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Published Version:

High-Resolution 3D Survey and Visualization of Mesopotamian Artefacts Bearing Cuneiform Inscriptions / Chiara Francolini, Gianni Marchesi, Gabriele Bitelli. - ELETTRONICO. - (2018), pp. 178-182. (Intervento presentato al convegno MetroArchaeo 2018 tenutosi a Cassino nel 22-24 ottobre, 2018) [10.1109/MetroArchaeo43810.2018.13617].

This version is available at: <https://hdl.handle.net/11585/675810> since: 2019-02-28

Published:

DOI: <http://doi.org/10.1109/MetroArchaeo43810.2018.13617>

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This is the final peer-reviewed accepted manuscript of:

C. Francolini, G. Marchesi, and G. Bitelli, "High-Resolution 3D Survey and Visualization of Mesopotamian Artefacts Bearing Cuneiform Inscriptions," presented at the MetroArchaeo 2018, Cassino, 2018, pp. 178-182

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High-resolution 3D survey and visualization of Mesopotamian artefacts bearing cuneiform inscriptions

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Abstract—This paper presents some considerations and experiences about the use of geomatic techniques in surveying and representing small archaeological artifacts, such as cuneiform tablets and other inscribed objects with cuneiform writing. Scanning by hand-guided structured light scanner and image processing on the 3D models permits a wider range of possibilities in respect to classical surveying methods and can help to improve the readability of the text.

Keywords—Geomatics, cuneiform inscriptions, 3D modelling, image processing

I. INTRODUCTION

In recent years, the field of Cultural Heritage has shown an increasing interest in the emerging digital techniques realized by means of geomatic methods [1][2]. The spread of Geomatics applications in this field is impressive, and has affected objects of very different nature and characteristics, from the large architectural structures to very small archaeological artefacts.

Geomatics provides new methodologies not only for the surveying and representation of these objects, but also for their management and sharing, allowing the realization of accurate and rigorous models, very frequently of three-dimensional type. The 3D entities constitute an important support to the analysis and study of objects and an interesting product for the documentation and divulgation of Cultural Heritage; moreover, they considerably help in the processes of restoration and reproduction of objects, and permit new approaches and researches.

This experimentation focuses on the application of a structured light scanner for high-resolution 3D survey to small clay artefacts of different shape and size. All the surveyed objects belong to the Ancarani Collection of the Civic Archaeological Museum in Bologna. They come from ancient Mesopotamia and bear cuneiform inscriptions, characterized by small signs made up by wedge-shaped elements. This is the reason why this kind of writing, which was used by the ancient inhabitants of Mesopotamia (Sumerians, Babylonians, Assyrians) for more than three thousand years, is called “cuneiform” (from Latin *cuneus*, “wedge”).

The present work firstly aims at highlighting the advantages of the advanced surveying techniques offered by Geomatics with respect to the classical surveying techniques used for this kind of objects, such as photography, drawing, making

casts, and Polynomial Texture Mapping (henceforth PTM) [3] [4] [5] [6].

Photography and making casts do provide objective representations of artefacts, but the success of the first method is influenced by the illumination condition combined with the morphology of the object surface, while the second one is invasive (the casting material can leave deposits). Direct drawing is a non-invasive and economic surveying method that was widely used in the past; however, it lacks objectivity, depending very much on the skill and interpretation of the author of the sketch. The recently developed PTM, also known as Reflectance Transformation Imaging (RTI), solves great part of these problems, supplying a detailed surface model of the surveyed object. However, the models obtained with this method are only bi-dimensional. Figure 1 shows a classification of the above-mentioned classical surveying techniques.

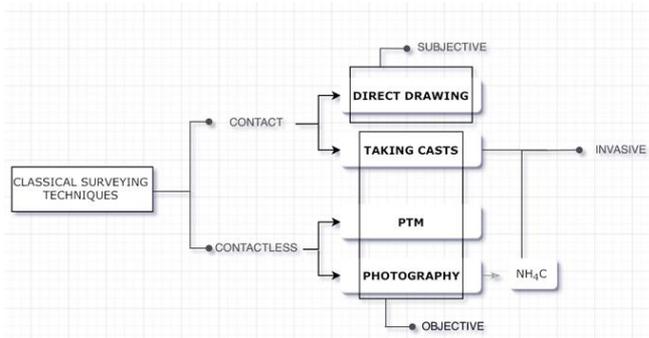


Fig. 1. Classical surveying techniques classification.

The mentioned classical methodologies can be nowadays complemented, or overcame, by the advanced geomatic techniques, that can offer in many ways greater potential: in particular the *digital photogrammetry* [7] and the *3D structured light scanning* provide several advantages in both surveying and post-processing phases and represent an innovation in Cultural Heritage field.

Here, the application of the structured light projection technology is considered: because of its characteristics, the structured light 3D scanning technique is in several aspects a better alternative, especially when we have to do with small objects characterized by a complex geometry and an irregular surface.

The instrumentation is non-invasive and contactless, the acquisition process is rapid and objective, and the 3D results are in digital format and can thus be used for multiple

applications. The instrument used for the survey is an active sensor (3D scanner), which, projecting and then acquiring a codified pattern is capable to obtain geometrical information about the shape of the surveyed object. The set of data acquired by the scanner shapes by a mesh a detailed 3D model of the object in question.

The hand-guided scanner that was used in this experimentation, *Artec Spider* from Artec3D (Figure 2), is capable to acquire up to 1 million points per second with a maximum accuracy in the order of few tens of microns, thus providing an extremely detailed high-precision 3D model, which also contains chromatic information (provided in real-time by the scanner itself during the survey).



Fig. 2. Hand-guided structured light projection scanner, *Artec Spider*.

The objects until now surveyed are four tablets and a cone, but only two of them are considered here (Figure 3). Both artefacts are made of baked clay and bear inscriptions in cuneiform writing.



Fig. 3. Above: dark clay tablet; below: brick-red clay cone (images not to scale).

The tablet ($5,8 \times 5,4 \times 1,8$ cm; museum siglum EG 4013) is a letter in Old Assyrian script and language, sent by a well-known Assyrian merchant, one Puzur-Assur, to two agents of his, and contains a series of instructions of the former for his subordinates concerning various trade and business matters [8] [9] [10]. It comes from the ancient city of Kanesh (corresponding to the modern site of Kültepe in central Turkey) and dates to the 19th century BC.

As far as the cone is concerned (EG 4200; height: 12,6 cm; diameter at the base: 4,3 cm), we have here an example of royal inscription in Old Babylonian script and Sumerian language. It was commissioned by Ishme-Dagan (ca. 1953-1935 BC), king of Isin (modern Ishan al-Bahriyat in southern Iraq), in order to commemorate his building of the “great wall of Isin” (*bàd gal i-si-in^{ki}-na*) [11]. Such objects were usually embedded in the foundation walls of temples or other built structures and served as a sort of time capsule to transmit to the future generations the memory of the king and of his accomplishments [12].

In the next paragraphs the results of the survey of these two objects and the main phases of the process are presented; in addition, the potentialities of the created 3D models are investigated.

II. SURVEYING AND 3D MODEL RECONSTRUCTION

The survey of the tablet and the cone turns out to be a quite simple and rapid operation because of the small dimensions of the objects in question and the characteristics of the instrument itself; in fact, the guide by hand allows the operator to move around the considered object and to choose the most suitable survey criteria. In both cases the survey approach consists in two successive phases: first the object rotates on a moving support while the scanner is fixed in a position; then, vice versa, the object is fixed in a position and it is the scanner that moves around it. This procedure has been proved to ensure a complete survey without any lack of data and a systematic data acquisition.

The instrument is capable to scan the surfaces in *real-time* and to automatically perform the alignment of the frames acquired during the survey: the result is a first rough 3D model of the object (i.e. a mesh) that can be visualized and explored by the user immediately after the scanning phase, also permitting to check the quality of data.

The data processing follows; usually the duration of this phase highly exceeds the acquisition phase; however, the surveying method described above, together with the dimensions of the objects, ensures an easy and a relatively rapid processing of the data, characterized by a total duration of few hours, editing phase included.

In both cases the processing approach consists in treating the scans of different parts of the objects separately, until the reconstruction of separate meshes, one for each scan; then, the final 3D model is reconstructed aligning and merging the separate models, to reconstruct a single complete mesh of the object. The mesh reconstruction process, specifically, reconstructs a polygonal model whose resolution indicates the mean distance between two points constituting the model, i.e. the sharpness of the 3D model. In both cases the mesh is reconstructed using a resolution value such that the model is capable to represent the real object surface and its surface

peculiarities, i.e. the engravings representing the cuneiform signs: in both cases, the mean distance between the points constituting the model is 0,1 mm; however, a compatibility problems occurs between the high-resolution mesh and the texture mapping, and a simplification of the meshes is necessary in order to imprint the chromatic information on the models.

Even if the triangulated mesh is simplified, the high detail of the model is maintained: in both cases, the result is a three-dimensional digital product, which also contains texture information.

The 3D model of the tablet is shown in Figure 4; the final mesh is composed by one million points and contains chromatic information.



Fig. 4. Tablet 3D model creation; left: point cloud and triangulation phases; right: final textured mesh.

Figure 5 shows the model representing the cone; it is textured and composed by two million points.



Fig. 5. Textured 3D model of the cone.

III. DIGITAL ENHANCEMENT

The decipherment and interpretation of the inscriptions, often constituted by very small engravings that are not easily visible to the naked eye, is facilitated by the possibility to apply algorithms, digital filters, and artificial light to the model; these digital solutions provide the enhancement of the cuneiform signs that cover the object surface ensuring an

easier reading of the text and, therefore, its correct interpretation [13] [14] [15] [16].

Concerning the visualization issues, the approach here used consists in applying the *Lambertian radiance scaling* and *Minnaert reflection* algorithms [17].

The first one is a tool that allow to enhance the concavities (or convexities) of a surface under arbitrary illumination relying on the reflected light intensity adjustment, which depends on surface curvature and material characteristics. The quantity considered is the outgoing radiance on an object surface. The reflected radiance equation assumes the following form:

$$L'(\mathbf{p} \rightarrow \mathbf{e}) = \int_{\Omega} \rho(\mathbf{e}, \ell) (\mathbf{n} \cdot \ell) \sigma(\mathbf{p}, \mathbf{e}, \ell) L(\mathbf{p} \leftarrow \ell) d\ell$$

where the mathematical quantities involved are: the enhanced radiance L' , a surface point \mathbf{p} , the direction toward the eye \mathbf{e} , the surface normal \mathbf{n} at point \mathbf{p} , the hemisphere of directions around the normal $\Omega (= \int_{\Omega})$, the light direction ℓ , the material bidirectional reflection distribution function (BRDF) ρ , a scaling function σ , and the incoming radiance L . The *Minnaert reflection* algorithm, originally developed for the interpretation of astronomical observations and remote sensing data, starts from the Lambertian BRDF expression and corrects the radiance formulation by introducing a constant k that weights the incidence and emission angle contributions. This darkens the entity limbs along the edges, providing a 3D model characterized by a high level of surface detail. As Figures 6 and 7 show, *Lambertian radiance scaling* and *Minnaert reflection* algorithms provide very good results in terms of visibility of wedges and, consequently, of readability of signs.

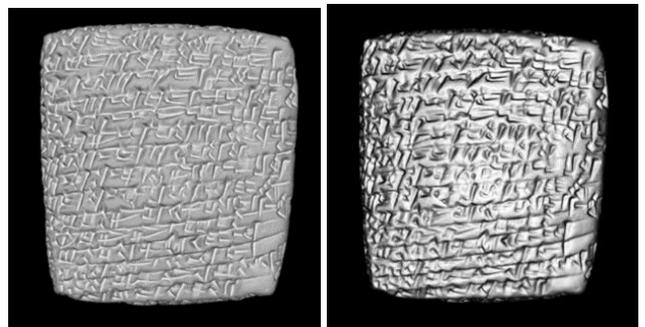


Fig. 6. Application of radiance scaling (left) and Minnaert reflection (right) to the 3D model of the tablet.

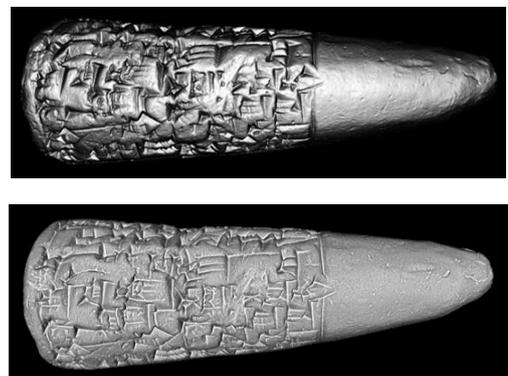


Fig. 7. Application of radiance scaling (above) and Minnaert reflection (below) to the 3D model of the cone.

In order to further improve the visualization of the engraved text, one can take advantage of the application of artificial lights to the digital model (Figure 8); by applying and varying the direction of the beams of light, it is possible to enlighten certain parts of the text of particular interest.

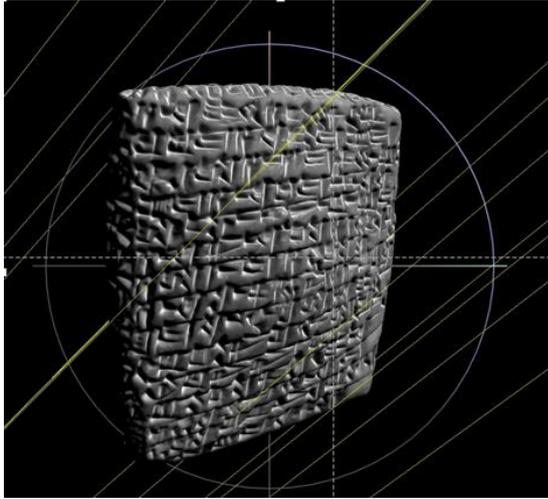


Fig. 8. Artificial illumination; in yellow, varying direction of the beams of light.

IV. SURFACE UNROLLING

In the case of inscribed artefacts with a conical or cylindrical shape there are specific problems related to the readability of their inscriptions. In fact, although the three-dimensional representation ensures a complete exploration of the object and helps the users in focusing on its peculiarities, the text engraved around the surface cannot be entirely seen unless rotating the 3D model during the reading [18] [19]. However, by approximating the model to a regular geometric solid (a cone or a cylinder) and performing a surface unrolling procedure in the three-dimensional environment (Figure 9), the text can be displayed in its entirety, which facilitates the study of it. The basic principle consists in the reprojection of the conic surface on a flat fictitious support; the result obtained is a 3D entity, which approximately corresponds to the flat envelope of the cone.

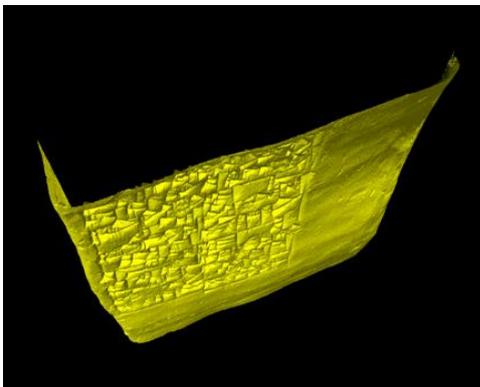


Fig. 9. Cone surface after the unrolling operation.

Such a flat representation of the cone represents a digital base for additional applications: the previously described digital enhancement of signs can be applied to the unrolled cone

(Figure 10), thus permitting an even more clear reading of the text. In addition, this model also constitutes a starting point for the vectorization of signs.



Fig. 10. Flat representation of the cone inscription after a series of image processing algorithm applications.

V. VECTORIZATION

The vectorization process is a sequence of operations that allows to obtain the vector representation (unique and objective) of the wedges engraved on the objects surface. The process starts from the 2D representation of the object and applies image processing procedures until the extraction of each single wedge (Figure 11). The signs extracted are vector entities.

This is the starting point for creating a drawing of the text much more reliable and objective than a hand-made copy (the so-called "autography"). This operation represents a useful alternative to the 3D model visualization, especially when a simpler representation of the text is required for study, teaching, or publication purposes.

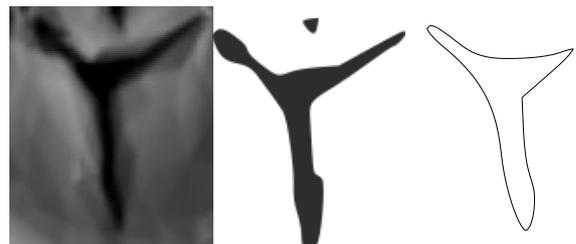


Fig. 11. Vectorization process: (from left to right) a wedge after image processing procedures, binary representation of the wedge, and its vector representation.

A research is currently in development in order to obtain is vector representation in automatic or semi-automatic mode, after an appropriate setting of parameters.

VI. CONCLUSIONS

The results obtained show that, nowadays, advanced geomatic techniques can give a concrete support to the researches related to Cultural Heritage: especially in presence of small archaeological artefacts with inscriptions, structured

light 3D scanning technology offers a non-invasive, contactless, rapid and objective surveying method that overcomes the traditional ones. The models created are three-dimensional digital entities characterized by a high degree of detail and extreme versatility: in fact, as this experimentation has shown, digital filtering algorithms, unrolling operations, and vectorization of signs can be applied to solve common readability issues related to the inscriptions on these objects, ensuring an easier study of texts.

To conclude, the new techniques described and illustrated above allow a complete and accurate vision of the entire surface of an inscribed artefact, from every possible point of view, in general and in every detail. In practice, it is like having the object in one's hand — and maybe even better, thus allowing a scholar to examine the object in question and read and translate its inscription regardless of being thousands of miles far away from the object itself. Needless to say, this fact can have a tremendous impact on the manner to carry out research on such artefacts. From now on, epigraphists may no longer be forced to go to museums or to the field, during archaeological excavations, to study epigraphical documents. Clearly, we stand at the door of a new era for epigraphy: the age of remote reading.

ACKNOWLEDGMENTS

This project has been carried out in collaboration with the Civic Archaeological Museum in Bologna. We would like to thank Paola Giovetti, director of the museum, and Daniela Picchi, conservator of the Egyptian collection, for granting us the access to the artefacts that have been surveyed.

The work has been partially supported by the GAMHer project: Geomatics Data Acquisition and Management for Landscape and Built Heritage in a European Perspective, PRIN: Progetti di Ricerca di Rilevante Interesse Nazionale – Bando 2015, Prot. 2015HJLS7E.

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