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, which works using a mesh model of the fragment taken from a 3D scanner.

To get the appropriate orientation, the archaeologist selects some areas of the border. A genetic algorithm is then applied to the points on these areas obtaining the plane that best fits the border of the fragment.

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

Finally, the system makes it possible to create a 3D virtual view of the complete vessel and the traditional 2D drawing, such that it can be edited (i.e. by positioning the original fragment or placing measurement lines).

The software is very efficient, enabling the creation of the drawings in a few minutes.

Introduction

One of the more tedious tasks after an archaeological excavation is to manage the thousands of small fragments of pottery that may appear on the site, trying to select those which offer more information so as to be able to reconstruct the original shape of the vessels, to draw them and take the measurements necessary to classify the pots. Once the sherds from a vessel have been selected, the process of reconstructing it can take about fifteen minutes, and involves five steps:

1. Orientation. The sherd is placed on a table, with its rim completely in contact with the table surface. In this position, the vertical projection of the sherd is measured; the sherd is oriented by placing it in such way that the vertical projection is the same as the previously measured (see Fig.1a).

2. Diameter estimation. Carried out using a bordimeter (Fig.1b), i.e. is a set of concentric circles drawn on a sheet of paper. The diameter of the vessel at the rim is the diameter of the circle that best fits 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.1c)
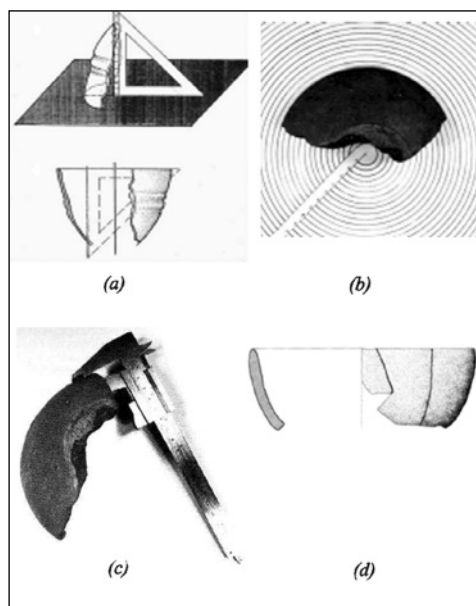

Figure 1 Steps in the traditional reconstructing method: a) Orientation, b) diameter estimation; c) Profile extraction; d) Drawing
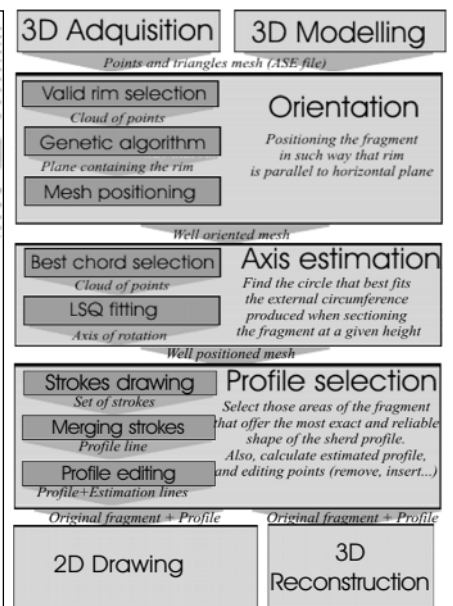

Figure 2 Scheme proposed in this paper

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, stippling lines, textures, etc… (Fig.1d)

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

The error made via this procedure has been estimated at ± 15% (Leonardi and Penello 1991).

OUR APPROACH

We have designed a software tool to carry out this task in a semi-automatic way. The software has been developed under the Windows platform, using C++ as programming language and OpenGL as graphic library (Davis et al. 1993).

One of the aims of this software is that the archaeologist should feel comfortable working with it. The goal was not to build "perfect" software which would leave no room for the expert to interact in the reconstruction process, giving the solution without taking into account the archaeologist's experience and knowledge.

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

[1] Data acquisition

Our goal is to be able to use a 3D scanner to capture the polygonal surface of the sherd, and then manipulate it with the software. However, although scanner technology has improved in both accuracy and speed, it is still very expensive and the error margins are unacceptable when small sherds are scanned.

Figure 3 Constructing the synthetic models

In fact, these errors are a consequence of the high accuracy demanded, but from our point of view, no more than one point per millimetre is necessary to get a good mesh.

Due to these technical problems, during development phase we used synthetic models generated with 3D Studio Max, based on real profiles and with irregularities like real ones (Fig.3). Thus, we were able to test the method without the problem of acquiring tri-dimensional data.

[2] Orientation

Orienting a sherd merely involves finding the plane that contains the rim and rotating the sherd in such way that the plane is parallel to the XZ plane.

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

A GA is based on a set of individuals, each one defined by a chromosome, which is a solution for the problem at hand.

In our case, we have a chromosome composed of three genes, each one corresponding to 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 the chromosome contains one gene for each zone. These three points define a plane, and our aim 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 the number left to one side of the plane. That is to say, it's not sufficient to have a plane containing a lot of points, but it's also necessary for it to lean on the rim, just touching it, not crossing through the middle of the fragment.
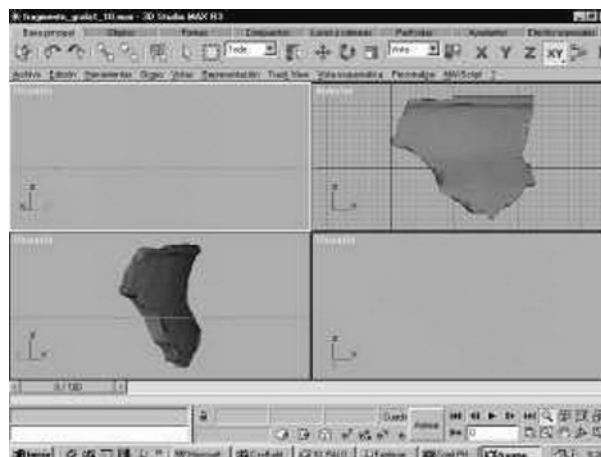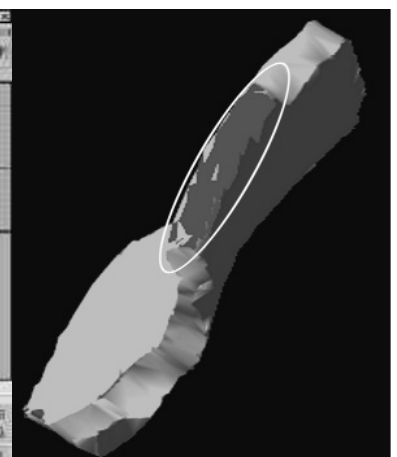

Figure 4 Area of the rim selected as valid

The goodness of a chromosome c can be expressed as:

Where Rc and Lc means the number of points at right and at left respectively, of the plane defined by c, and Nb is the number of points selected as a part of the rim. Pc is the number of points whose distance to the plane is below a threshold. The rest of the parameters of the GA (e.g. cross and mutation probability) can be modified by the user.

In our software, the user must select the area of the rim that is useful for this step (Fig.4), seeking 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 finding the plane.
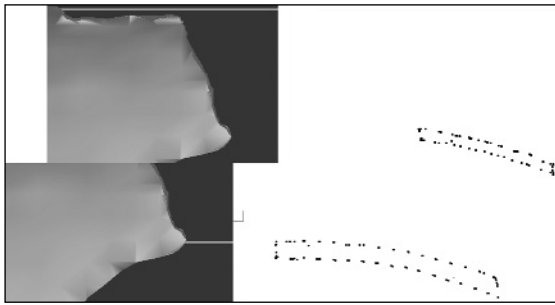
Figure 5 Two arcs obtained at different heights of the sherd by cutting it with a horizontal plane
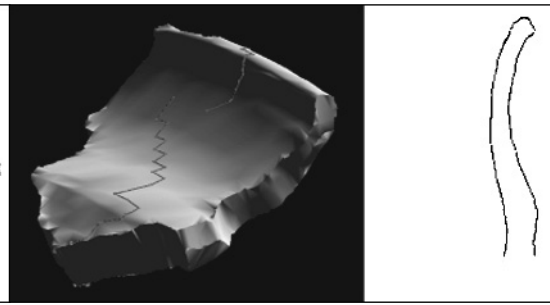

Figure 6 Profile extraction. Note at left the strokes on the surface of the sherd, and at right the profile obtained

unique stroke, detecting overlapping and irregularities. This profile is fully editable, being possible to add, eliminate or move points, so, if the software does not remove all irregularities, the expert can do it in a few seconds.

[3] Diameter estimation

Estimating the diameter of the original vessel is analogous to finding the rotational axis of the pot. As we work with prehistoric ceramics, made without a potter's wheel, its surfaces are very irregular, and it is 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:

- The expert selects a horizontal cut through the sherd by moving a horizontal plane with the mouse (Fig.5). The expert
  may have selected the longest arc or the one with fewest irregularities.
- From this arc (in fact, its a double arc: the external and the internal), the problem is now that of finding the centre of the circle that best fits 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 by minimizing geometric distance with the sequence of points that define the external arc.

The rotational axis is the vertical line that passes through the centre of the calculated circle.

[4] Profile extraction

From the tri-dimensional model of the sherd, the expert selects those areas considered to best define the shape of the profile. This step is done by drawing lines over the sherd, using the mouse, as if it were a pen over the real sherd (Fig.6), thus obtaining a set of 3D lines that are projected over the planes containing the previously calculated rotational axis. This can be done because we have previously translated the point coordinates into polar coordinates; when selecting a point, we take the module and the azimuth of its polar coordinate, and so it is easily translated into 2D coordinates.

Given the sequence of 2D lines, the system fixes them in an

As described above, the drawing of the vessel includes an estimated profile, that indicates how the profile should have continued if the whole vessel had been available. The length of this estimation differs from one sherd to another, because it depends on the typology and the experience of the expert, but standard practice is to extend it by about two centimetres.

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 5% of the height of the profile obtained.

As typologies in prehistoric ceramics 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 also allow him/her to edit the estimated prolongation, by moving the points or the tangents at the end of the prolongation (Fig.7).
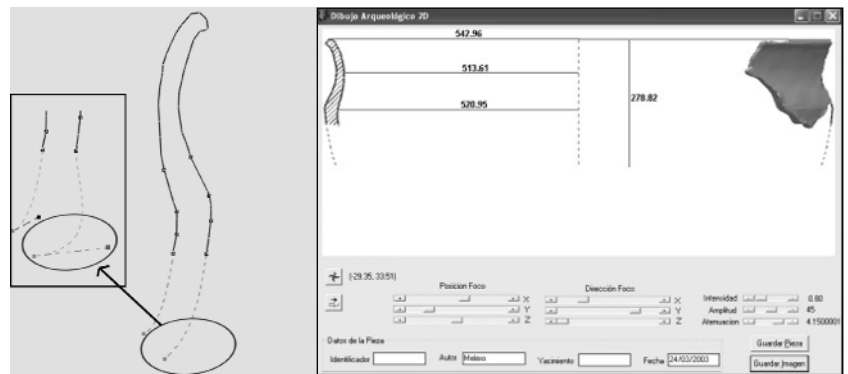

Figure 7 (left) Editing the estimated profile. Note the tangent has been moved and, due to this, the estimated profile has changed.

Figure 8 (right) 2D Drawing following the standards and with the measurement lines

[5] Drawing and 3D reconstruction

Once the profile and the rotational axis have been obtained, it is an easy matter 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 hiding 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 as the diameter at several points, height of the sherd, etc... These measurements can be translated, modified, etc.
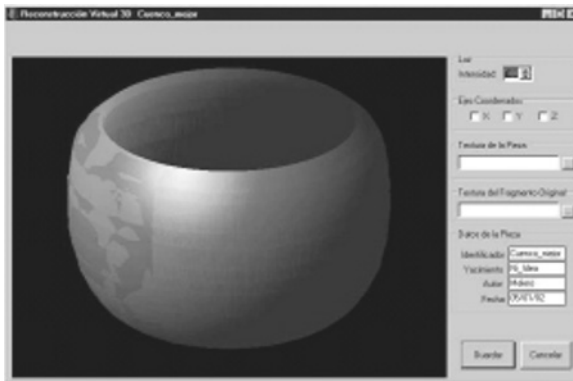

Figure 9 Virtual reconstruction of a pot. Note the original sherd and the lighting
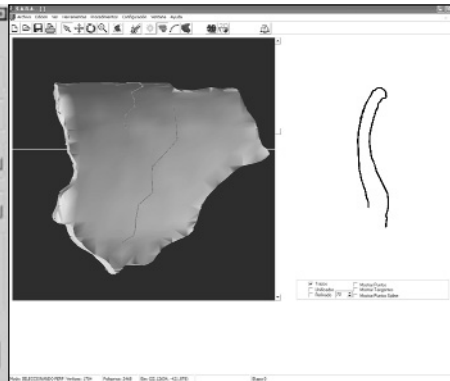

Figure 10 The software working at the profile extraction step

The image can be saved as a GIF, JPEG or BMP image, and so it can be edited by any image editing software.

The tri-dimensional reconstruction of the pot is generated by rotating the profile (both the real one and the 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. The original sherd is shown in the vessel, as in real reconstructions, so the goodness of the reconstruction and the exact place where the sherd was located can be appreciated (Fig.9).

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

CONCLUSIONS AND FUTURE WORKS

We have proposed a software that reduces the time required to draw and measure a sherd by 80 %.

We have tested it with several synthetic models, and the error margin is reduced by 60% with respect to the traditional method. It has been estimated by reconstructing some pieces several times, and computing the average and standard deviation of measurements on each reconstructed piece. We have got an error margin of +/- 5%. So, we believe this system can be very useful for archaeologists.

The most serious problems were encountered in scanning the sherd, and so the software won't be fully operative until the scanning procedure is capable of providing sufficient accuracy and speed.

Our intention is to add other capabilities to the software such as:
- morphological measurements, such as the angle of the rim, volume, etc...
- realistic textures for the tri-dimensional reconstruction
- pen-and-ink textures for traditional drawing
- the addition of a database to register all measurements for later statistical studies.

More detailed information about the software can be found at http://lsi.ugr.es/ ~fjmelero

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