Geometrical Feature Identification of Cuneiform Signs on Micro-Survey Reconstruction

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Abstract. According to the increasing possibilities offered by technological innovation, new ways of visualizing and exploring data are now accessible in the context of 3D digital documentation. Surveying small artifacts and accurately representing their geometry, however, remains challenging. This can be ascribed to the still high cost of the most popular equipment for that purpose (active sensors) as well as the requirement for professional expertise when employing less expensive methods (passive sensors).

This project aims to provide a low-cost configuration for an image-based approach to the demand for a digital survey and 3D representation of sub-millimeter morphological features. A portable USB microscope was used as equipment. The subject of the experiments is a cuneiform tablet belonging to the collection of Ghent University (Belgium) and datable to the end of the 3rd millennium B.C. More specifically, the study seeks to examine the geometry of the wedge-shaped impressions on the clay artifact. Going beyond the traditional practices of text analysis, an accurate representation of the cuneiform signs can be helpful for researchers in conducting comparative geometric studies. This goal can be enriched by recognizing from the analysis the type of stylus used to validate a manufacturing identity and a chronological classification. It is desirable that the data collected can then be shared, on the one hand, by enabling descriptive assessments even between different collections around the world and, on the other hand, by improving the promotion and interaction with the contents of a future exhibition.

Keywords: Cuneiform Tablet · Geometric Feature · Detailed Representations · USB Microscope · Digital Legacy

1 Introduction

Although digital documentation techniques are well-defined for architectural sizes, small items provide a complex challenge owing to the level of detail and accuracy required. Only some research fields specialized in high-precision metrological applications, such as mechanical and medical [1], are nowadays achieving highly performing results [2] in the three-dimensional reconstruction of very small objects, usually under 5 cm and

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with sub-millimetric characteristics. Unfortunately, due to the prices, generally high, of hardware and software as well as the level of expertise expected by operators [3], these techniques for very accurate micrometric surveys usually are out of the price range of the majority of museums and cultural organizations[1]. As a result, the current market's need for affordable and effective solutions drives attention toward less expensive alternatives, such as image-based technologies for accurately digitizing even the smallest artefacts.

Without the support of mechanical automation, photogrammetric solutions could be repetitive and time-consuming [4]. In addition, photogrammetry still requires in-depth knowledge of photography along with issues specific to macro photography, most notably the narrow depth of field. Although there is a benefit to digital micro-surveying procedures based on passive sensors: they are flexible and open to novel technology experimentations and applications. Therefore, based on previous experiments conducted by the authors [5, 6], an attempt was made to implement the photogrammetric acquisition workflow by employing the images obtained with Dino-Lite USB digital microscopes as a data set for photogrammetric processing. The results have shown a non-negligible potential for modelling small objects, especially when compared to much more expensive instruments, highlighting greater flexibility due to the small size and weight of the hardware and its ease of use due to simplified photo controls. It consequently appeared promising to incorporate these tools into a structured photogrammetric workflow, keeping in mind that their principal disadvantage is that they were not initially intended for photogrammetric applications.

The authors chose a highly complex case study, i.e., a cuneiform tablet (LW21.CUN.126) ascribable to the Third Dynasty of Ur (2112-2004 B.C.), coming from ancient Mesopotamia (modern Iraq), and nowadays belonging to the collection of Ghent University (Belgium) (see Fig. 1). Cuneiform tablets are among the oldest written artifacts of humankind (the very first exemplars date back to 3300 B.C.). Ancient scribes realized the tablets in clay and conveyed information on them by impressing with a stylus wedge-shaped signs, giving rise to the so-called cuneiform script, a writing system that lasted for more than three millennia. The current study focuses on tablet LW21.CUN.126 but intends to establish a standard methodology repeatable for this type of artefact, capable of satisfying the aims and requirements of the related assyriological research. In this direction, a low-cost setup based on a USB microscope and customized for macro-photogrammetric acquisitions (see Fig. 2 and deep descriptions in Sect. 2) is used for the cuneiform tablet digitalization.

Special requirements that limit common problems associated with an uneven form, degradation from environmental causes, low-contrast areas, and discoloration are needed

[1] The most expensive systems, direct competitors of micro-photogrammetry nowadays, are structured light scanners. Among the best-performing ones currently available on the market, there are desktop scanners that achieve accuracies of 0.01 mm, resolution down to 0.03 mm, color acquisition, and marker-less registration. The cost is around €30,000 (e.g., artec3d.com/it/portable-3d-scanners/artec-micro). Whereas with slightly lower performance, the average cost can be around €10,000 (e.g., einscan.com/handheld-3d-scanner/einscan-pro-hd/). However, one also comes across low-cost scanners, i.e., from €500, which are naturally designed for non-professional applications, with correspondingly much lower accuracy and resolution and mostly for educational and/or amateur use, and which do not perform well enough for micro-metrological applications (e.g. it.shop.revopoint3d).

Fig. 1. Clay cuneiform tablet LW21.CUN.126, recto.

Fig. 2. A turntable- and clamp-based acquisition system with ring illumination that supports integrated LED lighting for the microscope. The USB microscope is fixed on a plastic microphone holder customized to be set to a plate with several flexible hooks.

to ensure acceptable readability of every portion of the artefact despite the high reproduction ratio. After fully reconstructing the individual tablet geometry, the focus was directed on studying some particularly significant wedges, using higher magnifications of the digital microscope. Indeed, the three-dimensional modelling of the single wedge geometry makes it possible to identify certain characteristic features for defining the specific shape of the signs.

The objective is to generate a digital replica that is always consultable, 3D explorable and geometrically accurate. The possible applications of the digital reconstructions of the cuneiform tablet are truly manifold. Digital visualization aims to provide experts with a way to read tablets without actually holding one in their hands, enabling virtual manipulation of these delicate artefacts and offering additional details on artefacts that conventional documentary methods did not allow [7]. Furthermore, digital models can be used to experiment with machine learning and artificial intelligence applications for the automatic recognition of characters and wedges impressed on the clay [8, 9].

In addition, a precise digital model facilitates communication for further examination and comparison, enabling interdisciplinary research among various experts. For example, the creation of digital libraries also would provide a unique opportunity for the multitude of artefacts buried in museum warehouses or simply unpublished for some reason. A potential installation, distribution, and promotion of 3D models of cuneiform tablets would be of significant interest and facilitate the display and exhibition of these artefacts, particularly remotely in the form of virtual museums. It is intended to implement virtual communication with the public and the visualization of archaeological artefacts, which are among the main objectives of several European projects that have been launched in recent years in the field of cultural heritage management [10].

Finally, from a broader perspective, the representations carried out in this study can be an inspiration for exhibition designers and artists who work with scales of detail and who, for an investment of a few hundred euros, can capture, show, share and promote details of their works that would be difficult to observe with the naked eye.

2 Materials and Methods

USB digital microscopes were initially developed for inspection, documentation, and digital metrology analysis. They are already widely used in the medical field and in the manufacturing industry for quality control. Nevertheless, employing these instruments for the photogrammetric surveys makes it possible to obtain 3D models even a tenth of a millimeter in precision [11]. In fact, due to their tiny size and form, they can tilt, allowing pictures to be taken with the proper intersection angles to the object for the creation of three-dimensional models by established SfM processes. These instruments can be considered optical inspection devices [12] that are made to obtain an image and display it on a screen, optionally using specialized software.

The USB microscope used for this research activity is the Dino-Lite AM7013MZT model, characterized by a 5.0 MP CMOS sensor (2592 × 1944 pixel). The following Table 1 summarizes the technical specifications of the employed microscope in the function of the declared magnification achievable [13].

Digital magnification[2] values of 20× were used for reconstructing the entire geometry of the tablets (see Fig. 3).

Table 1. Working Distance (WD), Field Of View (FOV) dimensions related to the Magnification rate (M) expressed in millimeters for Dino-Lite AM7013MZT microscope.

M	WD	X_{FOV}	Y_{FOV}
20	48.7	19.8	14.9
30	21.7	13.2	9.9
40	9.0	9.9	7.4
50	1.9	7.9	5.9
60	−2.3	6.6	5.0
220	−0.1	1.8	1.4
230	1.0	1.7	1.3
240	2.1	1.7	1.2

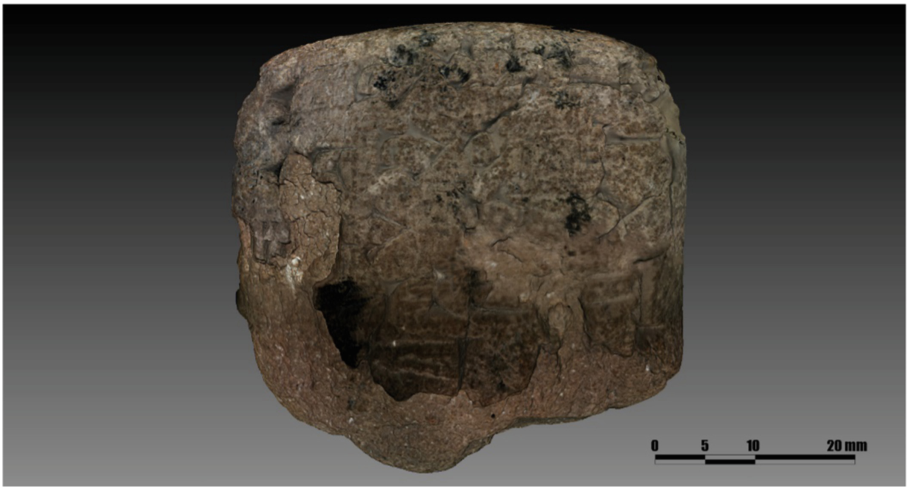

Fig. 3. Clay cuneiform tablet LW21.CUN.126, recto of the texturized digital model.

In contrast, values of 40× were used for individual wedges. The relative spatial resolution in order to quantify the less visible details, i.e., Ground Sampling Distance (GSD), measures respectively 7.64 μm/px and 3.82 μm/px.

[2] It is noteworthy to point out that the reported magnification for Dino-Lite USB microscopes includes digital magnification forms. As the manufacturer advises, it is frequently more beneficial to compare the field of view in this instance rather than the magnification, that is, to compare the actual dimensions of the original object being enlarged to the final size of the object on the display.

Before beginning the photogrammetric image processing, the first estimation of the interior orientation parameters is supplied (data configured based on the calibration results), because this information cannot be automatically inferred from the EXIF, as metadata are not present in the raster data file for these microscopes.

Due to the minimal Field Of View, the requirement to incorporate metric references or calibrated items in the scene to scale the model is one of the key issues at high magnification. Even after overcoming this obstacle, it is still challenging to build a calibration pattern appropriate for the size of the measured item [14]. The problem was overcome by designing an adhesive pattern of coded targets introduced into the scene, ensuring it was fixed on a flat rigid support and could be correctly focused. Each target pattern has a diameter proportional to the area framed related to a chosen magnification so that it can be photographed in several contiguous images and subsequently automatically recognized by the photogrammetric software.

Optimized camera calibration is achieved by using the pattern as a grid of constraint points (GCPs) spread uniformly over the framed region. In order to avoid invalidating the process with unquantifiable uncertainties associated with the pattern printing process, the operator might import the coordinates of each target into the photogrammetric project just to scale the model.

The problem of the shallow Depth Of Field was addressed by focusing the object in different planes, similar to the well-known manual Focus Stacking technique [15]. The dense point cloud generated by SfM is subjected to the following specific criteria filtering of the sparse cloud points noise generated by the blurred areas: (i) Reconstruction uncertainty; (ii) Reprojection error; (iii) Projection accuracy.

The microscope incorporates an integrated adjustable polarizer to lessen reflections at very close-range acquisition distances. However, installing an illumination ring [16] has improved the lighting condition at the image borders, avoiding the typical light decrease at the edges of the frame.

In order to orient the object knife-edge relative to the microscope camera, the acquisition geometry included a screw clamp frequently used in model-making. The clamp is mounted on a rotating base, taking care to align the center of rotation with the mounting axis of the object. Despite the limited Depth Of Field, this arrangement enables adequate sharpness of the tablet surface and the markers, as well as simultaneous capturing of the tablet front and back. With this configuration, an average of 1.000 photos are taken per tablet to acquire the whole volume, taking about two hours for each artefact. Data processing took an average of 3–4 h, often motivated by the tablet's very homogeneous texture, which makes recognizing homologous points between images more difficult. Acquiring the individual wedges was a much faster operation, considering 10–15 shots per wedge and a processing time of 10 min for each. At the end of the acquisition campaign, both complete and detailed models for each tablet are obtained.

3 Experimental Results and Discussion

The model of the entire tablet volume was entirely reconstructed with high definition (see Fig. 4), i.e., a GSD equal to 0.0076 mm/px. The resulting mesh can be oriented and zoomed as well as subjected to grazing lighting to highlight the wedges in a more contrasted manner.

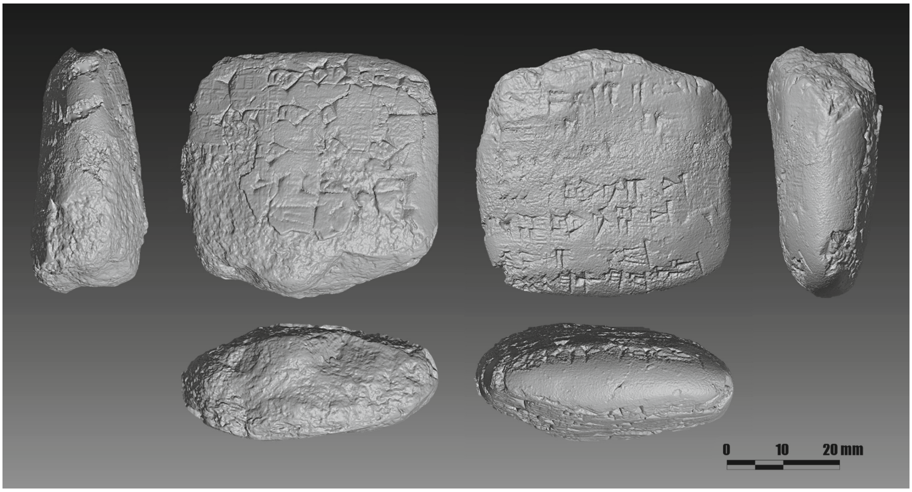

Fig. 4. Clay cuneiform tablet LW21.CUN.126, digital model mesh surface.

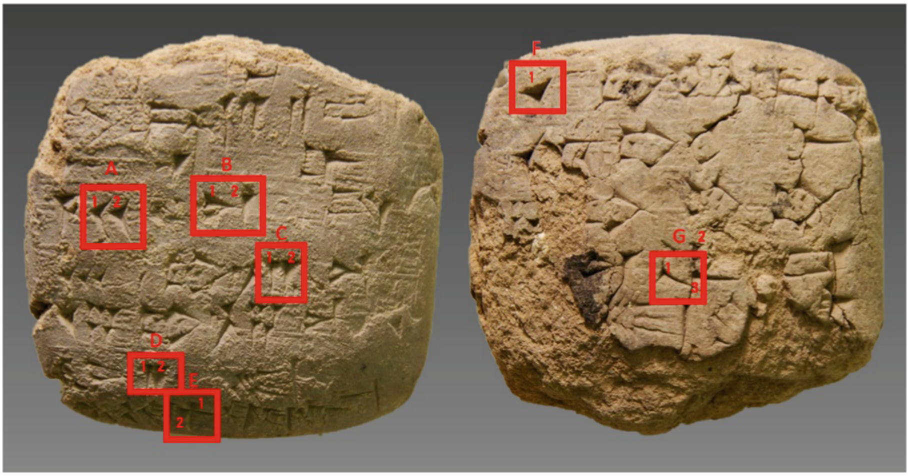

Fig. 5. Identification of the wedge locations on the recto (right) and verso (left) of the tablet LW21.CUN.126.

In order to extract key features for the single impressions of the stylus, the wedge was considered to be formed by the union of three triangular surfaces sharing a vertex, generating three impluviums (grooves) that match the stylus footprint (see Fig. 5).

Two approaches were followed for the identification of the geometrical features: the first involved identifying the faces of the wedge by employing a plane that fits the mesh surface; the second involved identifying the edges of the wedge impression by automatic contour recognition of the mesh ridges.

Concerning the first approach, the triangular mesh of the area over which each wedge insists was imported into the Artec Studio 16 software environment. As a first step, a manual selection was necessary in order to define the surface of the wedge of interest only in the larger region imported. A plane is formed for each wedge face by a primitive construction based on a fitting on the polygonal mesh selected. The planes were then imported into the CAD environment for angle measurements between planes (see Fig. 6). This process was repeated five times for each wedge to strengthen the estimation; the average results are reported in Table 2.

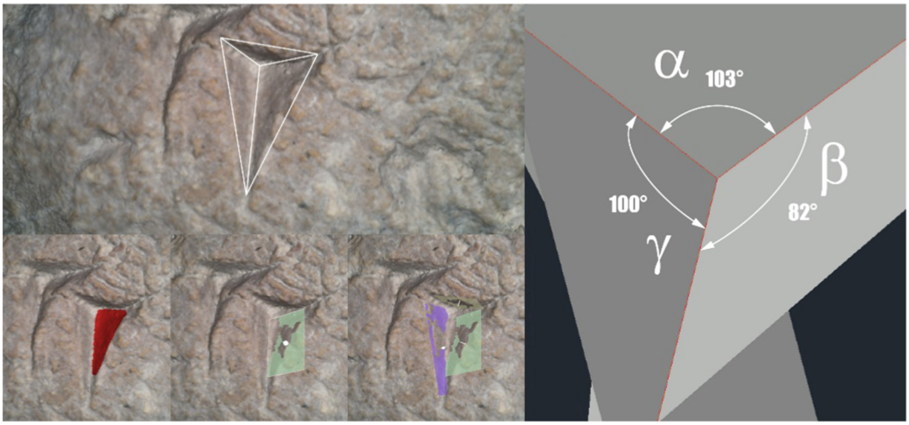

Fig. 6. Wedge identification, faces selection and planes of the model (on the left). Subsequent export for the measurement of dihedral angles (on the right). A2 wedge is represented.

Table 2. The estimated average value of the angles between the wedge planes obtained by Artec Studio 16 fitting algorithm for 14 wedges of tablet LW21.CUN.126.

	α	β	γ
A1	97°	104°	96°
A2	105°	83°	96°
B1	79°	105°	105°
B2	73°	101°	101°
C1	106°	85°	104°
C2	98°	93°	98°
D1	93°	96°	101°
D2	103°	98°	95°
E1	90°	102°	96°
E2	93°	97°	106°
F1	89°	87°	94°

(*continued*)

Table 2. (*continued*)

	α	β	γ
G1	83°	101°	79°
G2	63°	94°	93°
G3	82°	86°	83°

It can be observed that mean of the measurements for each angle ($\alpha = 90°$, $\beta = 95°$ and $\gamma = 96°$) shows that the stylus is characterized by dihedral angles tending to be right angles. The deviation is, on average, 9°.

These wedge features are consistent with the shape of the reed stylus proposed by Messerschmidt [17]. Indeed, reed fibrous impressions can be observed on the left-hand face of the wedges both on the original tablet and on the 3D models.

The second detection method was performed in the Geomagic software environment. After noise reduction filtering, the software automatically allows the recognition and contours of the region of maximum curvature extraction. A contour recognition check was performed on the automatic line generation to optimize inconsistencies.

Then a model is produced (i.e., a template model) to define the line of the primary wedge geometry. The template is exported as an IGES model and imported into the CAD environment for edge line generation (see Fig. 7). The observations from this latest analysis show slightly larger angles. Unfortunately, comparing the two methods does not deliver sufficient consistency in the results.

Nevertheless, the former method seems more accurate than the latter because the irregularity of the impluvium does not allow an exact reference for the precise measurement of angles. The limited number of observations and several factors, such as model noise due to instrumental limitations and deformations due to the proximity of other wedges, are among the most uncertainty-generating factors [18].

In addition, possible variations of the stylus writing trajectory [19] can lead to a wedge with angles that do not correspond to those of the stylus, with non-negligible geometric consequences between wedge and wedge that further complicate the reconstruction and recognition of a given stylus.

These variables will be taken into account for future analyses, which will include a larger sample, different tablets, and other software (e.g., Cuneiform Analyzer) for the extraction and analysis of the cuneiform wedges [20–22].

However, what becomes evident is that contemporary digitizing and computing systems provide the basis for a novel method for studying the cuneiform script, enabling structured investigations and wedge layouts in relation to specific quantities for the development of more accurate paradigms.

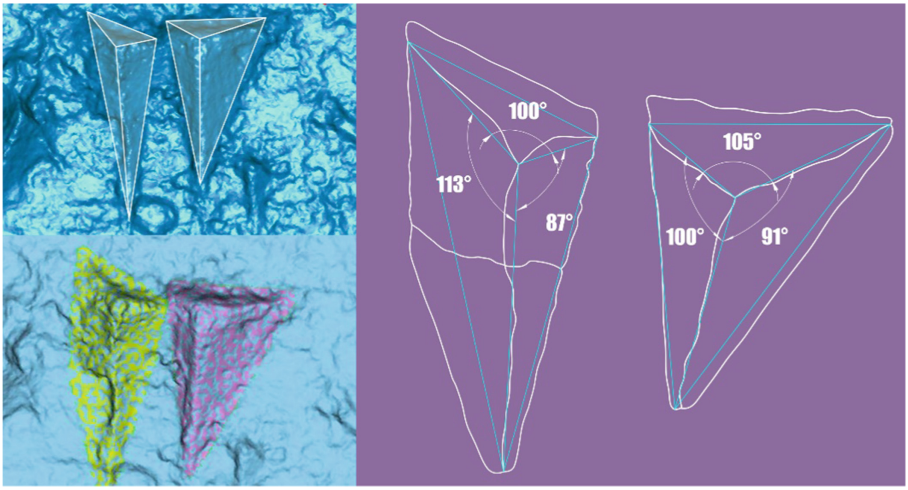

Fig. 7. Wedge identification and contour extraction of the main geometry from the mesh model (on the left). Subsequent measurements of dihedral angles (on the right). C1 and C2 wedges are represented.

4 Conclusions

The study proposes a method for identifying key features on cuneiform tablets from three-dimensional models generated with low-cost USB microscopes. The aim is both to reconstruct the complete geometry of a complicated micro-engraved object and to propose a classification not only on the legibility of the entire volume but also on the individual signs, possibly including the exact shape of the impression tools used for the wedges. It is shown that the question remains open as to whether the level of accuracy achieved does not allow experts to distinguish the distinctive handwriting of the scribe or the shape of a particular stylus. Anyway, this first approach reveals the need to conduct the survey with more accurate instrumentation for wedge analysis and a comparison between different tablets. In this sense, future research will be oriented to analyze a larger sample and extrapolate data with smaller uncertainties.

An expeditious approach nevertheless proves satisfactory for a reconstruction of the general geometry of the tablets and a formulation of an applicative methodology. An aim that starts from archaeological necessity but which has repercussions on the artistic value of these artefacts and emphasizes their complexity, making their representation clearer and more attractive to an audience not only of technicians. Presenting artefacts to the public through the display of three-dimensional models is a challenge for many. However, improving the documentation of artefacts preserved and displayed to visitors is possible even for complex objects. Digitalization constitutes the prerequisite for Virtual Reality and Augmented Reality applications, video animations, games and generally all activities that benefit from the digital reproduction of detailed artifact for both technical and artistic filed.

References

1. Gallo, A., Muzzupappa, M., Bruno, F.: 3D reconstruction of small sized objects from a sequence of multi-focused images. J. Cult. Herit. **15**(2), 173–182 (2014)
2. Hansen, H.N., Carneiro, K., Haitjemac, H., De Chiffrea, L.: Dimensional micro and nano metrology. CIRP Ann. **55**(2), 721–743 (2006)
3. Caine, M., Magen, M.: Low cost heritage imaging techniques compared. In: EVA-Electronic Visualisation and the Arts, pp. 430–743. BCS Learning and Development Ltd., London (2017)
4. Collins, T., Woolley, S.I., Gehlken, E., Ch'ng, E.: Automated low-cost photogrammetric acquisition of 3D models from small form-factor artefacts. Electronics **8**(12), 1441–1458 (2019)
5. Antinozzi, S., Fiorillo, F.: Optimized configurations for micro-photogrammetric surveying adaptable to macro optics and digital microscope. ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLVI-2/W1-2022**, 25–32 (2022)
6. Antinozzi, S., Fiorillo, F., Surdi, M.: Cuneiform tablets micro-surveying in an optimized photogrammetric configuration. Heritage **5**, 3133–3164 (2022)
7. Cohen, J., et al.: iClay: digitizing cuneiform. In: Chrysanthou, Y., Cain, K., Silberman, N., Niccolucci, F. (eds.) The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST, pp. 135–143. The Eurographics Association (2004)
8. Bogacz, B., Mara, H.: Digital assyriology—Advances in visual cuneiform analysis. J. Comput. Cult. Herit. **15**, 1–22 (2022)
9. Homburg, T., Zwick, R., Mara, H., Bruhn, K.-C.: Annotated 3D-models of cuneiform tablets. J. Open Archaeol. Data **10**, 1–8 (2022)
10. Official Website of the European Union. https://culture.ec.europa.eu/it/cultural-heritage/cultural-heritage-in-eu-policies/european-digital-heritage
11. Esmaeli, F., Ebadi, H.: Handy microscopic close-range videogrammetry. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLII-4/W4**, 65–67 (2017)
12. Mokobi, F.: Digital Microscope. https://www.academia.edu/42195781/Digital_Microscope
13. Dino-Lite. https://www.dino-lite.eu/it/component/eshop/am7013mzt?Itemid=0
14. Lavecchia, F., Guerra, M.G., Galatucci, L.M.: Performance verification of a photogrammetric scanning system. Int. J. Adv. Manuf. Technol. **96**(9), 4267–4279 (2018)
15. Clini, P., Frapiccini, N., Mengoni, M., Nespeca, R., Ruggeri, L.: SFM technique and focus stacking for digital documentation of archaeological artifacts. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLI-B5**, 229–236 (2016)
16. Antinozzi, S., Fiorillo, F.: Optimized configurations for micro-photogrammetric surveying adaptable to macro optics and digital microscope. ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLVI-2/W1**, 25–32 (2022)
17. Messerschmidt, L.: Zur Technik des Tontafel-Schreibens. Orientalistische Literaturzeitung **9**, 185–196, 304–312, 372–380 (1906)
18. Richardson, A., Smilansky, U.: Geometrical feature extraction for cuneiforms. In: Schaub, T., et al. (eds.) ECAI 2014 - 21st European Conference on Artificial Intelligence, pp. 1173–1178. IOS Press, Amsterdam (2014)
19. Cammarosano, M. The cuneiform stylus. Mesopotamia **XLIX**, 53–90 (2014)
20. Fisseler, D., Weichert, F., Müller, G. G.W., Cammarosano, M.: Towards an interactive and automated script feature analysis of 3D scanned cuneiform tablets. Sci. Comput. Cult. Herit. 1–10 (2013)
21. Cammarosano, M., Müller, G.G.W., Fisseler, D., Weichert, F.: Schriftmetrologie des Keils: Dreidimensionale Analyse von Keileindrücken und Handschriften. Die Welt des Orients 2–36 (2014)
22. Cuneiform Analyser. http://www.cuneiform.de