# A complete, automatic procedure for pottery documentation and analysis

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# A Complete, Automatic Procedure for Pottery Documentation and Analysis

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## Abstract

The Computerized Archaeological Laboratory, at the Hebrew University of Jerusalem started to operate on January 1st 2010. Its purpose is to harness mathematical and computational methods to support archaeological research, documentation and visualization. The laboratory is equipped with modern, high precision scanners which provide digital three dimensional models of archaeological finds. We concentrated on ceramic and lithic artifacts, and developed several tools and algorithms which are used routinely as the standard procedure for their analysis and publications. The current paper summarizes the main novel features which are relevant to *ceramics*: 1) Efficient, high precision data acquisition using 3D scanners. 2) A stable and reliable algorithm which automatically finds the symmetry axis of pottery fragments. 3) A user friendly interface which creates print quality drawings of the objects. 4) A new procedure for automatic typology and classification of ceramic assemblages, which is based on mathematical representations of the cross-section profiles.

These four steps of documentation and analysis are now the routine tasks in the lab. So far we have successfully tested the procedure for more than 10,000 fragments from a large variety of archaeological excavations.

## 1. Introduction

One of the most time consuming yet unavoidable tasks in Archaeology is the study of ceramic potsherds. These finds provide a considerable part of the archaeological information, and yet, it is exactly the abundance of the potsherds, which obstructs their detailed analysis. When the original vessels are axially symmetric, the potsherds can be completely characterized by their profiles. Extraction of the profile thus becomes the unavoidable first step in the analysis. Traditional methods for studying pottery, based on the slow and often inaccurate manual drawings, simply cannot handle the volume of information within reasonable time and cost [1, 2: 89-93, 3, 4].

In the last decades, an increasing number of archaeological groups in the world have acquired 3D scanners, and used them for pottery documentation and research [5-13]. Some have also developed algorithms designed for automatic extraction of useful information from the 3D models, ranging from discrete metric measurements to the entire cross-section profiles of the fragments [5, 13-16]. The next step was to establish classifications based on the extracted measurements [5, 17], or even using computer-learning techniques [13, 15]. However, these studies mainly focused on the analysis of complete vessels. Pottery fragments, which are the major bulk of ceramic finds, were treated less frequently. In this paper we shall describe the main insights which were gained by our experience of documenting and analyzing more than 10,000 pottery fragments.

## 2. An accelerated method for 3D scans of ceramics

We use a 3D scanner which is based on the principle of structured light projected on the object and recorded by two digital cameras. In order to have the full image of the object, one has to scan it several times from different directions and register the scans together into one model. This is conveniently done by placing the object on a turn table which is controlled by the software. Since most of the ceramic finds are small fragments we can position several items with minimal mutual obstruction in the relatively large sensitive volume of the scanner. This allows us to scan up to 8 fragments simultaneously, thus increasing the scanning efficiency by the same factor. In practice, the fragments are attached to a light metallic frame by clamps whose position in space can be adjusted (See Figure 1). The fragments are attached to the holders



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such that their rims are approximately parallel to the axis of rotation of the table, and their surfaces are perpendicular to the plane of the frame. It is clear that the upper and lower sides of the potsherds are badly exposed, and the clamps also show in the reconstructed surface. However, because of the way the fragments are attached to the frame, the eliminated portions of the potsherds consist mainly of the fracture surfaces. The rim and the bulk of the fragment surface are not affected. This is a price worth paying for achieving high scanning efficiency.

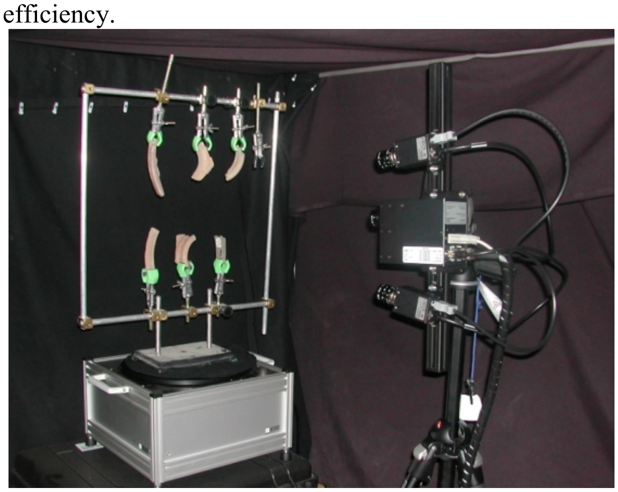

Figure 1: The scanning system (right) and a frame, with 6 fragments attached to it, standing on the rotation table.

The final 3D models are saved as '.wrl' files, which are the raw data for the following steps. The average volume of such a file is 1-2 Mb. The scanning is carried out by students who achieve after some training an efficiency of ~15 fragments per hour.

## 3. The automatic positioning procedure

The position of a potsherd is determined once the axis of symmetry of the original vessel is known. To define an axis uniquely one must specify two angles $\theta$ and $\varphi$ which determine the orientation of the axis (see Figure 2) and the anchor-point $\mathbf{b} = (b_x, b_y)$ in the (*x,y*) plane. The computer algorithm reorients and shifts the axis until a satisfactory positioning is determines.

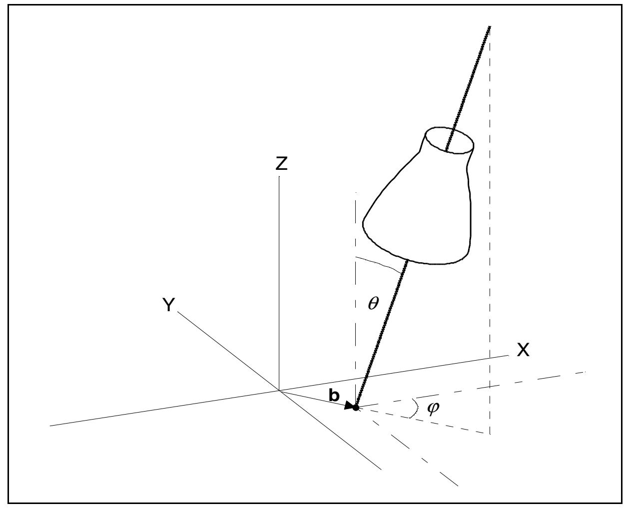


Figure 2: The parameters which define the axis position relative to the fixed reference frame [from: 16].

Our method of positioning emulates and generalizes the traditional method which is based on placing the rim on a planar plate such that the contact between the rim and the plate is maximal. The plate then defines the tangent plane which is parallel to the plane of the original potter's wheel. Any plane which is parallel to the tangent plane, intersects the fragment in two *concentric* arcs (or circles when the vessel is complete), and their common center lies on the axis of rotation. Thus, by cutting the 3D model at several parallel planes, the axis of rotation is identified as the line which goes through the centers of the concentric circles. Further details of the method are amply described in the original publication [16]. It is important to note here that the automatic search of the symmetry axis terminates when the intersection of the fragment with several planes which fan out from the axis overlap to the required accuracy. Figure 3 illustrates the fanning planes and the resulting profiles which perfectly match in this case. Figure 4 (top) shows a tilted fragment where the optimal axis provides profiles which do not match exactly. Our analysis and experience shows that for most non deformed fragments whose rim extends more than $13^0$ of the total circumference, the axis found by the algorithm provides accurately overlapping profiles and hence an accurate profile for the potsherds.

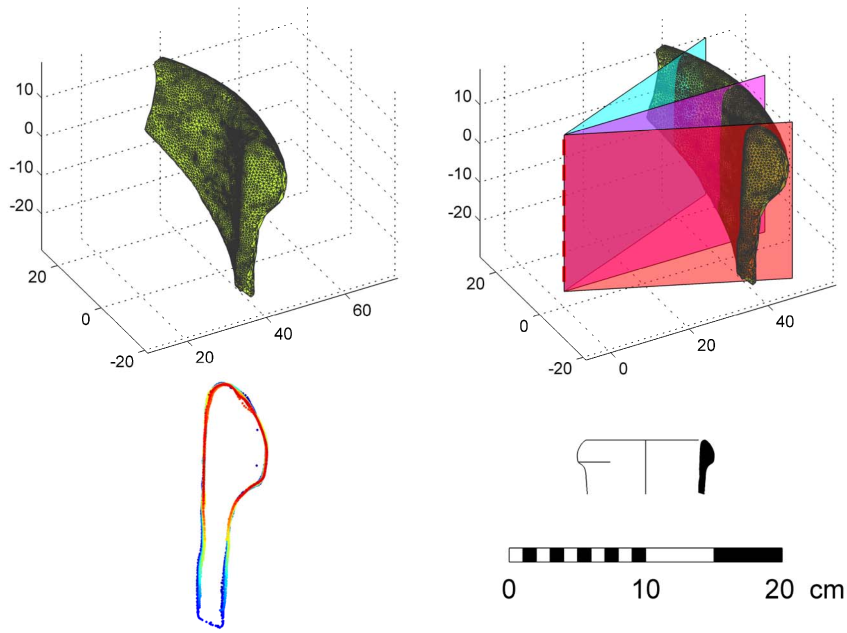


Figure 3: From a 3D model to a standard profile drawing. Top-left: The 3D model. Top-right: Computed symmetry axis for best position, and three fanning planes. Bottom left: The overlapping profiles - their perfect overlap proves the successful determination of the symmetry axis. Bottom right: Computerized conversion of the profile to a standard line drawing [from: 18].

## 4. Exporting print quality drawings for publications

The outputs of the former step are well positioned 3D models of ceramics. Thus, an accurate cross-section profile can be extracted by the computer. We have developed a computerized procedure which automatically extracts those profiles and produces print quality drawings according to the archaeological conventions. This procedure was further integrated within a user friendly interface that controls the quality and the accuracy of the final products (see Figure 4). Moreover, various parameters, such as line width, raster and other archaeological conventions can be modified to match the publication standards.

To emphasize the power of our method and its accuracy, we show on Figure 4 two screen plots of the same fragment from the quality control interface. The left plots show the colored overlapping cross-sections together with their mean profile (black dots). The right plots are illustrations of the mean profile after it has been automatically exported as standard archaeological drawing accompanied by two views of the 3D model and a scale. The bottom plot demonstrates the final positioning as was determined by the computerized algorithm with perfect overlap of cross-sections. On the other hand, the top plot shows a slightly tilted alignment of the same fragment. Note that the two final drawings are very similar and could hardly be differentiate by the naked eye. Nevertheless, the corresponding colored cross-sections show significant preference to the bottom version, what highlights the accuracy of our algorithm and the ability to control its quality.

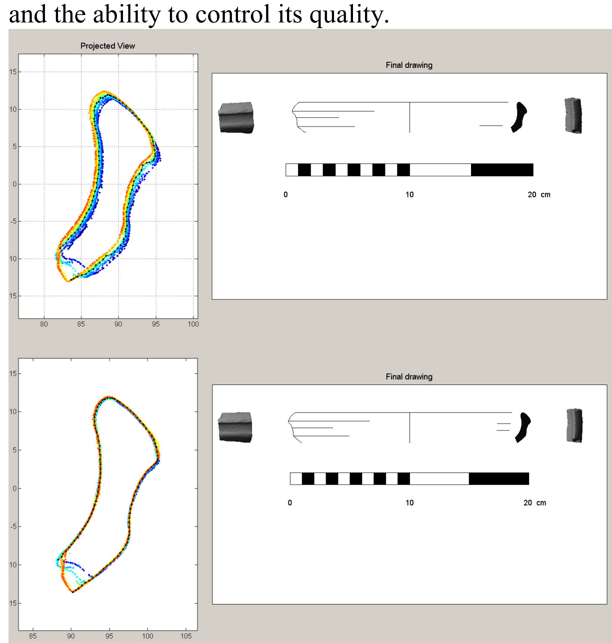


Figure 4: Two screen plots of the same fragment from the quality control interface. At the top plot the fragment is tilted relatively to the best positioning that was determined by the algorithm and is shown at the bottom plot.

## 5. An automatic typology and classification of assemblages

Our method is based on treating the cross-section profiles as planar curves. Each curve is further represented by three mathematical functions given as a function of the arc-length of the profile. Mathematically speaking, each of the three representations (radius – $R(s)$, tangent – $\theta(s)$ and curvature – $\kappa(s)$) of the profile stores the entire morphological information of the curve (but for shifts). They are in one to one correspondence with the profile, and each can be fully reconstructed from the other without any loss of information [19, 20]. They differ, however, in the sort of features to which they are most sensitive (see figure 4).

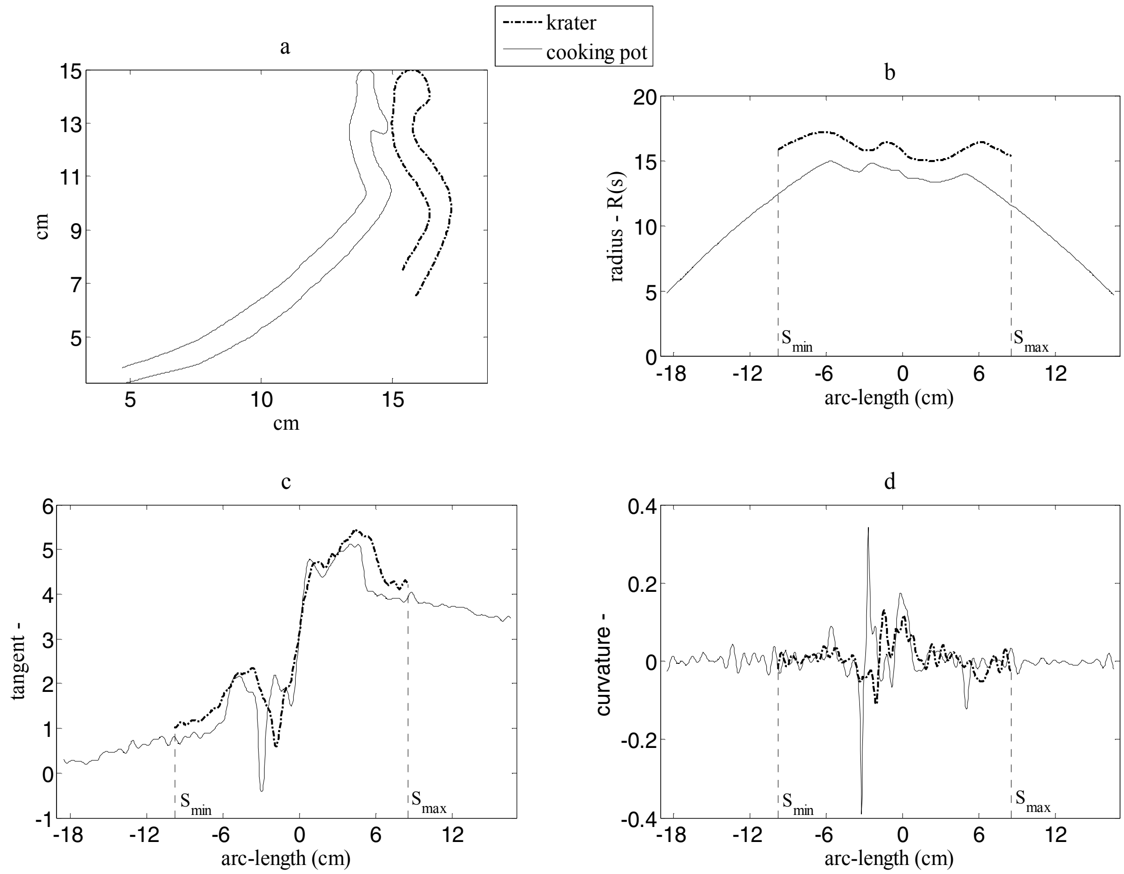


Figure 5: Two rather similar profiles (a), and their representative mathematical functions – radius (b), tangent (c) and curvature (d).

The definition of a distance (or a correlation) between corresponding representative functions provides the key for comparing and relating any given profile to all the rest. Each of the definitions expresses different aspect of similarity and can be used independently in morphological studies [4, 19, 21]. The most convenient framework for expressing this information is the symmetric distance matrix, which can also be averaged over the three representative functions.

Three steps are followed in the computerized typology recommended in the present work: Principal Component Analysis (PCA) which provides the most economical characterization of the correlations within the data. Cluster Analysis which is based on the PCA coefficients, constructs a hierarchical tree from which the types and sub-types can be defined (see Figure 6). Then, Discriminant Analysis (DA) tests the significance of the resulting typological classification. Figure 6 (top right) shows the cluster tree after applying the first two steps on an assemblage of 755 fragments. Each branch on this tree corresponds to a group of fragments with similar morphology which can also be defined as segregate archaeological type, as can be seen in the figure.

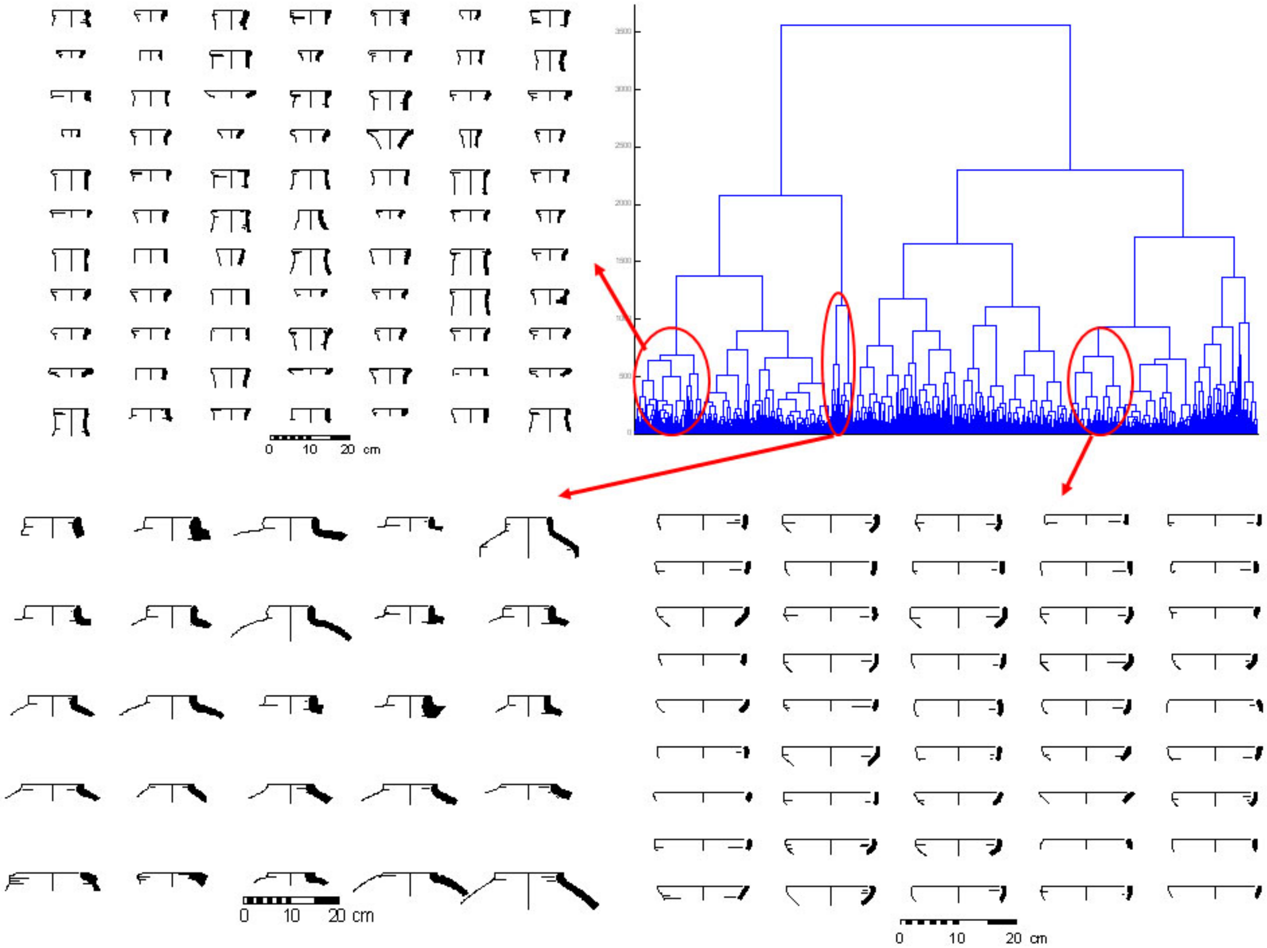


Figure 6: Bottom – Plot of the two leading PCA components for the distance matrix of 358 fragments from the early Iron Age at Tel Dor. Top – Four groups of profiles which correspond to the four clusters at the bottom plot. Each group represents a distinct morphological and archaeological type of vessel.

## 6. Summary

The ceramic processing procedure that was described in this paper is now the routine at the Computerized Archaeological Laboratory at the Hebrew University of Jerusalem. Nevertheless, it is only part of our current projects and interests. We invite colleagues from all around the world to collaborate and to share ideas and information about all aspects of computerized archaeology.

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