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# Measurement of constant radius geometric features in archaeological pottery

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ABSTRACT

Constant radius geometric features are a common type of manufacturing features of ancient ceramics. They are obtained by a sweeping action of a tool, which leaves negative or positive traces characterized by a cross-section with one or more constant radii. The automatic recognition and dimensional characterization of these features could be useful for understanding the technology used to manufacture ceramics. Thus, a new perspective in archaeological investigations can be furnished.

For this purpose, in this paper a new computer-based methodology suited to segmenting constant radius geometric features and measuring their dimensional parameters is proposed. Starting from a 3D discrete geometric model of the ceramic, the region pertaining to these features is determined and measurements of their radii are performed. Due to the uncertainties of various sources, which affect the investigated object, the required process is not trivial. In order to solve this problem, the segmentation phase is conducted using a non-conventional logic suitable for exploring the object with a fuzzy sensitivity, and the measurement is performed by a robust fitting method applied to the segmented entities.

The methodology has been tested in the identification of embossed decorations of an ancient olla. The combined effects of the feature segmentation process together with the measure detection approach on the obtained results are critically analyzed and discussed.

## 1. Introduction

Ceramic was a frequently used material for artifacts in antiquity and, due to its nature as a non-degradable material, it is found in large quantities. Due to its brittleness, it is frequently damaged and broken into many fragments. Most archaeological work is devoted to identifying these fragments, classifying and grouping them into sets that pertain to the same pottery. An interest in automatic methods of performing the previously mentioned activities is evidenced from the growing number of scientific papers concerning this topic [1–5]. The 3D technology is the modern support to implement the methods required to investigate pottery fragments.

Generally, the methods used for analyzing archaeological pottery focus on the recognition of its axially symmetric geometry, which is a geometric property of the greater part of a vessel. In ancient pottery, elements not classified in the category of axially symmetric geometry can frequently be found. These parts can also be semantically significant and associated with recognizable geometric features. This is the case with some details such as handles, lugs, decorations or inscriptions that can be considered useful to study and classify archaeological artifacts. In particular, some detail features result in traces left by tools, both intentionally, such as inscriptions and decorative motifs, or unintentionally, such as working marks. In order to recognize detail features, some recurrent geometric properties must be identified on the finds, by an algorithmically defined process. A geometric recurrent property is introduced in the detail features of an artifact by the action of a tool, which gives a circular (or nearly circular) geometry to the cross-section of the feature. These features can be part of an axially symmetric shape, as in the case of fillets or rounds, or located in a not axially symmetric part. The last case is an interesting situation, since it refers to types of ceramic fragments that are not considered by the typical automatic methods proposed in the literature on investigating ceramic finds [6–8].

The analysis of the dimensions of these features is also important in order to identify the tools used to create the decoration. Since the identification of such features is affected by large uncertainties, the result of the measuring process is largely dependent on the way the geometric features are segmented, as well as the specific criteria used to

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evaluate the measurement.

In this paper, a computer-based methodology aimed at the automatic measurement of constant radius geometric features in archaeological pottery is proposed. This methodology consists of two main phases: constant radius geometric feature segmentation and measurement of the features' radii. In the earlier phase, first of all, the principal curvatures at the points of 3D discrete geometric models of ceramic vessels are analyzed; then the nodes that can potentially be attributed to detail features of the constant radius are identified. This feature segmentation is based on recognition rules implemented by a fuzzy logic. In the latter phase, the characteristic radii of each segmented feature are evaluated by a fitting method which approximates a properly chosen section of it.

In the paper, an *olla*, experimentally acquired by a 3D laser scanner, is used as a case study to describe and test the methodology proposed.

## 2. Constant radius detail features in archaeological pottery

The variety of decorative syntax that characterizes ancient pottery repertoire is wide. Therefore, it is difficult to propose a systematic coding of all known decorative motifs distinguishing diverse cultures and historical periods. Some decorations are carried out by finger action or by various tools, when the clay is fresh or in a leather state, or through a sweeping action that leaves negative or positive traces on the ceramic surface. In some cases, the decoration consists of clay application of constant section swept geometries. These features are characterized by one or more constant radius shapes or something like them.

In what follows, decoration techniques used in antiquity, where a constant radius can be recognized, are summarized [9–11]:

- Negative decoration;
- Engraving, graffiti, excised decoration;
- Impression/stamping;
- Burnishing;
- Roulette decoration;
- Positive decoration;
- Barbotine decoration;
- Applied/plastic decoration;
- Molded relief decoration.

Negative decoration means that a decoration is done by cutting or removing clay from the artifact. This operation leaves behind marks that can be analyzed by considering them as signs arising around sweep lines. Depending on the decorative technique, the potter imprints the tool in a perpendicular direction or at an angle. Traces left by the engraving may have a rounded or sloped rim. If done on clay in a plastic state, the engravings are thin V-shaped sections presenting a rounded rim, a situation that allows them to be identified as detail features of constant radius. If the clay is dry, on the other hand, the groove is wider and the engraving takes on the characteristics of graffiti or even epigraphic testimonies. Excised decoration, however, consists of removing small portions of the surface of the article with a pointed object. The result is a relief decoration and a low relief background. Depending on the nature of the tools used to realize the epigraph or the decoration pattern, also in these last examples a geometric feature with constant radius can be found. Impressed/stamped decoration is used to decorate the clay while it is still damp with various patterns, using different instruments like individual stamps, cords or fingers. These decorations present the necessary conditions to be examined as constant radius geometric features, considering the tools used to impress them on the pottery's surface. It is one of the oldest processes used by the potters of every civilization to decorate their works, so it is a widely diffused pattern that it is very useful to automatically recognize. Burnishing is carried out before the pot is dry enough to be fired (leather-hard). It includes rubbing the surface of the pot in order to make it smooth and shiny. Large areas, such as the shoulder, can be done with a pebble or flat piece of wood, while decorative lines can be done with a blunt stick. These can be considered more as working marks since they have a functional purpose. Therefore, it can be useful to tell apart this peculiar burnishing pattern from the signs that have a purely decorative meaning. Roulette decoration is achieved with a small-toothed tool called a roulette, which consists of a wheel turning on an axle. The patterns are produced by the continuous rolling motion of the roulette pressed into contact with a rotating vessel, leaving a continuous band of decoration in the clay. The roulette wheel impresses the clay without removing material. So, the traces left by this tool only partially adapt to the requirements required to perform a segmentation of detail features of constant radius, depending on the decoration left by the roulette instrument [12].

Positive decoration refers to a decoration obtained by adding clay on the surface of the artifact. This is the case, for example, of the barbotine technique. Here a thicker mixture of water and clay is added by hand to the pot to create a slightly raised decoration, usually made of lines, plants, and animals. The ceramic slip would normally contrast with the rest of the vessel, forming a pattern or inscription that is slightly raised above the main surface. The geometric decorative pattern realized with this process, particularly, can be recognized as a case where the constant radius geometric features could be found. In addition to this approach, a plastic decoration can be obtained by adding more clay on the vessel already formed, thus having a great variety of decorations, such as bosses and ribs. The last technique presented here is the mold decorative technique, which uses a mold as a tool that impresses the decoration on the vessel surface, thus increasing the volume of the smooth surface of the artifact. The mold can be in different shapes and sizes, so, once again, the possibility of finding detail features of constant radius in vessels decorated with such methods depends on the geometric nature of the decoration impressed by the mold, which comes in different styles.

## 3. The recognition of detail features of constant radius from archaeological artifacts

The detail feature of constant radius (*DFCR*) is a feature of the surface model, which develops along a line (*sweep line* of the feature) and whose transverse section, performed by a plane which is orthogonal to the *sweep line*, is circular with a radius $R_i$, called the *characteristic radius*.

A computer-based recognition method of *DFCR*s of real archaeological artifacts has to be suitable to analyze discrete models resulting from a 3D scanning, where the original surface is approximated by triangular facets. These 3D geometrical models contain just low-level geometric information, such as the coordinates of points and normal of triangles; high-level information, such as the measurement of the *DFCR*s radii, can be obtained by a complex processing of 3D data. In the case of archaeological artifacts, the above-mentioned evaluation is complicated by their limited extension with respect to the mesh sampling, by manufacturing error and by modification of the surface properties due to the action of time and weather.

Based on the previous considerations, in this paper, a robust method for the automatic segmentation of *DFCR*s from scanned archaeological artifacts is proposed. In Fig. 1, a flow-chart of the methodology is shown; it consists of the following principal phases:

- Normal and curvatures estimation at all the nodes of the tessellated model;
- Identification of the values of the *characteristic radius* of the *DFCR* that can be recognized in the object. Measurement of the radius is performed, at this stage, in a qualitative way, since it is aimed just at segmenting the geometric features;
- Automatic selection of the nodes that can potentially be attributed to the *DFCR*;