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► To cite this version:

Thibaud Poigt. Volume measurement by photogrammetry. Applications for the weighing metrology studies. 1st International Conference on Metrology for Archaeology, Oct 2015, Benevento, Italy. pp.197-202. halshs-01613978

HAL Id: halshs-01613978

<https://shs.hal.science/halshs-01613978>

Submitted on 19 Feb 2019

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Volume measurement by photogrammetry

Applications for the weighing metrology studies

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Abstract – The fieldwork of the weighing metrology studies faces issues concerning the conservation of the artefact. More specifically for the European Protohistory, for which the metrological standards and systems are not identified by the texts, the weights studies leave out the broken ones, difficult to integrate. The method presented here is intended to remedy this issue proposing a way to calculate the volume of an object with a non-intrusive measurement and permitting later a numerical restitution of the morphology and mass of the original object.

I. INTRODUCTION

This work is included in the bigger fieldwork of my PhD thesis, treating about the weighing instruments in Western Europe during the Metal Ages. Concerning the metrology studies, this chrono-geographical area is, on the one hand, characterized by a heterogeneous state of the art, and on the other hand, it is particularly favorable to this kind of study because of the great number of social and economic network implanted inside it.

To be more specific, we identify weights and scales from the Late Bronze Age to the end of the Iron Age but without a clearly line of apparition and development in time and space. Without a global and diachronic analysis, it remains impossible to explain if this lack is the consequence of the state of the scientific research or by human implications dated from the concerned periods. The studies of Metal Ages weights, identified since the beginning of the 20th century, permits to dress a summarized typology for the Western Europe [1].

In this domain, the Iberian Peninsula is the well-studied area, from the Late Bronze Age to the Roman Period. An original type of weight, presented as a cylindroid piece of copper alloy or lead, perforated in its center, is identified since the 30's [2]. During the next decades, many authors worked on the subject and, particularly, on the metrological aspect of this artefacts. Indeed, the weights have the particularity to be interesting in their typological



Fig. 1. A copper-alloy weight with its perforation filled with lead and a broken lead weight. Alcludia de Elche (Spain).

aspects but also, and maybe especially, by the metrological data they contain. Nevertheless, as all the archaeological artefacts, they suffer the ravages of the time. If the typological aspects remains accessible, the metrological ones are partially or completely lost. Furthermore, since the first study of Iberian weights, the archaeologists bring to light the adjustment of some weights, by the cutting or the secondary adjunction of metal. Always for the Iberian Peninsula, this question was well-studied by Ignacio Grau Mira and Jesús Moratalla Jávega [3].

All this elements imply that a part of the data is still inaccessible for metrological studies. Solutions exist to determine the lack of an artefact, by the reconstruction of an entire model, generally with plastic material as Plasticine. Nevertheless, this process is long and necessitates an important manipulation of the archaeological object during the impression-taking [4][5]. For this reason, it is hardly applicable to all the pieces and it doesn't permit the mass determination of an additive metal in the cases of mass adjustment.

Through this paper, I will propose an alternative method to measure the volume of an object, faster than the creation of material model and necessitating the minimal manipulations possible. This method is based on the use of photogrammetry, combining to a "mesh builder" software.

II. PHOTOGRAMMETRY APPLIED TO VOLUME MEASUREMENT

A. The photogrammetry and its uses in Archaeology

By this own name, the photogrammetry imply a measurement process. It is defined by the Collins dictionary as: “the process of making measurements from photographs” and by the Larousse as: “Ensemble des techniques qui permettent de déterminer la forme, les dimensions, la position dans l’espace d’un objet à partir de photographies.” It is a process as old as the photography itself, used since the middle of 19th c. to the cartography and military applications, particularly after aerials pictures [6]. The photogrammetry consists of giving 3D properties to an object derived from 2D images, using principles of trigonometry to relying photographs taken from different locations and determine 3D location of points of interests. With the development of computing since the 60’s, then the introduction of digital photographs during the 90’s, the photogrammetry became a semi-automatic or automatic process, through computational solutions and the use of specific algorithms [7]. In most cases, mainly for aerial photogrammetry, the models obtained are not a complete 3D but only convex surfaces [8].

Recently, the photogrammetry and especially its digital applications became particularly appreciated by archaeologist as a new way to register archaeological heritage. Indeed, it is increasingly considered as a more precise and global system in comparison to the traditional 2D ways of registration. Thus, it is adopted as a privileged tool for underwater archaeology [9], aerial archaeology [10] but also for the diary in-field documentation [7].

B. Measuring by photogrammetry

If the use of photogrammetry for the distances measuring or areas is becoming common, its logical application on volume measurement is, for now, rare, at least in archaeology. One reason to explain this lack is the difficulty to obtain a complete 3D model of an artefact. Indeed, it implies to take pictures of the entire subject, on its both sides, this is to say moving it after taking photographs of the first side. Nevertheless, as we will see, it is possible to obtain good results even with this issue.

As we explained, the photogrammetry is, by nature, a way of measurement. However, the 3D model obtained, with digital photogrammetry like here, only has relative metrological properties. In this way, the steps of measurement, whatever they are, need a phase of scaling, this to say attributing metric data to the model. For this, it is obligatory to observe a subject in the model for which the lengths are known. Indeed, a model obtained by photogrammetry and not scaled is as useless as a map without scale. In practical terms, this implies to place a field scale, visible in the most of the pictures composing the photogrammetry, in the same way that for classical

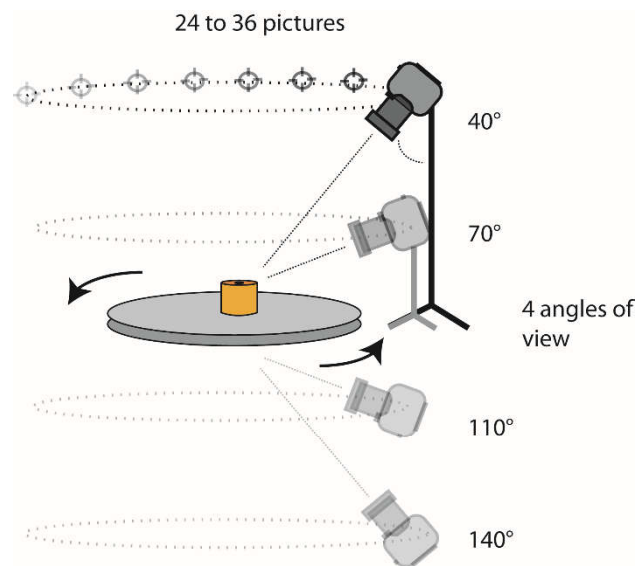


Fig. 2. Scanning Method, after Poigt, Th. [12]

archaeological photographs.

If these elements are reunited, the photogrammetry permits the registration of three-dimensional data in an objective way. Once registered in this form, all the measurements are then possible in the three dimensions, including the volume, which particularly interests us here.

C. Method

The use of photogrammetry to obtain an exploitable digital model implies few prerequisites: a digital camera, a computer and the software which will compute the data and create the model. In our case, we use the software *Agisoft Photoscan®*, already well-used by archaeologist and permitting the building of high resolution models, even with the smallest subjects.

At this point, for maximizing the quality of the results, I use a camera remote control, a turning table, two tripods, a mini photographic studio and, of course, a scale of 5cm. The turning table and the tripods permit a minimum of manipulations. Indeed, once the subject is put on its support, the camera and the object do not need to be moved anymore, only the table has to be turned. To obtain the better quality of pictures, the diaphragm of the camera needs to be the closest. This have as consequence a slowdown of the shot to obtain pictures sufficiently illuminated. Thus, the remote control serves to eliminate the shaking of the camera and obtain net pictures. The studio aims to avoid the drop shadows, diffusing homogeneously the light. It is not useful to come back to the rule of the scale except saying that its length needs to be adapted to the subject and it has to be placed the closest to it.

The first and most primordial step is the scanning and consists to take the pictures of our subject. On the quality

of this step depends all the results. In the way of obtaining the best model, we privileged several angles of view, six in most of the cases. As the subject is immobile, excepting the rotation on the “z” axe, the camera needs to be moved. Its translation on the “z” axe permits the change of the angle of shooting. In our cases, we obtained the best scans adopting angles corresponding approximatively to 40°, 70°, 110° and 140° from the vertical of the camera. For each one, 24 to 36 pictures are taken. The two last angles of shooting are represented by two zenithal pictures, one on each side (or two slightly decaled from the zenith). We can note that the more the surface of the object is smooth, the more the number of pictures needs to be important for maximizing the points of matching. Without a number of photograph sufficiently high, the alignment does not can work (Fig. 2).

Once the photographs acquired and imported on the computer, the step of calculating starts. As we said, with the actual software, this step can be realized in a way, at least semi-automatic, and entirely automatic in certain cases. With *Photoscan*, we keep sufficiently control on the procedure to fix the potential issues that can occur during the process.

Four principal steps exist: the alignment of the photos, the dense cloud building, the mesh building and the texture building. The first step represents the real photogrammetry process consisting in calculating the position of the camera from the points of interests for each shot. To be effective, it is primordial that the same pixel appears in several pictures. Logically, following our protocol, we have not to face these kinds of problems. To isolate the subject of the rest of the picture, we can apply a mask to restrict the zone of calculation. If the protocol is respected, the software can normally integrate all the pictures of both sides of the object. If it does not, it is possible to build two faces of the object separately and glue them in a second time. Nevertheless, this method has to be avoid to obtain precise volume data as we will see.

During the second step, the software increase the number of points in basing on the results of the first step. After this, we normally have already a good idea of the three dimensions of our subject.

The third step produces the final 3D model, combining the points to create triangular faces between them. At this phase, we have all the parameters to effectuate measurement.

The final step, building the texture has a great interest for the visual aspect. In the case of length measurement, it can also show details permitting a better identification of the object surface.

After this four steps, we are in possession of a complete *mesh*, namely a 3D model of our object, textured, but not scaled. The process of scaling is really simple but necessitates precision. The objective it is to transform the relative metrological information of our model in standardized data (based on the metric system for example). It consists of applying markers on several pictures and define a distance between them. Here, we

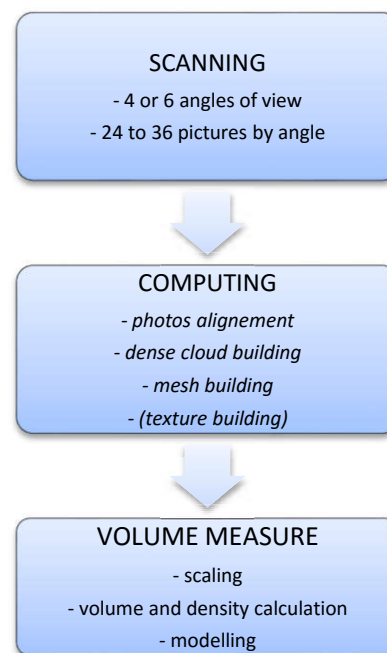


Fig. 3. Volume measurement by photogrammetry

create markers on the scale presented on the photographs, and define the measure indicated (for example: one marker on the 0 and another on the 2 and we attribute to the distance the value 2cm or 20mm). To increase the precision, we prefer creating three markers corresponding to two scales (generally 10 and 20mm). With *Photoscan*, the markers need to be placed on two or three pictures before the software integrates them on the 3D model. Sometimes, it is necessary to replace some of them directly on the pictures to avoid precision issues. It is important to keep in mind that it is this step which conditions all the metrological properties of our model. Even the smallest deviation could have consequences on the measurement results.

If all the protocol is well-respected, we obtain a three-dimensional model of our object, scaled and with high precision. With the software *Photoscan*, the volume is already calculated and expressed in the same unit as the scale (mm³ for mm, m³ for m etc...). Almost all the software permitting the manipulation of *meshes* has also this parameter of volume measure (*Blender*®, *CloudCompare*®...).

III. RESULTS AND APPLICATION ON WEIGHING STUDIES

There are not a vast number of method to measure the volume of an object. We can calculate it geometrically for the simplest form, with well-known geometrical formulas, or we can measure it by immersion in liquid. Other solutions exist, used for example in the industrial world, but they are expensive and not well adapted to

archaeological artefacts. The immersion in a liquid is clearly not practicable either in our domain and the object rarely has geometrically perfect forms. For these reasons, when the archaeologists need to measure the volume of an object, most of the time, they do not have other choices than creating a copy and immerse it in a liquid.

To have the possibility to use the process described in this paper as a real measurement tool, its precision needs to be compared to another way of volume measurement. For this, I reproduce my protocol on an object with a geometrically perfect form: a sphere. I compared the result of this volume measurement with the geometrical calculation and I obtain a deviation between the two of them inferior to one percent. We can consider this result totally acceptable and admit the potential of photogrammetry as a way of volume measure.

Nevertheless, it is possible to go further in the exploitation of 3D properties of the data registered. Indeed, once the volume is measured, if we weigh the artefact, we can easily calculate its density. Using a 3D modelling software, it is also possible to create the missing part of a broken object and thus reconstitute its original form and volume. In other words, it became conceivable to deduce the original weight of an object which, for a reason or another, changed at a moment. This application, which is the most interesting for me in the context of my PhD thesis, brings to recover a very important set of metrological data hardly accessible at the moment.

This step of numerical restitution necessitates a good knowledge of the typologies because it brings to recreate the lack of the artefact with precision. In our case, we use the software *Blender*® to realize this work. Even if it is probably the most subjective part of the method, it gives an approximation of the original mass of weights which is essential to the extension of the weighing metrology studies.

The application of the method on archaeological artefacts is a work in progress within the context of my PhD thesis. For now, the main results concern Iberian weights dated from the Iron Age. I applied the process on two specific series of weights.

The first one is a series of stone, from the site of Malvieu (Saint-Pons-de-Thomières, Hérault, France), supervised by Alexis Gorgues (MCF, University Bordeaux Montaigne). In this hillfort, occupied since the Late Bronze Age, all the material made of a stone not naturally present on the site, was conserved during the archaeological excavations. Inside this corpus, we identified a series of ellipsoidal objects, looking like small pebbles. The observation of repetitive masses brings us to consider their function as weights. Three of the fifteen pieces are broken and we cannot use the photogrammetry



Fig. 4. Numerical reconstitution of the possible weight G from Malvieu (Hérault, France)



Fig. 5. Numerical model of the weight Cig-F, from the tomb 200 (El Cigarralejo, Murcia Spain), before and after the filling of the notches.

and the numerical reconstruction to approach their original mass. Even if their weighing function remained to be confirmed, the photogrammetry gave interesting results concerning the density and the reconstructed masses, permitting to propose a hypothetical weighing system. One of the most interesting elements is the restitution of the only bispherical object as twice the standard found studying the relation between the object masses (Fig. 4).

The second one is a series of weights containing two sets from two Iberian graves (tomb 18 and 200, El Cigarralejo, Mula, Murcia, Spain), one of two weights and another of ten weights. If the method gave excellent results concerning the acquisition step, the restitution concerns only one weight. This one presents two notches on one side and we estimated the lack concerning them to determine if they could concern an adjustment from a metrological system to another. It appears that the mass difference is too small to have a chance to correspond to a volunteer modification of the object (21-21.5 g after the filling of the two notches for an original mass of 20.48g). In this way, it seems more probable that the notches have a mark function or are the result of a mass transformation in order to refine the precision. The restitution of the metrological system shows that this precise weight seems to be the standard of the set, in this way, the notches would show this function [11][12].



Fig. 6. Three examples of voluntary mass alteration (Alicante, Spain). A. Cabeço de Mariola, adjunction of a copper-alloy sheet rolled around the weight ; B. Ex Xarpolar, secondary perforation filled by lead ; C. and D. La Serreta, central perforation filled by iron and base digged.

IV. CONCLUSIONS

The photogrammetry had undoubtedly showed that it is a powerful tool of measurement in the three dimensions in addition to very useful properties for the registration of the archaeological evidences. Now more than ever, the 3D appears as a privileged way to safeguard an archaeological heritage suffering from the lack of money in order to assure its conservation or the resulting destructions of wars (we think particularly about the very recent destructions at the ancient city of Palmyra). If the protocol presented here is specially centered on the small size artefacts, the applicability of the photogrammetry include also bigger vestiges, as architectural elements or the statuary, and the in-field data.

In the case of the artefact study, we saw that it permits the scanning of pieces in a few minutes, with a maximum of metrological data acquired and a minimal of manipulations. The use of this method as a way of volume measurement is independent of the artefact and can be applied at other types of subjects. Furthermore, the combination of the photogrammetry and modelling increase the measure applications: inside volume of a pottery or of pit, of a silo, of a ceramic kiln etc...

The use of the photogrammetry presented here, combined to a modelling step in order to rebuild numerically artefacts which the form changed over time, is an alternative to the conception of material copy. The major aim is to facilitate the obtaining of volumetric data, using a numerical model and avoiding the over-manipulation of the artefacts. A significant consequence of this process is the acquisition of a numerical model, with a high level definition, easy to manipulate and saving with precision all the metrological data.

In the fieldwork of the ancient weighing systems, the contribution of this method is essential. It permits the

incorporation into the corpus of the weights having suffered the ravages of the time but also the ones voluntarily broken for metrological reasons. Maybe most significantly, that will lead us to consider otherwise the artefacts presenting voluntary mass alterations (Fig. 6). Finally, this work in progress will give new metrological data, bringing a new vision of the weights adjustments and, probably, a better understanding of the creation and adoption of weighing systems during the Protohistory.

ACKNOWLEDGMENTS

I want to thanks the curators of the museums of La Alcudia (Elche, Spain), El Cigarralejo (Mula, Spain), Alcoi (Alcoi, Spain) and Alexis Gorgues, supervisor of the site of Malvieu (Hérault, France), to let me access to their collections from which are taken respectively the examples from the figures 1, 5, 6 and 4. A special thanks to Maëva Caubraque and Carissa Di Scala for their proofreading and corrections.

The different software used in this study are: Agisoft Photoscan, Blender, CloudCompare and 3D Builder.

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