Measuring deformations of wheel-produced ceramics using high resolution 3D reconstructions

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ABSTRACT[1]

Many artefacts, such as wheel-produced ceramics, are intended to be axially symmetric. Therefore, the boundaries of their intersections by planes that are perpendicular to the axis of rotation should be perfect circles (we shall use the term "horizontal sections" for these sections). However, these ideally symmetric objects may suffer deformations when still on the wheel, or during the drying and firing stages. As a result, the afore-mentioned sections will deviate from perfect circles. In traditional archaeological publications which rely on hand drawn single profiles, this information is completely lost – the drawn profile can only represent an average profile. The introduction of accurate measuring devices such as 3D scanning cameras (Leymarie et al., 2001; Razdan et al., 2001; Sablatnig & Menard, 1996) has made 3D representations of pottery available. Using these data, it is now possible to deduce the deformations of wheel-produced pottery. A systematic study of these deformations may reveal the technological flaws that induced them, and might possibly be used to characterize workshops methods and production patterns.

Our goal here is to provide a simple and convenient method to describe and quantify deformations of ceramics. The combination of an objective and accurate method together with high resolution 3D reconstructions is the key of this research. This enables us to zoom-in into the morphology of the vessels and deduce archaeologically meaningful insights.

1. METHOD

A quantitative measure of the deformations can be obtained by using the polar representation of the curves that are the boundaries of the horizontal sections. Fig. 1.a shows the curves obtained by measuring two horizontal sections of a jug using a 3D camera. The jug in question is a closed and complete vessel and therefore the 3D camera provided only the horizontal section of its exterior surface. As can be seen in Fig. 1.b, the curves are certainly not the ideally expected concentric circles (to be explained below).

The purpose of this paper is to provide a quantitative measure of these deformations. The points on the curve are specified by their polar coordinates ($r(s)$, $\varphi(s)$). For convex curves (and when the origin is in the interior) $\varphi(s)$ is a monotonic function of the arc length s, and one can describe the curve by the function $r(\varphi)$ (Gero & Mazzullo, 1984; Liming *et al.*, 1989). It is customary to use the Fourier coefficients of $r(\varphi)$.

$$\hat{x}_n = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \cos n\varphi \; r(\varphi) \quad ; \quad \hat{y}_n = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \sin n\varphi \; r(\varphi)$$

to define the n'th deformation parameter and associated phase by:

$$r_n = \sqrt{\hat{x}_n^2 + \hat{y}_n^2} \quad ; \quad \alpha_n = \arcsin\left(\frac{\hat{x}_n}{r_n}\right).$$

The deformation parameters are determined in an unambiguous way when we choose the origin such that the coefficient $\hat{x}_1$ and $\hat{y}_1$ vanish. For simple shapes, this choice is equivalent to setting the origin at the center of gravity of the curve. The parameter r_0 is the mean radius, and it serves to set the scale (size) of the section. The first non trivial coefficients ($\hat{x}_2$, $\hat{y}_2$) or equivalently (r_2, α_2) determine the parameters of the ellipse which fits the curve best: $\frac{r_2}{r_0}$ is proportional to the eccentricity and α_2 is the tilt angle of the main axes of the ellipsoid relative to the coordinate axes. The higher order parameters provide information on deformations on smaller scales. When the curve is not convex, $\varphi(s)$ is not necessarily monotonic, and therefore one has to define the Fourier transform in another way, which coincides with the definition above for convex curves. This can be simply done by changing the integration variable so that

1 **Other version of this research was already published by some of us as part of a paper dealing with morphological analysis of planar curves (Saragusti *et al.*, 2005).**

$$\hat{x}_n = \frac{1}{2\pi}\int_0^L d \frac{d\varphi}{d} \cos n\varphi(s)\, r(s) \quad ; \quad \hat{y}_n = \frac{1}{2\pi}\int_0^L d \frac{d\varphi}{d} \sin n\varphi(s)\, r(s) \,.$$

Once this modification is introduced, the rest follows in the same way as in the discussion of the convex case. Fig. 1.b shows the values of 10 scaled Fourier coefficients $\frac{r_n}{r_0}$ for the sections shown in Fig. 1.a.

To demonstrate the potential value of the study of deformations in the archaeological context we discuss below a case study in which the deformation of the horizontal sections can yield information relevant to the manufacturing process of the ceramic vessels.

2. TEST CASE – DEFORMATIONS OF CONTEMPORARY WHEEL-MADE JUGS.

Two contemporary but traditionally-produced wheel-made jugs were scanned by a 3D scanner (Fig. 2 left). This scanner provides a complete three dimensional digital representation of the studied object, from which the horizontal sections at various heights were computed (Adler *et al.*, 2001; Sablatnig & Menard, 1996). This detailed information was used to determine various quantities that are relevant to the shape of the objects and their deviations from cylindrical symmetry (Mara *et al.*, 2004). Here we shall only discuss the information provided by the 10 leading Fourier coefficients computed for 45 different horizontal sections for each of the jugs.

Even though the two jugs look rather similar, their averaged scaled Fourier coefficients $\frac{r_n}{r_0}$ are quite different, as can be seen in Fig. 3; the right hand jug is more deformed than the one on the left.

The detailed investigation to be discussed below reveals that the deformation is not uniform along the jar, which indicates that different parts underwent different types of stress and pressure before the final shape was set. To reach this conclusion we analysed the deformations by dividing the 45 horizontal sections into 4 groups (Fig. 2 right): 1. *The neck* (upper 8 horizontal sections); 2. *The shoulder* (the next 7 sections); 3. *The body* (the next 25 sections); and 4. *The base* (the lowest 5 sections). Since some horizontal sections include the handle we used the points on the 180° arc opposite the handle. The mean scaled Fourier coefficients for each group were computed, and they are shown in Fig. 4.

How to explain this pattern of deformation which is very different for the two jugs? The body of the two jugs are the closest to perfect circles. This implies that the deviations from perfect symmetries were not caused by external pressure such as induced by e.g, too crowded packing of the kiln. Moreover, the potter was probably well trained and his wheels were balanced if he could produce such a symmetric vessels. The right hand jug is *more* deformed as far as the neck and shoulders are concerned, although its base is *less* deformed than the base of the other jug. On the other hand, the base of the left hand jug is more deformed than the one on the right jug (although on a smaller scale). Previous analysis showed that the most significant deformation of the neck is probably due to the attachement of the handle, which was pressed onto the still soft neck and deformed it. The difference between the two neck deformations can be explained by the application of stronger force when the potter attached the handle to the right hand jug. Such action would break the circular symmetry of the vessel, but would preserve the mirror symmetry about the line which crosses through the handle. When we computed the phase of the best fitted ellipse to the neck of the deformed jug we have found out that the axis of mirror symmetry cross exactly through the handle area correspondingly to our assumption (see: Mara *et al.*, 2004, for further details).

Even if the potter produced similar vessels, as can be suggested by the low deformation values of the body, he deformed them in different ways while he added decoration, handles or removed them to be dried elsewhere.

CONCLUSION

We introduced new quantitative tool which measures minute deformations and differences between ceramic vessels. This tool may reveal significant features when large assemblages are involved. The differences between the jugs were noticed only through the Fourier analysis and could hardly be traced by eye. It also highlights the importance of the 3D technology in archaeology, not only as a tool for visualization or data acquisition but also as a platform for new scientific challenges. We propose these measures as relevant archaeologically to provide technical information about the production process and workshop skills, and may be even for the identification of potters hand marks.

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FIGURES

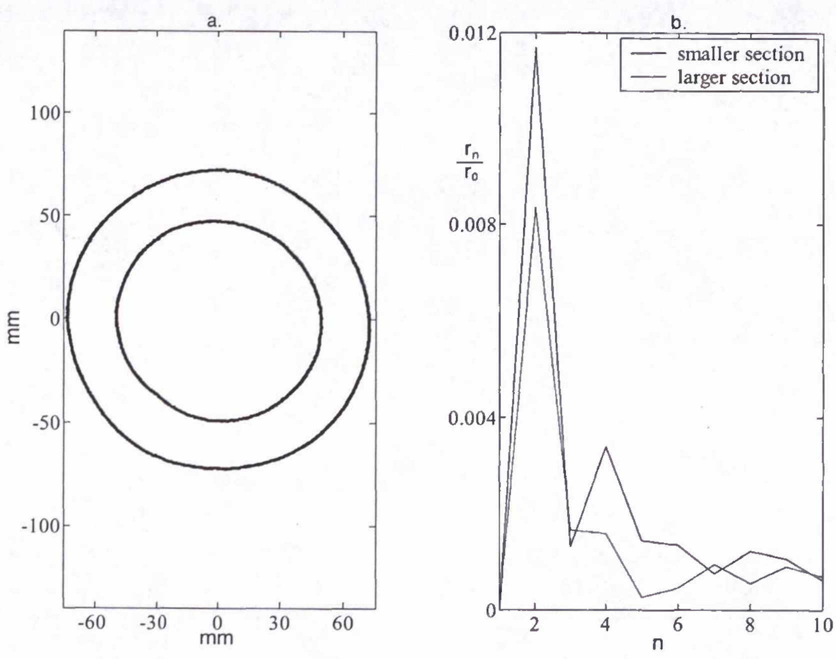

Fig. 1 (a) – Two horizontal sections of the jug shown on the left in Fig. 2 (b) The leading 10 Fourier coefficients (scaled by r_0) of the sections shown in (a).

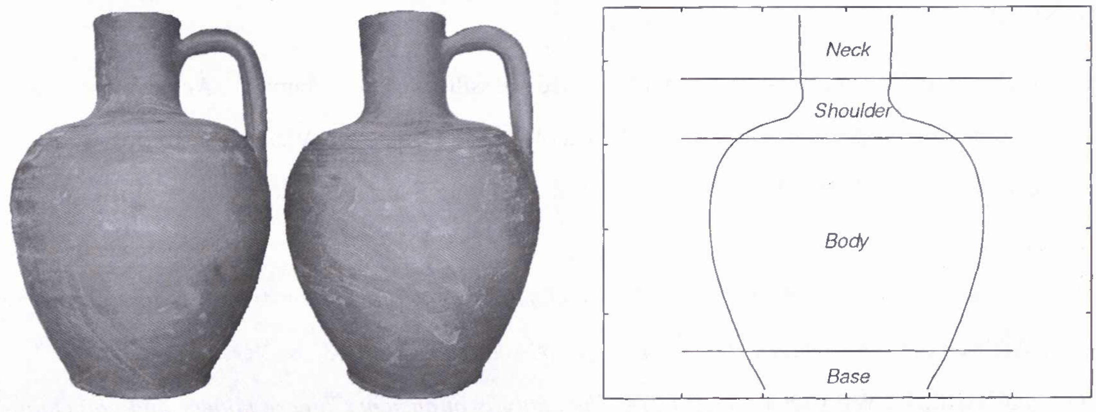

Fig. 2 – Left: Two similar wheel-made jugs from the market of Vienna. Right: A plan view of a jar where the four regions used in the current study are indicated.

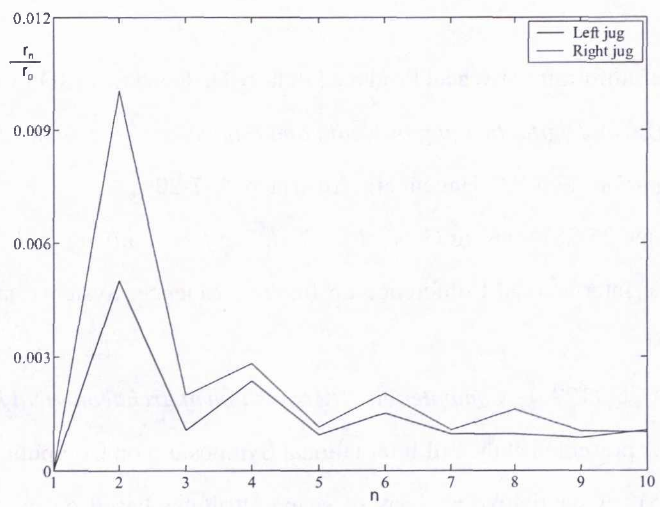

Fig. 3 – The mean scaled Fourier coefficients averaged over the entire height.

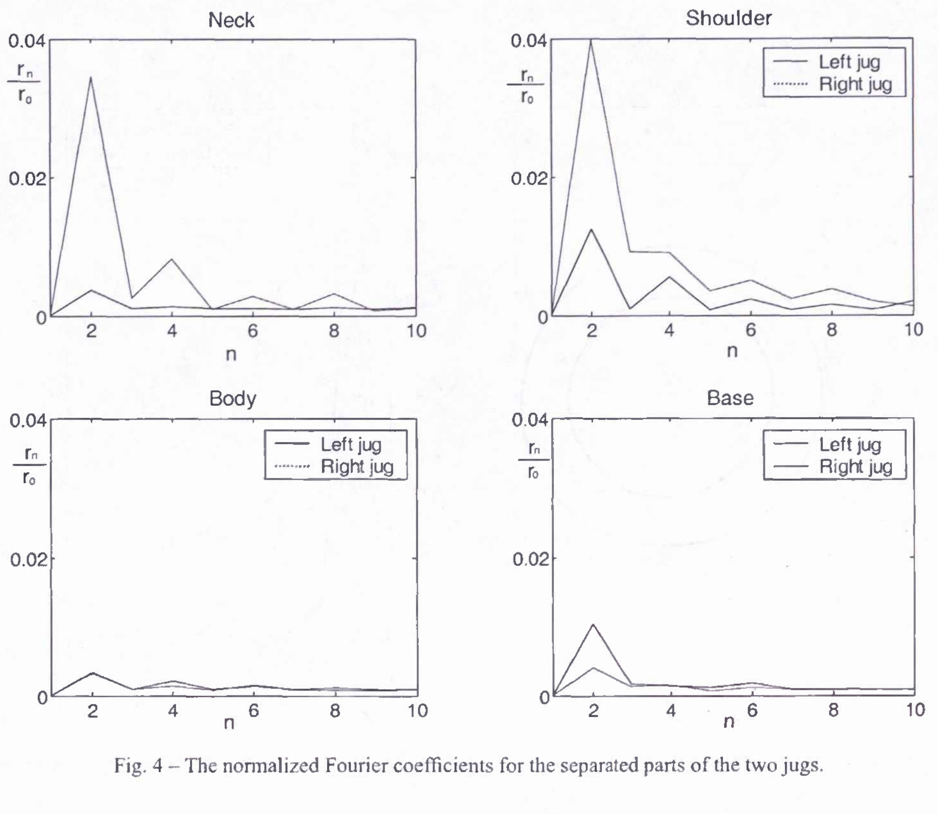

Fig. 4 – The normalized Fourier coefficients for the separated parts of the two jugs.