

MODELING OF AN AZTEC SCULPTURE WITH PHOTOGRAMMETRY

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Abstract:

Modeling of complex figures using photogrammetric software is being increasingly used in the field of cultural heritage as an alternative to techniques based on 3D scans, due to its low cost and flexibility of use. We have applied this technique to the modeling of the chac-mool of Tenochtitlan, an emblematic figure of the Mesoamerican culture which has been associated with the ritual of human sacrifices.

The aim of this work is to obtain a precise three-dimensional model, i.e. a complete record of its current state, which we will use for the preparation of interactive museum models and for the production of stereoscopic videos. Art historians will also use it to study its proportion and to understand its design.

We will describe the methodology used for the recording and modeling, the problems encountered during the process and their solutions. Finally, we will comment on the use of this tool for recording the architecture and works of art of the Mesoamerican world.

1. BACKGROUND

The *chac-mool* is an emblematic figure of pre-Hispanic culture found in both the Mayan and Aztec worlds. In the more than twenty sculptures that have been found, a standardization of elements can be observed that allows the figure to be identified, along with a degree of freedom in the shapes, sizes and decorations of each one. [1,2]

The figure we digitalized using photogrammetric techniques is still in the same place it was left by the governor Acamapichtli during his reign from 1375 to 1395, in the upper part of the principal pyramid of the Aztec capital, Tenochtitlan, in front of the temple dedicated to Tlaloc, the god of rain. It forms the shape of a person lying on its back, with the legs folded and the head turned to the left. Its hands hold a cylindrical container on his stomach. Sculptured in volcanic stone, it has a painted stucco finish and remains of black, red, blue, white and yellow paint can still be seen. It measures 1.17 x 0.47 m by 0.78 m in height.

Research has been able to demonstrate that it was a key element during religious ceremonies, being used as a table for making human sacrifices, as well as offerings to the gods that could be left in the container, such as the heart of the executed person [1]. As was the custom in the pre-Hispanic world, buildings were regularly renewed and new structures were superimposed over existing ones, and in the case of Tenochtitlan, 7 stages of construction have been counted. This example of *chac-mool* corresponds to the second stage and was buried inside the pyramid that covered all the structures from this time. It is very probable that the upper pyramids had their own *chac-mool*.

Its location at the top of the most important building of the Aztec empire and its ritual use in these centuries prior to the Spanish conquest give the *chac-mool* special importance. The destruction of the Mesoamerican world and of the last building stages of the ceremonial center and of the pre-Hispanic city for the

construction of Mexico City erased these important samples of a complex civilization and it was only as a result of the excavations started at the end of 1978 in the heart of the city that part of the ceremonial center of the pre-Hispanic city began to be recovered, representing a very important historical legacy.



Figure 1: Photograph of the *chac-mool* in situ

We carried out the three-dimensional digitalization of the *chac-mool* with the aim of having a precise record that would allow the model to be given various uses. The University will soon be opening a new pre-Hispanic art and science museum at the archeological site of Tlatelolco, twin city of Tenochtitlan, located less than 2 kilometers away, and we want to generate a 3D video to explain this piece. The model will give us complete freedom of movement of the camera and reduce the difficulty and cost of the production of stereoscopic images. We will also use it for an interactive desk with touch screen at which the user will be able to freely manipulate the piece. Another reason that lead us to carry out this work with the greatest precision and quality is our interest in exploring the potential of scan-type photogrammetry as an alternate tool to scanner digitalization, in order to discover the detailed characteristics of this way of working and so explore the pertinence of its use in the recording of pre-Hispanic heritage in general. When working on recording archeological sites we only use a total station and the combination of several recording tools will help us to reduce field working times and obtain more complete and precise information for irregular shapes. Finally, art historians want to exploit the virtual models in order to carry out composition studies on the statue.

A model of a sculpture can only be built based on a complex mesh generated from point clouds. In order to obtain the initial information of the clouds, at present two large families of solutions exist: one based on the use of a scanner and the other on image processing. We previously built polygonal models with Photomodeler and the version which includes “photo-based 3d scanning” processes opened the possibility of modeling more complex figures with point clouds. The idea is simple, consisting of taking photographs radially around the piece. In each position, at least a couple of parallel photographs are taken in order to obtain a correlation between images which allows the triangulation of the paired pixels and their location in space. However, making a global model of a closed figure is complex: any deviation or approach at an angle

can mean that the point clouds do not fit and that, consequently, the figure does not close. The work has to be very precise and any error is immediately notable.

2. PROCEDURE

PhotoModeler Scanner has been on the market for several years and extensive literature exists on its heritage use. The main difference between what we did and the method explained in great detail by [3,4] resides in our inability to locate targets on the object; for everything else we utilized the explained procedure. The work [5] also shows details of the initial capture of information and makes a comparative study with another low-cost technique based on the use of a laser.

2.1 Photographic shoot

For the photographic shoot we used a Canon Eos 5D Mark II camera with 21.1 mega pixels (5616 x 3744 pixels) with a 24 mm lens, at a distance of 1.50 m from the object. The obtained resolution is approximately 2.66 pixels per millimeter of the *chac-mool*.

The location of the camera should ensure a complete shot of the surface and overlapping zones between the photos in virtue of which we took the shots radially, every 45 degrees. At each location, one low position and another high position of the camera were chosen, obtaining 16 locations. In order to make the correlation between the images it is necessary to take two parallel photographs with a separation of a tenth to a quarter of the distance to the object. However, in order to have additional material in the case that one of the photographs cannot be utilized (note: recommendation found in Hullo, 2009), we took 3 photographs in each position instead of 2, with a separation of about 30 cm. This ideal layout had to be adapted due to the irregularity of the floor and the short distance to the border of the platform. We also took additional photographs closer to the head, giving a total of 68 photographs.

When the processing of the information in the cabinet had been completed, we realized that it would have been possible to improve the shots with a better orientation of the camera. More diagonal views from the bottom up and reverse were needed, that's the reason why the surfaces and textures corresponding to the inferior and superior zones of the sculpture are less precise. However, the conditions of the shoot and the tripod did not allow us to do so.

In order to be able to scale and orient the statue in a coordinate system, we located a series of targets around the *chac-mool* and recorded the position of some of them with a total station.

A roof protects part of the archeological zone, which gave us diffused lighting, very suitable for the execution of this work. We sought to conserve the same exposure all the time and we placed the camera in manual mode. However, in certain positions, the piece was against the light and it was necessary to change the parameters of the shot. We controlled the quality of the color using an x-rite color card.

2.2 Transfer and selection of the photographs

We worked based on the RAW file in order to prevent the processing that the camera performs to improve the image by means of changes in contrast and a "blur" effect, and we converted it into a jpeg without modifying the colors. It was necessary to reject certain photographs that were slightly blurry, keeping 56.

At the same time, the photographic system was calibrated. This process had to be carried out twice as after the first calibration, when the different clouds were joined, we observed that the information was out of phase without finding an explanation, in virtue of which we reached the conclusion that it was due to a lack of precision in the definition of the distortion model of the camera. We recalculated the calibration taking the photographs from the template with more precaution, we printed it in a size close to that of the *chac-mool*, making sure that it was very flat on the floor. After this second calibration, the problem we observed in the orientation of the point clouds did not arise.

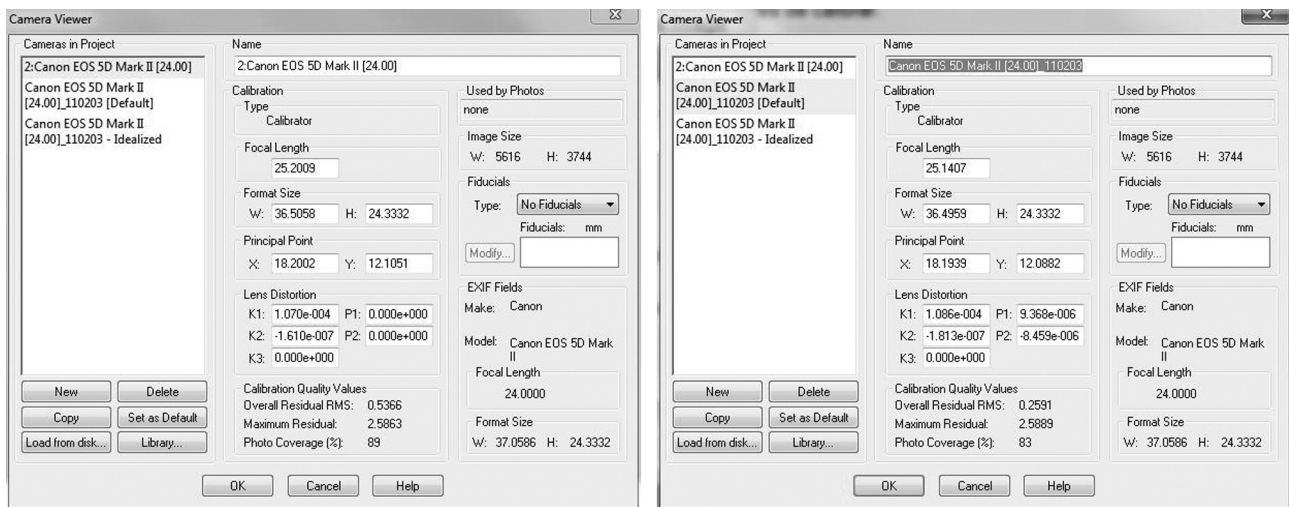


Figure 2: Results of the first and second camera calibration

2.3 Global spatial location of the photographic shots

This step has the aim of integrating an example of each of the 25 groups of photographs into a single file in order to have the location of all the camera groups in the same coordinate system. These photographs were referenced by means of the manual location of 6 to 8 points on each. After processing the information, idealizing the images and reprocessing, the residual value was less than 1.5. The quality of this result is fundamental, as it provides us with the coordinates that will allow all the point clouds calculated in the following steps to fit together.

Then, using the data taken with the total station, the coordinates of 3 points of the targets are specified in order to scale the object and define a system of coordinates.

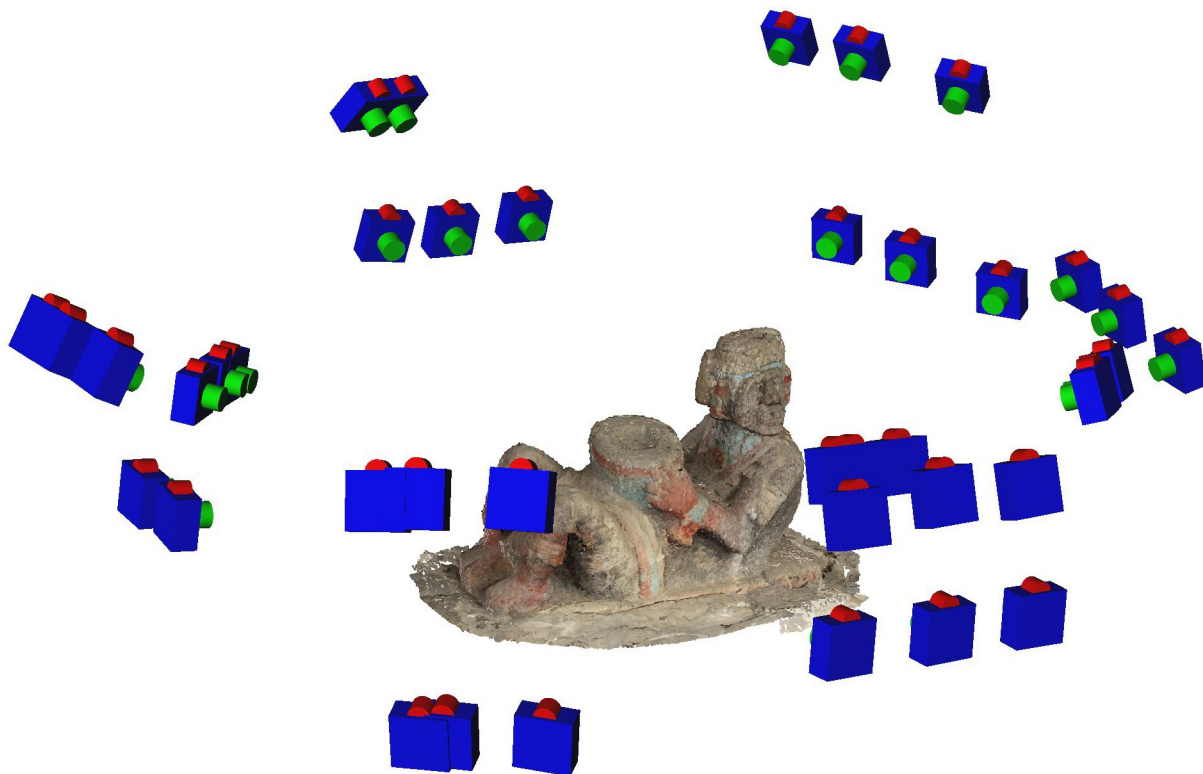


Figure 3: Orientation of the photographs

2.4 Creation of point clouds

Several strategies can be used for the creation of the point clouds. One consists of the integration of all the photographs in the global file, working on the file we previously describe and then calculating the clouds. This method has the advantage of locating all the point clouds in the same geometric references system and avoids locating them by means of the manual placement of 3 coordinates. We tested it and, unfortunately, the amount of information made the calculation of the clouds impossible. However, we did not rule out the file, as it was very useful to have the 56 photographs referenced in the same global system for the location of the meshes generated in independent files. The RSM obtained after this integration was 1.2461 pixels.

The point clouds were generated separately for 14 groups of cameras or stereo-photos and then joined together.

The process followed for each one consists of referencing the three photographs to each other, processing, idealizing, processing, scaling and orienting with 3 points. The distance ratios between cameras and angles are checked, and in principle the cloud calculation will work better if the ratio is close to 0.2 and the angle close to zero.

A problem arose when we attempted to create the first clouds, they were outside the object and did not correspond to its shape. In order to rectify this problem, the correlation points located outside of the figure were eliminated and we inserted points representing the different depths of the volume. The parameters used were: *Sampling rate* = 2, *Super sampling* = 4, *Matching* = 11 and *Texture* = 1

The result show floating points at the edges that should and can be cleaned automatically with the option “clean outliers”. The *cluster distance* parameters varied in each block from 4 to 10 and the *cluster size* from 0.01 to 0.5.

In order to locate the point clouds in space, given that the targets were located only on the floor around the *chac-mool*, they did not give us enough precision to achieve a high-quality result. Consequently, we used another method. This consisted of giving a name to 3 points in each individual file of stereo pairs and the same name to the equivalent points in the global file. At the moment of combining all the point cloud files, the global file that contains all the photos, heads the list followed by the 14 files with the clouds. In this way, the point clouds are automatically located in the corresponding places.



Figure 4: Model with all the point clouds

2.5 End model

Once all the clouds were in the same file, we observed that large areas of superposition of point clouds existed and we decided to clean the information. The selection of the information to be kept had to include quality criteria that would be hard to automate, in virtue of which we used a manual process.

Then we followed the steps to combine the different meshes into a single one with “Register and Merge”, cleaning the obtained cloud with the options “Clean outliers” and “Clear redundancy”. Once the triangles had been obtained, we had to reduce them because there was still too much information. Finally, we filled any holes. In order to fine-tune the parameters, we worked separately on a portion of the *chac-mool*, and then applied them to the statue as a whole. We began all this triangulation process of the head with 96055 points, finishing with 19263 points and 38403 triangles.

Once the mesh had been triangulated, the polygons were generated and the textures extracted. In this process we encountered many problems that forced us to go back to the previous step in order to reduce the number of points, as the hardware was unable to complete the process.



Figure 5: Point clouds before and after the reduction of points. Visualization with bigger dots.

3. RESULT



Figure 6: Model in Autodesk 3ds Max.

We obtained a model that meets the initially mentioned requirements. It is a complete digital representation of the statue, integrating textures, in virtue of which the finishes of the work can be appreciated, as well as its state of preservation, and we can restore its original appearance.

Based on this model, we can make interactive 3D videos and analyze the composition and proportions of the work, which meets our needs.

4. CONCLUSION

The result is satisfactory, however it required too many hours of work. The most demanding processes in terms of human intervention were the manual referencing between photographs, the naming of specific points for integrating the stereo pairs in a single file, the manual cleaning of the point clouds before the merge and the correction of the textures. It is probably possible to reduce times for the first two, better locating the targets and with the use of the new version of the software, which includes more image processing in order to compare them and find their coincidence. We could also avoid part of the cleaning if we had generated the point clouds more selectively and in a unique file, which was difficult due to having to work on them in separate files because of hardware limitation. We also noted that the zones of superposition of the point clouds don't match exactly and they present a slight rotation. We have not yet understood the reason for this lack of concordance, given that each of the steps of the work was carried out with the greatest possible care and we obtained very low residuals in the orientation calculations.

We also noted improvable factors in the software: it is unstable and on many occasions the processes froze up, as they were probably too heavy and we would expect to have better documentation about the maximum number of photographs, points, and triangles that can be calculated. Nor is it optimized to exploit the architecture of the computer hardware: we used a computer with two Intel dual core 2.66 GHz processors, 16 GB of RAM and the maximum used in the processing was 25% of the total capacity of the processors and only 1.7 GB of RAM. When the textures are extracted, the use of the hard disk is intense but this is not the case in the other processes.

Once these problems have been solved and if we are able to reduce manual working times, the tool will unquestionably be included in our way of registering archaeological sites. It has many advantages such as those extensively described in literature. It is a non-invasive method, does not damage the object, is low-cost, flexible and saves a lot of field work, as well as having the advantage of combining the generation of geometries and texture extraction. For these reasons, it is of promising use for the recording of pre-Hispanic cultural heritage.

5. THANKS

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