Photogrammetry: How to Create Low-cost, Realistic, and Easy to Operate 3D Models for Medical Teaching and Diagnosis

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Abstract: Introduction: Photogrammetry in the field of science and technology is responsible for the acquisition, accumulation and transformation of information about the shape, movement and deformation of an object by means of a beam of light. It is currently adopted by doctors for the reproduction of anatomical structures, as well as planning of surgical procedures and as a diagnostic tool. Objective: To provide a simple and low-cost method that allows to create three-dimensional models of realistic characteristics without the need of specific conditions for their use and reproduction. In addition, they are implemented as a combination of learning and diagnostic tools. Method: For the creation of the three-dimensional model, it was necessary to submit it to a rendering process with the software PhotoScan, Regard3D and 3DF Zaphyr. This procedure took photographs of a real model and converted them into information points that were compiled to create a high-quality three-dimensional model; since these programs were created for the realization and survey of geographic maps, it allowed us to preserve the texture and reliefs of each structure, with realistic characteristics in each model. Results: The final result was a three-dimensional model that could be manipulated in 360°, and thanks to its plasticity, it could be edited in any editing programme. Conclusion: Photogrammetry is a simple and low-cost method for creating three-dimensional models of realistic features that do not require great specifications for their reproduction, making them very plastic in their use and handling.

Key words: photogrammetry; 3D models; biologic material; anatomic pieces; medical education

1. Introduction

Photogrammetry in the field of science and technology deals with the acquisition, accumulation and transformation of information about the shape, movement and deformation of an object by means of a beam of light [1]. Its beginnings date back to the discovery of photography in 1839 by Arago, perfected by Niépce and Daguerre. Later, in 1850, Laussedat took advantage of photography to make topographic plans, designing and building the first photoelectric theodolite, and giving this technique the name of metrophotography [2].

It is widely used in geodesy, agriculture, architecture, and forestry, where digital images obtained through optical sensors are combined with new computing systems with necessary objective measurement potential. Due to the remote

nature of data collection, it triggers a revolution in cartography with high accuracy without touching the measured object [3].

Currently, it is adopted by dermatologists, ophthalmologists, and traumalogists [4], as well as many other branches of health science, to replicate body structures, better study spinal diseases such as scoliosis, and plan surgical procedures as diagnostic tools [5].

2. 3D in Medical Education

The use of three-dimensional models for teaching is becoming more and more common (Figure 1). At present, there are many applications in medical teaching, such as "Essential Anatomy 3" or "Visible Body", whose digital models enable students to have a clear understanding and approach to the relationships, specific functions, and surgical methods of the studied anatomical structure. Some of them have different requirements for use or playback, such as requiring the latest version of software, larger ROM or RAM memory, or exclusive designs for Windows, Apple, or Android systems. These designs may be difficult to obtain due to cost reasons, or may be difficult for students and teachers who are not familiar with technology or specific systems to use.
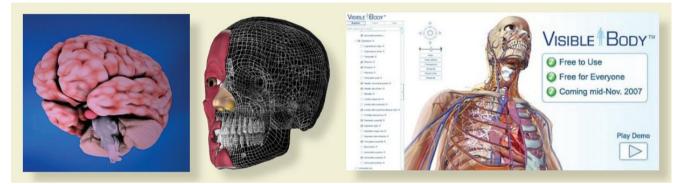

Figure 1. Examples of three-dimensional models currently available for teaching.

3. Objective

The use of three-dimensional models for teaching is more frequent, however, software and hardware limitations hinder their use in medical education. In response to these problems, our objective is to offer a simple and low-cost method that allows the creation of three-dimensional models with realistic characteristics without the need for specific conditions for their use and reproduction, as well as their incorporation as a learning and diagnostic tool.

4. Methods

The method for establishing a three-dimensional model is digital photogrammetry, which is a technique that accurately defines the shape, dimension, and spatial position of any object through photographs and software, and provides a virtual version of it. Therefore, the following are necessary for its realization: Models or biological parts, Dissection case, Computer, Nikon D3300 camera, Macro lens 50 mm, Lens 50 × 80 mm, Medium-high-end cell phone camera (in case no professional camera is available), 200 lumen lamps, Agisoft PhotoScan or any other software for 3D model creation (Regard3D, Visual SfM, insight3dng, Pix4Dmapper, RealityCapture, etc.), and Sketchfab online account.

To begin with, the model to work with was selected and three models were used: a plasticized heart, a left upper limb anatomy, and a neck triangle anatomy. For selected parts smaller than 20 cm (plasticized heart), fiducial marks are placed around them to locate the program in space and recognize the four axes of the part. For the other two parts (left upper limb and neck triangle), due to their volume, the surrounding structure is part of the environment. They serve as fiducial marks and do not require the placement of additional markers (Figure 2).
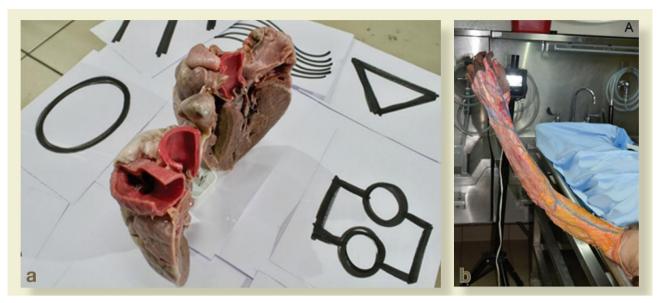
Figure 2. a) Plasticized heart in which fiducial marks were placed around as spatial orientation markers.
b) Left upper limb, in which environmental resources are used as fiducial markers.

When preparing the model, it is necessary to have appropriate lighting conditions, so the light is placed around parts to ensure uniform distribution of light and no significant changes on all surfaces of the model; subsequently, the camera was calibrated to obtain a clear image with good exposure; in addition to defining appropriate focal lengths, photographers can also capture a complete image of their work in a central and replicable frame within each photo (Figure 3).

Figure 3. This figure shows the light distribution in which the photographer is allowed to move freely around the set; in addition to a uniform distribution of light, for the correct taking of photographs.

Photographs were taken of each face of our piece surrounding it every 15° until we had 360° images. Subsequently, it was necessary to divide each face of the model into 3 parts: lower, middle and upper, in order to take pictures of each segment. The number of photographs per model was variable, depending on the size of the piece, but it was necessary to take a minimum of 80 photographs to facilitate its virtual creation in 3D.

Once the photographs were obtained, they were subjected to a rendering process with Agisoft PhotoScan software, with a standard license; 3DF Zephyr, with a free license, and with Regard3D, which is free to use. With this procedure, the photographs were taken and converted into information points that were compiled to create a high quality three-dimensional model (Figure 4).
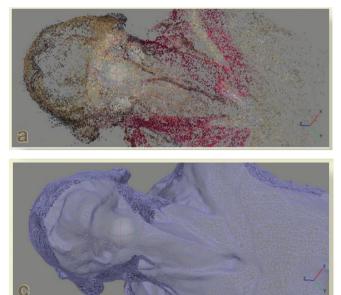

Figure 4. a) Points obtained from 93 photographs.

b) First condensation of points.

c) Creation of the base mesh for joining the points into a solid model.

d) Second condensation of points already in the mesh.
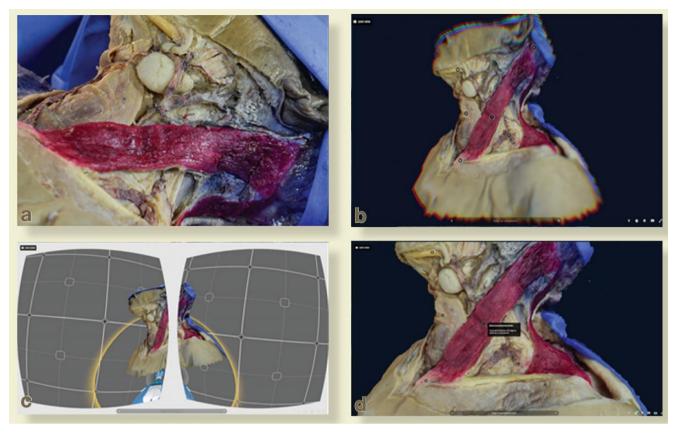
e) Texturing of the final point layer.

5. Ethical Considerations

In order to achieve the use of 3D models and simulators as supplements to medical teaching, it is considered that these tools are a means rather than an end. Different authors have adopted this idea and emphasized that this concept should not be ignored to avoid errors that lead to the dehumanization of medicine [5].

There is no substitute for the use of biological models. However, using 3D models offered an alternative to teaching which respects the Helsinki declaration, ensuring respectful treatment of the parts from which the models were obtained, confidentiality of data, dignity and integrity of the cadaver.
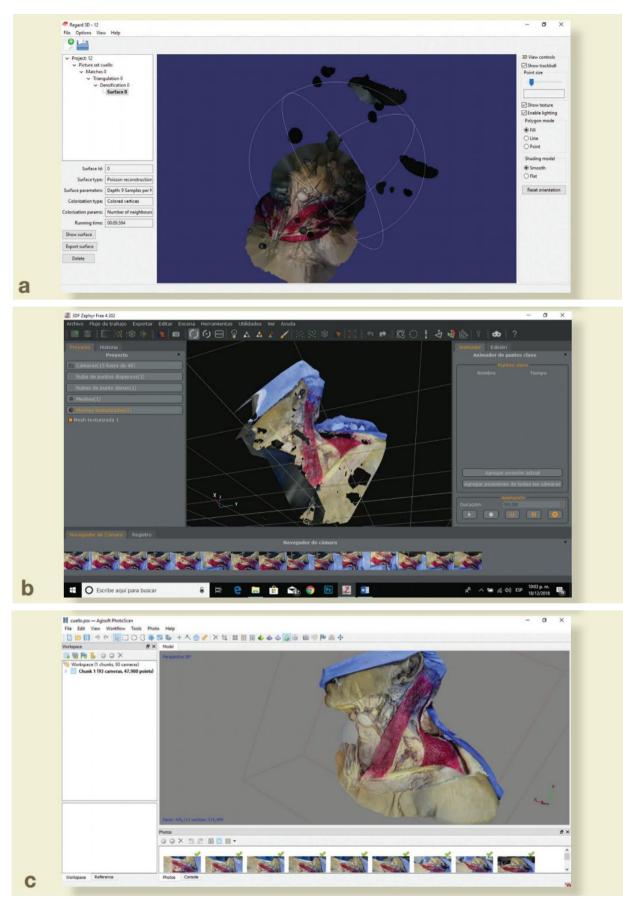
6. Results

Given that the three softwares used were for the creation and survey of geographic maps, they allowed us to obtain 360° manipulable models, which is suitable for exporting and editing in multiple programmes, such as Adobe Photoshop, Rhinoceros, Autodesk Maya, etc., as well as the possibility of being mounted on online platforms such as Sketchfab, where they can be used with Anaglyph vision (traditional 3D with red and blue glasses), in virtual reality (VR), and even generate animations or 3D printing (Figure 5).
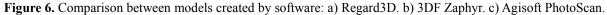
Figure 5. Virtual model compared to the real image and the different options offered by the online platform Sketchfab. a) Real biological model. b) Anaglyph view. c) Presentation for virtual reality glasses. d) Placement of descriptive labels.

However, when a more in-depth comparison of the models in each programme was made, it was found that Agisoft PhotoScan presented some outstanding points, which, despite being a paid version, put it above its competitors. Among these, its ease of use stands out, with friendly and intuitive menus, unlike Regard3D and 3DF Zephyr, which had accessible menus but presented a large number of sub-menus at each step, which can be confusing for the less experienced. A second point in favour is that Agisoft PhotoScan delivered a model with characteristics very close to reality, while 3DF Zephyr, due to the limited number of 50 photographs in the free version, delivered a model with good quality textures and reliefs, but with a large number of black holes due to lack of information, likewise, Regard3D ended up with a complete model that could not be modified, resulting in black spots and poor final quality (Figure 6). Thirdly, Agisoft PhotoScan did not present any compatibility problems or specific hardware requirements, as it was run on a basic computer and a high-performance computer, only affecting the completion time and being faster on better performing computers. On the other hand, 3DF Zephyr's performance was affected on both computers, as it only supports NVIDIA graphics cards, with a limited number of processing cores depending on the version being worked with, as well as requiring the latest version of the drivers, so its operation was very limited. Lastly, Regard3D did not present any change, as it had equally limited performance on both computers to finish the model.

More information about each option can be found in Table 1.

Figure 6. Comparison between models created by software: a) Regard3D. b) 3DF Zaphyr. c) Agisoft PhotoScan.

Table 1. Comparison of Photogrammetric software.

Software	License Type	Price	Pros of the version	Cons of the version
Agisoft PhotoScan	Free	$0.0	All features are available for 14 days.	It does not allow you to save the model or export it in another format unless you register for a 14-day licence.
	Standard	$179 dollars	Ease of use (no experience with this type of software is required). Allows for modifications between each step of the rendering process. Allows saving and exporting of models. Generation of high quality models. Generation of models without specific requirements. Support for an unlimited number of photographs. This version is sufficient to generate high quality models. Updates.	It is paid. Limited use of some functions such as movement and selection of image cameras. Fast model generation but dependent on computer capabilities
	Professional	$3,499 dollars	Ease of use (no experience with this type of software is required). Allows for modifications between each step of the rendering process. Allows saving and exporting of models. Generation of high quality models. Generation of models without specific requirements. Support for an unlimited number of photographs. Full unlocking of program functions. Updates.	Price. Rapid model generation but dependent on computer capabilities.
Regard3D	Free	$0.0	Allows modifications between each step of the rendering process. Allows saving and exporting of models. Full unlocking of programme functions.	Ease of use only if familiar with design programmes. Generation of low to medium quality models. Specific computer requirements such as minimum RAM memory of 4 GB, but 8 GB is recommended. Longer rendering time.
3DF Zephyr	Free	$0.0	Full 3D model generation. Support for NVIDIA graphics cards. Fast model creation.	Support for 50 photos only. Use for people with more experience with this kind of software. Specific support for NVIDIA graphics cards, but only for single-core graphics cards. Limited export of models. Support only in the program forums. No updates. No modifications between rendering steps.

Lite	$149 euros + iva	Full 3D model generation. Support for NVIDIA graphics cards. Fast model creation. 1 year of updates.	Use for people with more experience with this type of software. Specific support for NVIDIA graphics cards, but only for dual-core graphics cards. Limited export of models Basic support by email and in the program's forums No modifications between rendering steps	
Pro	$2,400 euros + iva	Full 3D model generation Full support for NVIDIA graphics cards Fast model creation Advanced support by email and in the software forums	Price Use for people with more experience with this type of software Full but specific support for NVIDIA cards and updated cards Limited export of models Does not allow modifications between rendering steps	
Aerial	$3,900 euros + iva	Full 3D model generation. Full support for NVIDIA graphics cards Fast model creation. Advanced model export. Advanced support by email and in the software forums.	Price. Use for people with more experience with this type of software. Full but specific support for NVIDIA cards and that are up to date. Does not allow modifications between rendering steps.	

7. Discussion

Anatomy is necessary for physicians to understand the function or specific presentation of a pathology, as well as being indispensable when performing invasive procedures on patients [6]. With the disadvantage that the images in anatomy atlases are flat 2D images, it is difficult for learners to understand visual-spatially. Three-dimensional images allow a more realistic appreciation of anatomical structures and their relationships to adjacent structures.

Nowadays, technology allows the creation of three-dimensional models with great ease. However, the cost of this is still high, at a personal and even institutional level, as it requires high-end equipment at an approximate cost of 1,700 dollars or the hiring of professional equipment with a monetary estimate of 500 thousand dollars.

Photogrammetry is easy to create models with a $400 computer, and a $300 mid range phone with a good camera and basic photography skills. Although the licensing cost of the basic version of the software can be added up to achieve true fidelity to the original work, the final budget can be used by businesses and individuals. Because this type of software was created for mapping, it can generate virtual versions of large-scale models; however, with the use of different lenses it can also make models from small parts or even generate 180-degree tunnel-like paths.

Another advantage is the storage and distribution of data, as these models can be stored in the cloud and can be shared or even used by schools without biological model preservation facilities. If we add the cost of internet services, hard drives, or any small tools that allow them to replicate, these costs will not be comparable to the cost represented by having a biological protection laboratory.

On the other hand, there are some disadvantages of the technique. Firstly and most relevantly, it is located in the models created in the Agisoft PhotoScan and 3DF Zephyr programmes, which despite delivering the best final version, the result can be affected by the modification of the quality, noise and quantity of the images available to obtain information, so that models of parts that shine, sparkle or have reflections cannot be made, making it impossible to create a virtual version from glass or metal parts.

The second limitation is that it is necessary to work under as similar lighting, exposure, and framing conditions as possible in each photo to avoid pigment changes, which may lead to a lack of information in the model, leading to the breeding, deformation, or tendency towards very warm or cold colors of black holes, as these are essentially very specific conditions that prevent us from generating models of moving objects. Animals may be supported by humans, as no matter how static they may be, breathing can cause millimeter changes and have catastrophic consequences. This limitation can be corrected by increasing the number of cameras capturing 360 degrees at the same time, however, increasing the number of cameras will also affect the cost in a directly proportional way.

A third disadvantage is the need for software to render the virtual part, which, although it can be done separately and manually, is a process that can take months, increasing the cost and making it difficult for inexperienced people to implement; so we will have to pay to use the full functions of these, given the results obtained in the comparison between free and paid software.

Compared to other studies, this branch of the technique manages to create a one hundred percent real model, which not only represents the photogrammetric spectrum of the light hitting a patient [7], but also facilitates the reading of data, thus providing a clear view that can even be printed in 3D [8] for doctors who are dealing with a pathology or learning a new procedure.

This is a very helpful teaching tool, however, it in no way replaces the study with cadaveric material, but it opens a new window in education accessible to any doctor with a camera, to develop manual skills that will be necessary in their future clinical work.

8. Conclusion

The basic paid version of Agisoft PhotoScan and 3DF Zephyr were found to be far superior to Regard3D, despite being fully licensed with all functions free of charge. The final cost of using this technique is approximately $900 with entry-level equipment and use of standard software, which is 40 times less than hiring professional equipment to create models.

Photogrammetry allows the creation of three-dimensional models with realistic characteristics, which do not require a specific operating system for their reproduction, use and manipulation, and are therefore available to anyone who has the model file, the link generated from online platforms or directly from cloud storage. This technique is not only for undergraduate use, but also for residents and junior doctors as a tool to support the presentation of clinical cases at forums and congresses.

Glossary General Concepts

It is essential to familiarize ourselves with the concepts of photographic technique in order to properly capture the images with which our model was constructed. In the following, we will describe the concepts that we consider essential.

- 3D: Abbreviation for three dimension.
- Diaphragm: The circular structure in the camera that focuses on limiting the entry of light rays.
- Focal length (f): The distance in an optical system between the centre of projection and the image or focal plane (where the negative is placed). The variation of this distance gives the scale of a photograph, as well as the image field to be photographed.
- Framing: Keeping the image of the desired part or structure completely within the field of photography.
- Fiducial marks: These are marks that serve as directors of the image, to allow recognition of the right and left sides, as well as the centre of the image. These marks should preferably be composed of geometric figures, as this facilitates their recognition in the software.

- Photographic lens: It is formed by a series of lenses which have their centres aligned.
- Shutter: This is the mechanism that opens and closes the light entering the lens in fractions of a second. The time that the shutter remains open is called "exposure time", and if this is exceeded, the photograph will be overexposed or burnt; conversely, if the shutter is not open long enough, the image will be underexposed.
- Plastination: A process in which a biological anatomical part is preserved by injecting latex.
- Depth of field: The distance in front of and behind the point in focus that appears sharp in a photograph.
- Rendering: A term used in computing to refer to the process of generating a photorealistic image from a 3D model.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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