The Uniformity of Wheel Produced Pottery Deduced from 3D Image Processing and Scanning[1)]

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Abstract:
Every archaeological excavation is confronted with a vast number of ceramic fragments. The documentation, administration and scientific processing of these fragments presents a temporal, personnel and financial problem. Scientific evaluation in archaeological practice often suffers due to extensive amounts of time required for the documentation and administration of ceramic finds. Classification and reconstruction of ancient pots and vessels out of fragments (so-called sherds) is an important aspect of archaeological research work. Up to now archaeological documentation has been done by hand which means a lot of routine work for archaeologists and a very inconsistent representation of the real object. There may be errors in the measuring process, hence grouping or classifying is a very difficult task based on inconsistent data. The profile section (which is a section of the fragment in the direction of the rotational axis) is the basis for traditional as well as automatic classification since this representation provides all shape features for discriminating different classes. This paper shows a profile based, classification method which serves as an objective and quantitative tool for typological studies of ceramics. Correlation based profile comparison results of test jars are shown and discussed.

1 Introduction

Accurate 3D scanning devices, together with sophisticated image processing and 3D reconstruction methods are now being developed to overcome some of the most severe obstacles in the study of archaeological ceramics [2, 4, 8, 7, 6, 10, 9]. These methods are mainly developed to render the documentation of ceramics efficient, accurate and complete. They enable, however, to get answers to questions of archaeological interest which were hitherto not accessible. This contribution aims to illustrate this new potential.

Traditionally, wheel produced ceramics (complete or fragmented) are represented by their contour which until very recently was drawn manually. This time consuming, and often inaccurate documentation has other severe limitations: the determination of the true axis of symmetry (especially when the vessel is not perfectly symmetric) is far from being accurate. The single drawn profile, does not provide any information on the

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variability within the vessel which is due to technological imperfections in the forming or firing stages of its production.

The use of 3D-scanners to acquire accurate representation of sherds overcome the above mentioned problems. The best fitting axis of rotation can be determined from the 3D data and many profile lines can be extracted [8], using sections through the best symmetry axis. The large number of profiles [7] enables us to study in the present paper the uniformity of the vessel, by performing a correlation analysis based on the curvature function of each profile [1]. The correlation analysis provides a quantitative measure for the vessel uniformity, which have direct bearing on the production technology and its development in the antiquity.

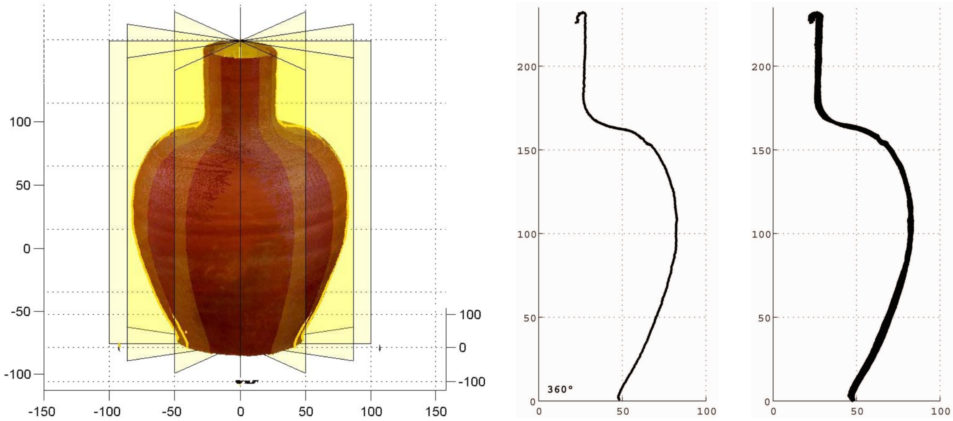
The next section explains the types of objects used for our experiments and the acquisition (Section 2) of the 3D- data in order to estimate (Section 3) the uniformity (Section 4). Finally the results are presented in Section 5 and a conclusion with an outlook for future enhancement (Section 6) is given.

2 Data Acquisition and Processing

To demonstrate our method, modern (but traditionally produced) jugs (Figure 1) were scanned using a Minolta VI-900 3D-Scanner. 57 profiles from the left jug and 38 profiles from the right jug were computed. If not otherwise mentioned all results and figures refer to these two pots. For testing our system we used also a set of 5 machine made pots, 11+2 modern pots manufactured in a traditional way on a rotational plate with a kicked wheel. The two of these 13 pots are shown in Figure 1. We also used 16 bowls from the excavation in Tel Dor [3].

Figure 1: Two similar jugs which were used in the computation of the correlations.

In our system, the profile sections are extracted automatically by a 3D-measurement system based on structured (coded) light technique: The object to be studied is projected by a well defined light pattern, and is photographed by a camera. The image, together with the knowledge about the pattern and its relative position to the camera are used to compute the coordinates of points belonging to the surface of the object [4]. The axis of rotation of the sherd can be found as the intersection of the normal vectors to the surface [10]. The intersections of the fragment with planes through the symmetry axis (see Figure 2a) give the cross-sections of the sherd (see Figure 2b,c). They form the data-base for the subsequent analysis.

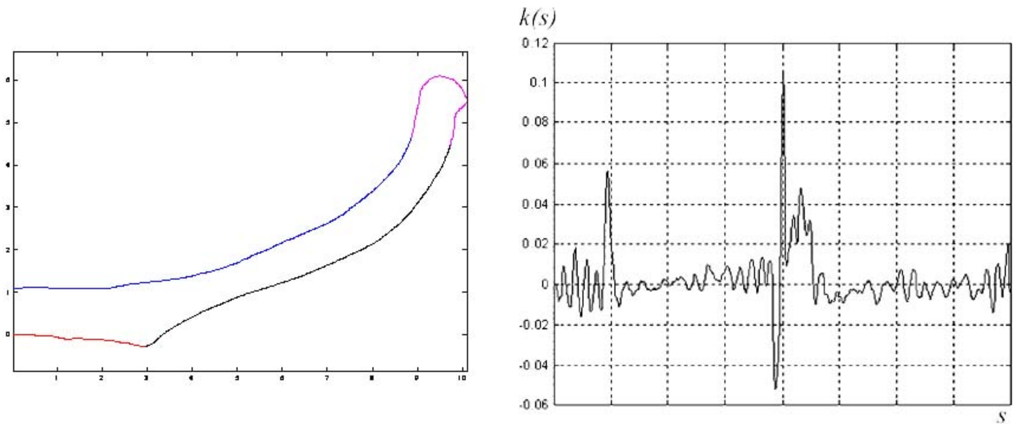


(a) (b) (c)

Figure 2: (a) Oriented object (dark gray), with the rotational axis identical to the z-axis intersecting planes (light gray), (b) A single extracted profile line at 360°, (c) All extracted profile lines from objects in (a).

3 Curvature

The need for an objective and fast way for comparing and sorting ceramic sherds has become a fundamental task for archaeologists. Lately, a new method has been suggested for this purpose [1]. It is based on the principle that one may consider the profiles' cross-sections as curves in the plane which are represented by their curvature given as a function of the arc length. This function has several characteristics, which are advantageous for pottery analysis [1]. Figure 3 demonstrates a profile of a bowl and its corresponding curvature function.



(a) (b)

Figure 3: (a) Profile line of one the data-sets from the iron age pots. (b) Curvature function of the Profile line.

The curve and its curvature function are in one to one relation, each can be uniquely and accurately reconstructed from the other. This means, that one variable describes the two-dimensional curve without any loss of information. Moreover, the curvature emphasizes features, which are important for the archaeological typology and classification (e.g. rims, corners, bases) [1]. For instance: in Figure 3b the most prominent features of the curvature function are along the rim area and the corner of the base. These features will have high effect on the correlation value.

4 Correlation

The correlation between two profiles is defined in terms of the scalar product of their corresponding curvature functions. For profiles with normalized arc-lengths the correlation between their curvature functions $k_1(s), k_2(s)$ is given by the equation 1.

$$C(k_1, k_2) = \frac{\int k_1(s)k_2(s)\delta s}{\sqrt{\int [k_1(s)]^2 \delta s}\sqrt{\int [k_2(s)]^2 \delta s}} \tag{1}$$

Notice that $-1 \leq C(k_1, k_2) \leq 1$ and it gets the highest value if and only if $k_1 = k_2$. This definition enables us to compute the correlations matrix of many profiles from the same vessel and also to compare different vessels. Statistical analysis of the correlation matrix (e.g. mean, standard deviation, etc.) yields the quantitative measures of the uniformity of the vessel. Such an analysis is justified only when a large number of accurately measured profile lines is available, which is the case with the data-base provided by the 3D scanning technique used here.

The profiles are ordered by the increasing angle of the corresponding sections. Correlations between all the possible pairs of profiles form the correlation matrix which is shown in Figure 4: The intra-jug correlations (main 57×57 and 38×38 squares on the diagonal) are substantially higher than the inter-jug correlations (57×38 off diagonal rectangles). The latter are not low in absolute terms, since the two jugs are very similar. The intra-jug correlation matrices are not uniform, but the correlation converges to 1 at the diagonal from top-left to bottom-right. This diagonal is the correlation of the profile with itself, which is always 1. This behavior, which is common to the two jugs, is summarized in Figure 5. The mean correlation of profiles from the same angle (which means the same profile photographed from different views) is higher then 0.9. On the other hand, the mean correlation between opposite profiles, with $180°$ distance, is near 0.6.

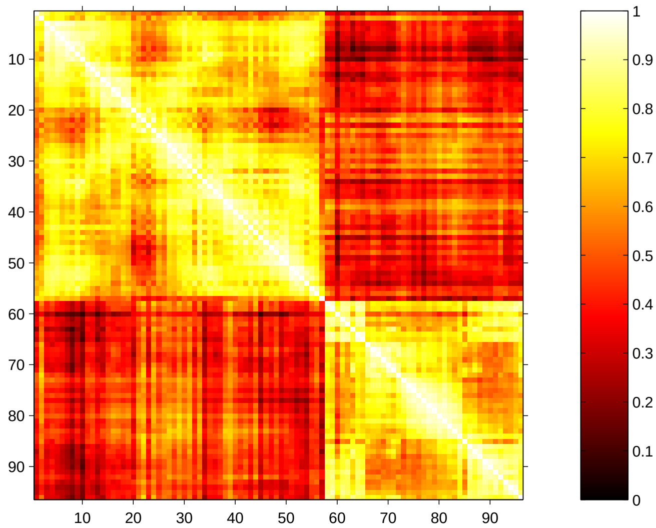


Figure 4: The correlation matrix between the profile lines of the pots in Figure 1. The x- and y-axis shows the number of the profiles, which are sorted by angle of extraction. The color-bar shows the correlation from 0 (un-correlated) to 1 (identical profiles).

So Figure 4 shows that the extra-jug correlation of profile lines has an average of 50% of the inner-jug correlation. In case this object would be broken and had to be reassembled the profile lines could be used to determine the affiliation of a fragment of the pot.

Figure 5: Another representation of the intra-jug correlation of a pot as a measurement for the uniformity is the correlation as function of the angular distance. The correlation steadily decreased for both pots by angular distance $0°$ from 1 to 0.6 at the angular distance $180°$, which is the profile line at the opposite side of the pot.

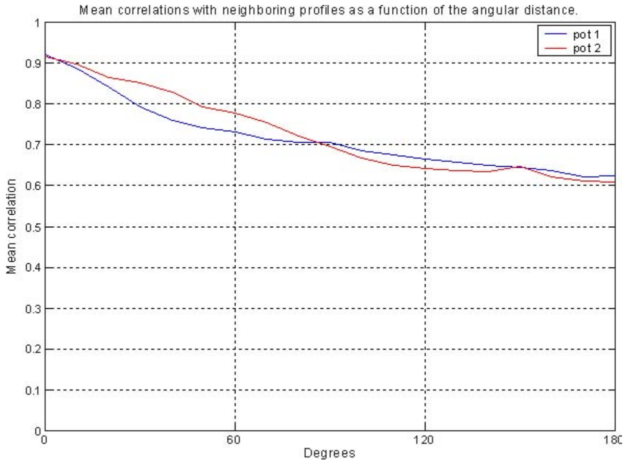


Figure 5: The mean correlation between profiles as a function of the angular distance between them.

Furthermore we also estimated the correlation between the pot itself with a second set of 3D Data to estimate the influence of the error from the 3D scanner. The correlation between two different scans was significant (30%) higher than between these two nearly identical pots.

5 Results

As mentioned earlier this kind of high-resolution pottery analysis may lead to new directions of investigation in which we understand better ancient technology and its development. Several analysis can be made based on the correlation matrix. The correlation can be used by archaeologists as measure for the precision of the manufacturing process. The correlation between profile lines can be used for matching of fragmented objects, which have the same shape.

Regarding [5] the segmentation of profile lines splits the profile and therefore the vessel into its primitives (e.g. cone, cylinder, sphere). So we used the global maxima of the curvature function to segment the profile-line. These segments of the profile line were analysed in the same way as the complete profile line. The result is shown in Figure 5. This figure shows the separated upper and lower part of the pot and the correlation matrix of these parts, which was estimated in the same way as show in Section 4.

So the intra-jug correlation-matrix of the lower profiles have a higher intra- jug correlation than the upper profiles. One of the upper profiles has also a low intra-jug correlation. Also the extra-jug correlation is lower for the upper profiles. We can show only with the results from the curvature analysis that the pot has been made from two different parts, which have been produced with different quality requirements. We have also

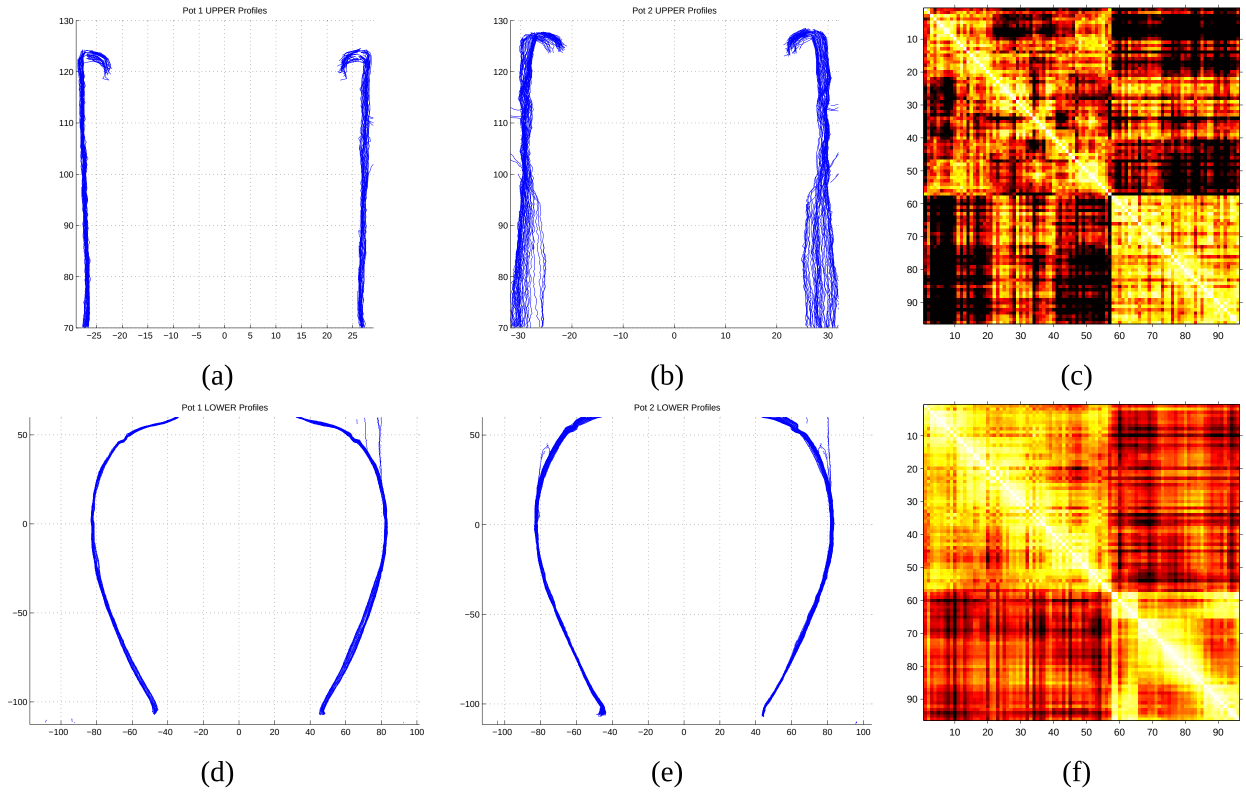


Figure 6: (c) Correlation matrix for the split profile lines for the upper parts (a,b) and (f) the correlation matrix for the lower parts (d,e) of the pots from Figure 1.

estimated the rotational axis for the upper and lower parts and the standard deviation of the diameters along the rotational axis. We could determine that the axis of the upper part is tilted by $10°$ and $6°$. The rotation axes of the two separated parts were neither parallel nor centered together and the deviation of the diameter was twice the deviation of the lower parts. This result corresponds to the manufacturing process, which is know for the modern pots.

We know that the bodies and the cylindrical necks of the jugs were treated separately. So that the non-uniformity is due to the clumsy way by which the well-produced bodies and the average-produce necks were connected together. Even though these changes were rather small, their influence on the correlation values was large.

Using the curvature function we could also estimate a common prototype for the 16 bowls of *Tel Dor*, which is required by archaeologists for comparison of trading relations between two ancient cities [1].

6 Conclusion

We can conclude that computerized typology and classification, meets archaeological requirements, and provides an objective, sensitive and quantitative tool for typological studies of ceramics. The main source of error; classification information derived from hand-drawn profiles, whose accuracy cannot be assessed; was eliminated by using 3D scanning camera, computing the best estimate for the axis of revolution of archaeological sherds and extracting a large number of profiles. The correlations between the extracted profiles enables the determination of the degree of non uniformity of the objects and their parts. Therefore this correlation method may also reveal unnoticed attributes and correlations in archaeological classification, offering new insights for subsequent archaeological studies, which can have impacts such as the identification of workshops, trends in technological developments and skills. The final ceramic documentation and reconstruction system is currently under development to be integrated in virtual excavation reconstruction projects and on a larger test set taken from excavation sites in Israel.

References

[1] I. Sharon A. Gilboa, A. Karasik and U. Smilansky. Towards computerized typology and classification of ceramics. *Journal of Archaeological Science*, 31:681–694, 2001.

[2] K. Adler, M. Kampel, R. Kastler, M. Penz, R. Sablatnig, K. Schindler, and S. Tosovic. Computer aided classification of ceramics - achievements and problems. In *Proc. of 6th Intl. Workshop on Archaeology and Computers*, Nov 2001.

[3] A. Gilboa. *Southern Phoenicia during Iron Age IIa in the light of the Tel Dor excavations. Ph.D. thesis*. The Hebrew University, Jerusalem, 2001.

[4] M. Kampel and R. Sablatnig. On 3d Modelling of Archaeological Sherds. In *Proceedings of International Workshop on Synthetic-Natural Hybrid Coding and Three Dimensional Imaging, Santorini, Greece*, pages 95–98, 1999.

[5] Martin Kampel, Robert Sablatnig, and Hubert Mara. Profile segmentation scheme for automated classification of archaeological sherds. In M. Doerr and A. Sarris, editors, *The Digital Heritage of Archaeology: Computer Applications and Quantitative Methods in Archaeology Conference, Proc. of CAA2002, Heraklion, Crete*, pages 275–280. Hellenic Ministry of Culture, 2002.

[6] U. Leute. *Archaeometry: An Introduction to Physical Methods in Archaeology and the History of Art*. John Wiley & Sons, December 1987.

[7] H. Mara, M. Kampel, and R. Sablatnig. Preprocessing of 3D-Data for Classification of Archaelogical Fragments in an Automated System. In F. Leberl and F. Frauendorfer, editors, *26th Workshop of the Austrian Association for Pattern Recognition (OeAGM/AAPR)*, pages 257–264, Graz, Austria, September 2002.

[8] C. Orton, P. Tyers, and A. Vince. *Pottery in Archaeology*, 1993.

[9] Rice P.M. *Pottery Analysis: A Sourcebook*, 1987.

[10] S. Ben Yacoub and C. Menard. Robust Axis Determination for Rotational Symmetric Objects out of Range data. In W. Burger and M. Burge, editors, *21 th Workshop of the Oeagm*, pages 197–202, Hallstatt, Austria, May 1997.