Handyscan is very easy to use. This free hand equipment can be moved and oriented in any position, producing a continuous 3D mesh of the almost entire object (except the parts that are facing the supporting table). The produced mesh is usually free of holes, because the scanner can be freely moved in order to reach the most hidden surfaces. The scan process may be paused and restarted at any time. Accordingly, it is possible to evaluate a partial mesh, and search for holes. A complete model can be usually produced with only two scans (covering the different halves of the object) which can be aligned using overlapping surfaces as references. These advantages, together with the high resolution (0.1 mm), make the hand scanners the ideal type of 3D laser scanner for any paleontological purpose and for any sample size.

(ii) Dardon *et al.* (2010) also pointed that hand scanners have the disadvantage of requiring a powerful computer, with sophisticated video cards. This basic requirement is shared not only by all types of 3D laser scanners but also by all graphic computing software and equipment.

Touch scanner

As pointed by Dardon *et al.* (2010), digitizing arms are portable, very precise, and recommended for the acquisition of 3D coordinates, which will be used as landmarks in geometric morphometric studies. Yet, an unmentioned main disadvantage is that, as this kind of scanner needs to probe the surface of the object by direct contact, it is not recommended for use with fragile material. A 3D laser scanner is much more suitable in such cases, providing the same resolution (and a much larger number of digitized points) with no risk to the specimen.

FINAL CONSIDERATIONS

Powerful computers are often considered a main requirement for 3D modeling projects (Azevedo *et al.*, 2004; Monnerat *et al.*, 2008, 2010; Dardon *et al.*, 2010). It is important to notice that computer technology evolves very fast and prices drop accordingly. Because of that, almost any mid-range personal computer (PC) nowadays has the minimum requirements to support 3D equipment. In order to obtain better performance, investments will be better on good graphic cards and additional RAM memory.

The cost of a PC is nowadays smaller or equivalent to that of the cheapest digitizing equipment and software (3D SOM, David 3D, and Nextengine scanners cost as much as an advanced PC). As pointed by Dardon *et al.* (2010), acquiring the license of modeling software is the main difficulty for this type of research. Apart from free alternatives such as *Blender 3D* and *CADX11 Free,* indicated by Dardon *et al.* (2010), some companies that produce the best 3D modeling and CAD/CAE tools provide free licenses for students and researchers with demonstrated relation to a research institution. Autodesk, for example, provides free licenses for most of their software (including *3ds Max*, *Maya,* and *Autocad*) for a period of 12 months. As new licenses are provided each time a new version of the software is released (which occurs, usually, on a yearly basis), the result is a virtually permanent free license.

Based on our experience, free hand 3D laser scanners are the best option to quickly and easily generate excellent models, but the investment will be high, as this is one of the most expensive types of 3D scanners. They are veryversatile, and we were able to digitize objects as small as isolated bones of the basal sauropodomorph dinosaur *Saturnalia tupiniquim* (some long bones of the arm are less than 50 mm long) and samples as large as a complete 140 cm long *Tyrannosaurus rex* skull cast.

For really small specimens (diameter of about 20 mm or less), the best option appears to be videogrammetry with white light projections, as presented by Dardon *et al.* (2010).

The equipment with the best cost/benefit is Nextengine scanner: (i) it is small and costs as much as a good PC; (ii) it can be mounted on a tripod; (iii) there is no limit on the size of the captured object (contrary to what was mentioned by Dardon *et al.* 2010), as large objects may be scanned in parts that can be assembled together (there is also the option to buy a PRO version software that increases resolution, speed and working area); (iv) resulting models are more precise and detailed, and less noisy than models produced with David 3D; (v) as any 3D laser scanner, it does not have the limitations of 3D SOM, which does not capture depressions and cavities on the surface of the object.

The main advantages of David 3D and 3D SOM are their portability, which allow their use during visits to museum collections to capture 3D data of the examined material. David 3D works best if the 3D virtual model is required for research projects. 3D SOM is excellent for edutainment and to produce virtual catalogues accessible to lay people (Romano *et al.*, 2007). Yet, if the aim of the virtual collection is to allow virtual exchange of material between institutions for research purposes, a better digitizing procedure must be adopted. In order to build a valuable virtual collection to be shared with other researchers, we highly recommend the use of a 3D laser scanner such as Nextengine, Handyscan, or even Computed Tomography, including Micro-CT. However, due to its high costs and the time necessary to process the resulting images, Computed Tomography is only recommended if it is necessary to study internal anatomy or to virtually prepare a fossil that is too fragile to be physically prepared (Azevedo *et al.*, 1994, 2000; Carvalho, 2007; Belmonte, 2009). It is important to emphasize that the discussion presented here is focused on edutainment purposes. As pointed recently by Rowe and Frank (2011), if 3D data is produced in order to test a scientific hypothesis, it is fundamental to employ the highest quality feasible (i.e.: the file with as many voxels as possible).

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