

A new system for interactive vessel reconstruction and drawing

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Abstract: We present an easy, automatic and efficient full vessel reconstruction and drawing system, that works using a mesh model of the fragment taken from a 3D scanner.

To get the appropriate orientation, the archaeologist select some areas of the border. Then, a genetic algorithm is applied to the point on these areas obtaining the plane that best fits to the border of the fragment.

The profile of the vessel is also interactively chosen by the expert, drawing it on the fragment like in a graphical editor. This profile is also editable, being possible to remove, move or insert points. From this information the system generates the unknown part of the profile using splines.

Finally, the system allows to create a 3D virtual view of the complete vessel and the traditional 2D drawing, allowing to edit it (i.e.: positioning the original fragment or placing measurement lines).

The software is very efficient, making it possible to create the drawings in a couple of minutes.

Key words:

1. Introduction

One of the more tedious tasks after an archaeological excavation is to manage thousands of small fragments of pottery appeared on the site, trying to select those which offers more information to be able to reconstruct the original shape of the vessels, in order to draw them and take the measurements necessary to classify the pots. Once selected the sherds from one vessel, the process of reconstructing it can take about fifteen minutes, and is possible to describe it by five steps:

1. *Orientation.* The sherd is placed in a table, with its rim completely in contact with the surface. When got such position, the vertical projection of the sherd is measured, so it's possible to allocate the sherd in the right orientation by placing it in such way that the vertical projection is the same as the previously measured (Fig. 1.a).

2. *Diameter estimation.* It's used a bordimeter (Fig. 1.b), which is a set of concentric circles drawn in a paper. The diameter of the vessel at the rim is the diameter of the circle that best fits to the external arc of the rim.

3. *Profile estimation.* The profile is the cross-section of the fragment in the direction of the rotational axis of symmetry (Kampel and Sablatnig 2000). To extract the profile, the expert uses a slide caliper, and measures the width of the sherd at different positions (Fig. 1.c)

4. *Drawing.* Based on the measures taken previously (diameter, vertical projection, profile), an artist makes a pen-and-ink drawing, following a standard that establishes the appearance of the drawing: lighting and shading, lines stippling, textures, etc... (Fig. 1.d)

5. *Additional measurements*, like diameter at different heights, rim angle, etc... that help archaeologist to classify the vessel.

Several authors estimates the error made via this procedure by $\pm 15\%$ (Leonardi and Penello 1991).

2. Our approach

The software has been developed under a Windows platform, using C++ as programming language and OpenGL as graphics library (Davis et al. 1993).

The aim of this software is to try that the archaeologist feels comfortable working with the tool. We do not want to build a “perfect” software, that doesn’t allow the expert to interact in the reconstruction process, giving the solution without taking into account the archaeologist experience and knowledge.

Due to this, our system follows the same steps as in the traditional procedure interactively (Fig. 2).

2.1. Data acquisition

Our goal is to be able to use a 3D scanner to get the polygonal surface of the sherd, and manipulate it with the software. But, although the scanner technology has improved its accuracy and speed, it’s still very expensive and the error margins are specially unacceptable when scanning small sherds.

Furthermore, these errors are originated by such high accuracy, but from our point of view, it’s not necessary more than one point per milimeter to get a good mesh.

Due to these technical problems, and only during development phase, we’ve used syntetic models generated with 3D Studio Max, based on real profiles and with irregularities like real ones (Fig. 3).

2.2. Orientation

To orientate a sherd is just to find the plane α that contains the rim and rotate the sherd in such way that the plane α is parallel to XZ plane.

This problem may be solved via Least Squares Fitting or other statistical or mathematical methods, but we’ve chosen a more flexible approach: Genetic Algorithms (GA) (Michalewicz 1996, Reynoso and Jezierski 2001). This algorithms are easy to implement and allows to change the goodness criteria, being possible to make more robust the method by adding constraints to this criteria (e.g. incident axis of the surface normals).

A GA is based on a set of individuals, defined each one by a chromosome. This chromosome is one solution of the problem we have.

In our problem, we have a chromosome composed by three genes, each one meaning a point of the selected rim. More precisely, the rim is divided into three zones (rightmost, central and leftmost) by a k-means algorithm, and there’s one gene of each zone in the chromosome. These three points define a plane, and what we have to do is to evaluate the goodness of this plane.

The goodness criteria for our chromosome (plane) is to consider the number of points of the rim contained by the plane and, also, the amount of points left at one side of the plane. It’s to say, it’s not enough to have a point containing a lot of points, it’s also necessary for it to be on the rim, just touching it, not in the middle of the fragment.

The goodness of a chromosome c can be expressed as:

$$G_c = 100 \times \frac{|R_c - L_c|}{N_b} + P_c$$

Where R_c and L_c means the number of points at right and at left of the plane defined by c , and N_b is the number of points selected as part of the rim. P_c is the number of points whose distance to the plane is under a treshold ϵ .

The rest of paramenters of the GA (cross and mutation probability, number of generations, etc...) can be modified by the user.

In our software, the user must select the area of the rim useful for this step (Fig. 4), being possible to avoid noisy parts of the rim like bubbles, breaks and other irregularities. This area is used for generating the population of the GA and find the plane.

2.3. Diameter estimation

To estimate the diameter of the original vessel is analogous to find the rotational axis of the pot. As we work with prehistoric ceramic, made without potter’s wheel, its surfaces are very irregular, and it’s not easy to find the axis by calculating the incident axis of the surface’s normals (Halír 1997).

We use a procedure similar to the traditional one:

- By moving an horizontal plane, the expert selects a section of the sherd. (Fig. 5) This section is an arc, so the expert might have selected the longest arc or that one with less irregularities.
- Having this arc (in fact, its a double arc: the external and the internal), the problem is just to find the center of the circle that best fit to the external arc.

To fit the circle to the arcs, we follow a LSQ fitting algorithm. First, we fit a circle using both arcs, so it will pass between them. Then, we remove the internal points and repeat the procedure with the external ones, so the new circle fits minimizing geometric distance with the sequence of points that define the external arc.

The rotational axis is the vertical line that pass through the center of the calculated circle.

2.4. Profile extraction

The expert selects over the tridimensional model of the sherd those areas that he considers best defines the shape of the profile. This step is done by drawing over the sherd with the mouse lines, like with a pen over the real sherd (*Fig. 6*), having a set of 3D lines that are projected over the planes that contains the calculated rotational axis. This can be done because previously we have translated the point coordinates into polar coordinates, and when selecting a point, we just take the module and the azimuth of its polar coordinate, translating easily it into 2D coordinates.

Having the sequence of 2D lines, the system fix them in a unique stroke, detecting overlappings and irregularities.

This profile is fully editable, being possible to add, remove or move points, so, if the software doesn't remove all irregularities, the expert can do it in a few seconds.

As shown before, the drawing of the vessel includes an estimated profile, that indicates how the profile should have continued if we had it. The length of this estimation differs from one sherd to other, because it depends on the typology and the experience of the expert, but the standards recommends drawing it along a couple of centimeters.

The software generates a first approach to this prolongation by a cubic spline that follows the shape indicated by the lowest 15% part of the profile. This spline is calculated by taking 4 points separated by a 5% of the height of the profile we have.

As the typologies in prehistoric ceramic are very hard to establish, and very restricted to small areas, we consider that the experience of the expert is very important at this point, so we allow also to edit the estimated prolongation, by moving the points or the tangents at the end of the prolongation (*Fig. 7*).

2.5. Drawing and 3D reconstruction

Having the profile and the rotational axis, it's easy to obtain the traditional drawing of the ceramic (*Fig. 8*).

This step of the reconstruction process is also interactive, because the system allows the expert to:

- Decide the position of the sherd in the drawing, depending on the details he wants to show. As in manual drawing, a false perspective is used, to avoid hide part of the surface when placing the sherd at left or rightmost position.
- Modify the lighting, to improve the visualization of several details of the sherd.
- Take measurements over the drawing, such diameter at several points, height of the sherd, etc... This measurements can be translated, modified, etc...

This image can be saved as a GIF, JPEG or BMP image, so it can be edited by any image edition software.

The tridimensional reconstruction of the pot is generated by rotating the profile (real and estimated prolongation) around the rotational axis. The surface corresponding to the estimated part of the pot is shown with a semi-transparent texture, in order to identify clearly both parts of the

reconstruction. Also, the original sherd is shown in the vessel, as in real reconstructions, so it can be appreciated the goodness of the reconstruction, and the exact place where it were located (*Fig 9*).

The reconstruction can be rotated and zoomed to get different views of the vessel, and each one of them can be saved also as an image.

3. Conclusions and future works

We have proposed a software that reduces the time of drawing and measuring of the sherd by an 80%.

We have tested it with several synthetic models, and reduces the error margin by a 60% with respect to the traditional method, so we think that this system can be very useful for archaeologist.

Anyway, we've found the biggest problems with the scanning of the sherd, so the software won't be fully operative until the scanning procedure give us enough accuracy and speed.

Our intention is to add other capabilities to the software like:

- morphologic measurements, like the angle of the rim, volume, etc...
- realistic textures for the tridimensional reconstruction
- pen-and-ink textures for the traditional drawing
- add a database were register all measurements in order to make statistic studies.

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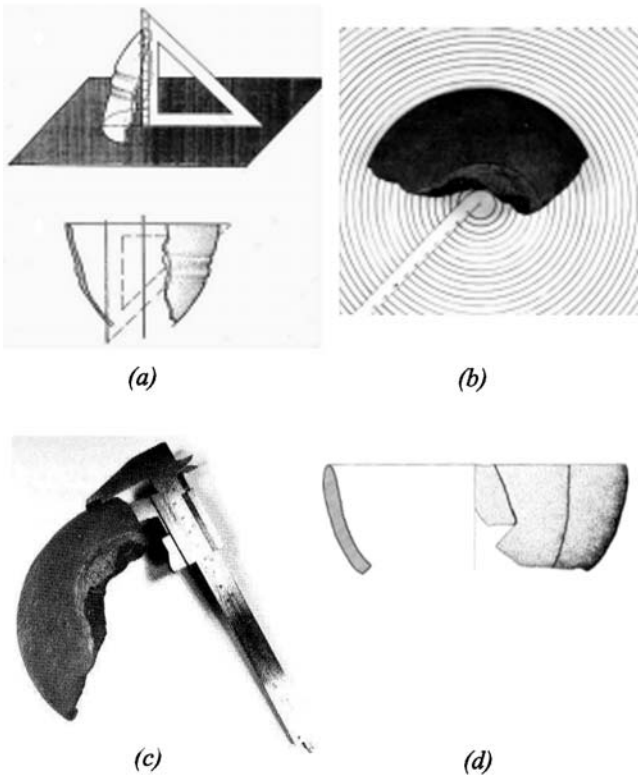


Figure 1. Steps in the traditional reconstructing method: a) Orientation, b) diameter estimation; c) Profile extraction; d) Drawing

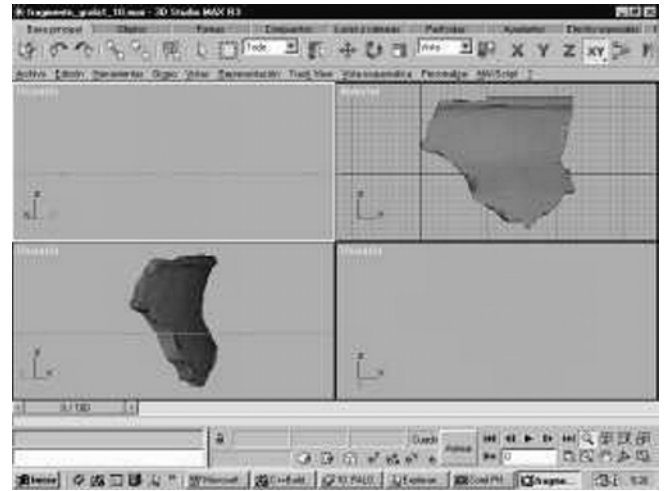


Figure 3. Constructing the synthetic models

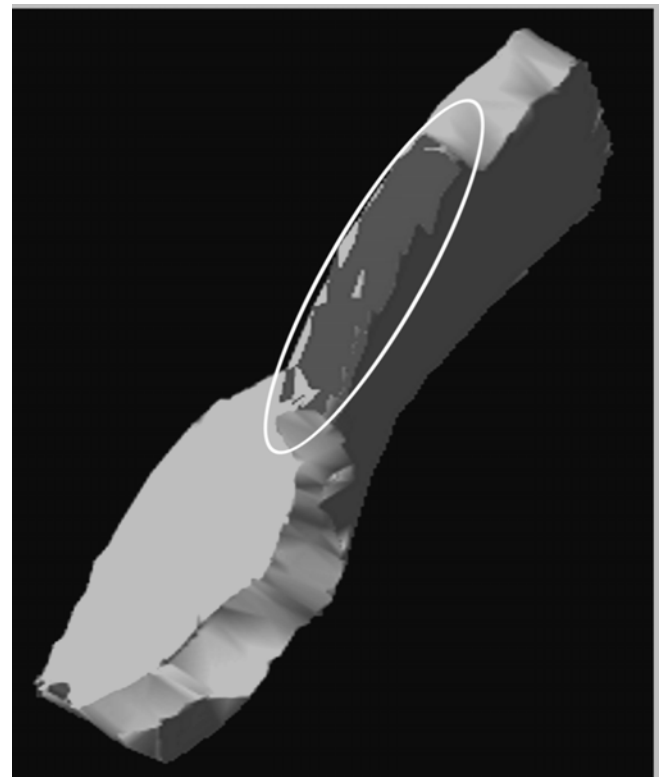


Figure 4. Area of the rim selected as valid rim

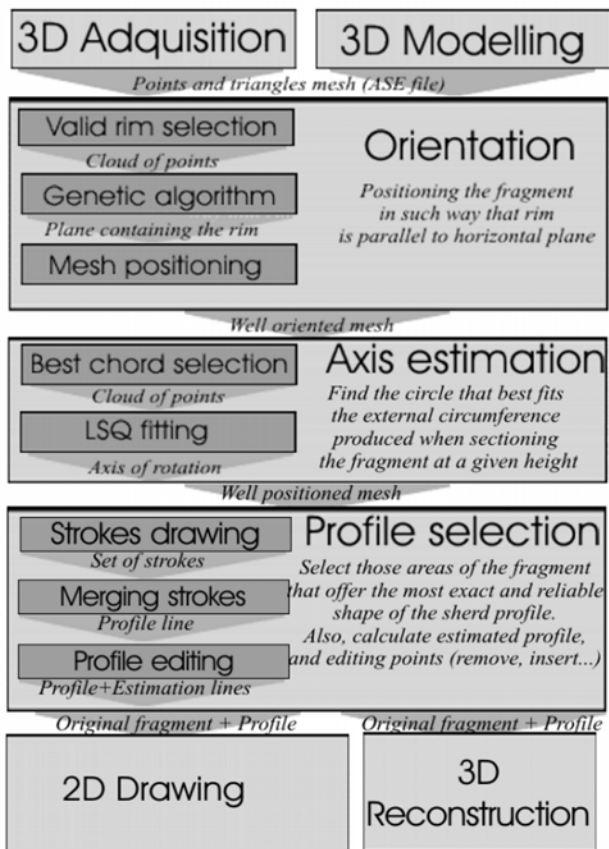


Figure 2. Scheme proposed by this paper.

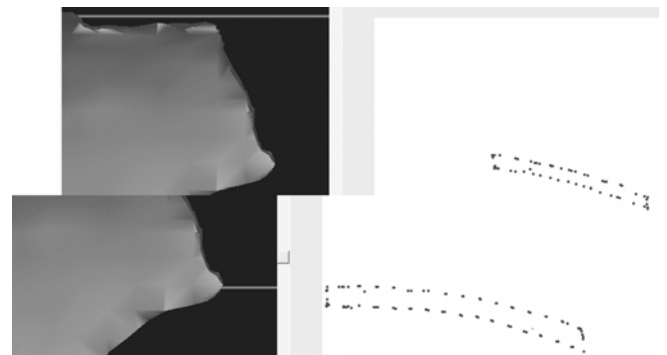


Figure 5. A couple of arcs obtained at different heights of the sherd by cutting it with an horizontal plane

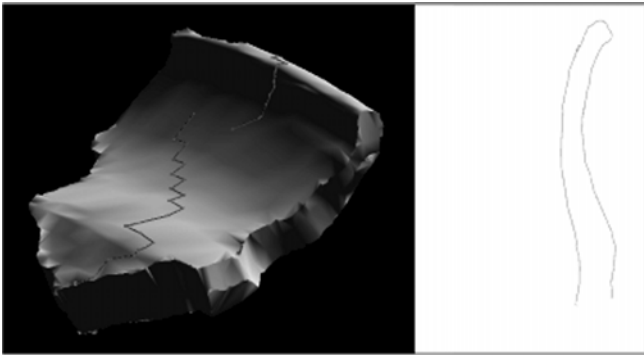


Figure 6. Profile extraction. See at left the strokes on the surface of the sherd, and at right the profile obtained

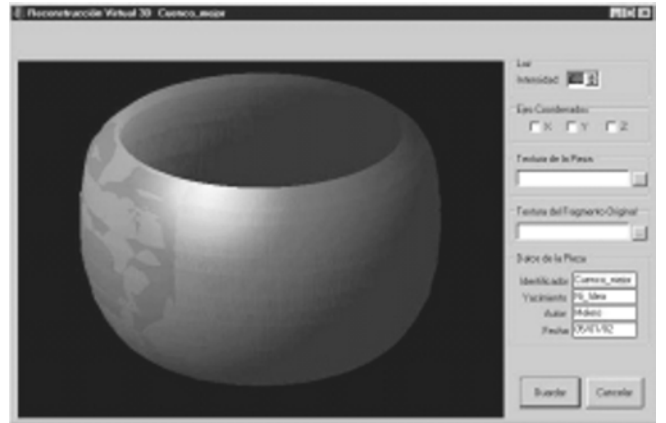


Figure 9. Virtual reconstruction of a pot. Note the original sherd and the lighting

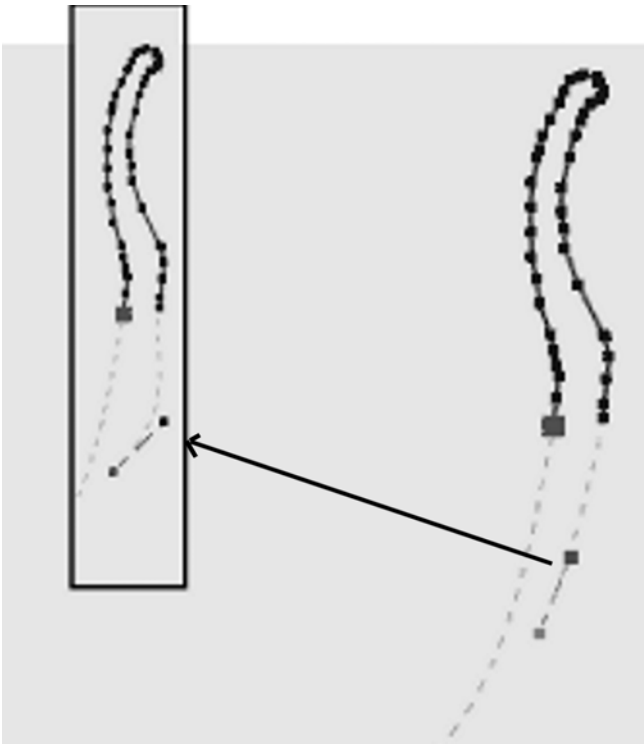


Figure 7. Editing the estimated profile. Note as the tangent has been moved and the stroke has changed.

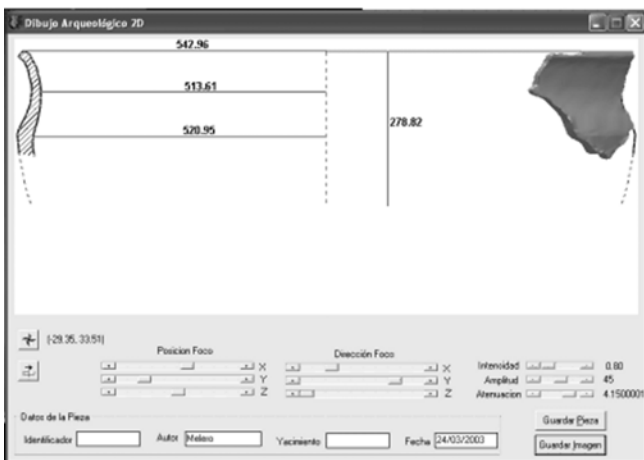


Figure 8. 2D Drawing following the standards and with the measurement lines