# Evaluating the Relational Parameters in 3D Reconstruction of Archaeological Objects using Photogrammetry

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## Summary

There exist many archeological objects which are broken in pieces. It is always important to find the neighbouring pieces so that different parts of the object can be put together and the original object reconstructed. Direct evaluation of broken objects has several disadvantages, such as being difficult and time-consuming. As an alternative, indirect techniques like photogrammetry and laser scanning can be applied, in which measurements of object pieces can be made and the overall shape of the object constructed by inspection of the relation between models of object parts. When compared with direct techniques, such methods enjoy being fast and non-contact so leading to the increased safety of the objects under reconstruction. In this project, photogrammetry is used to extract edges of the broken parts. The mathematical relations between the edges are then examined, the neighbouring parts are found and the model of the object is formed. This paper studies various parameters each of which defines some mathematical relation between parts of an object. The experiments carried out show that the radius of curvature is a suitable parameter which can be used to find the neighbouring pieces of the modelled object. The results show enough accuracy for 3D modelling of the object with the specified dimensions in our experiments. But in order to verify the validity of this method, it should be applied to a wide range of archaeological objects.

## 1 Introduction

In this project, photogrammetry is used to extract edges of the broken parts from archaeological objects found in pieces. In order to find a relation among the measured edges, one can use several methods, such as comparing the gray levels in the neighbouring pieces of the objects, finding the edges of those objects which have similar shapes, or finding those borders of the objects which have similar geometrical characteristics. Of these, the one which uses the comparison of the geometrical properties of the object has been selected in this paper. This is because it is faster, more accurate and retains the safety of the object being reconstructed. The geometrical parameters which are used to find a relation between parts of an object are: curvatures and their radius; twists and their radius; the angle between three overlapping neighbouring points; the thickness of the edges; and the length of the vectors which construct the borders of the pieces. These mathematical relations between the edges need to be studied in order to find the adjacent parts.

In the following, first the process of photogrammetric measurements is described, and then the mathematical relations are introduced and compared. The final model of the object is then studied and the conclusions reported.

## 2 Photogrammetric Measurements of Archaeological Objects

Before imaging the object pieces a photogrammetric network needs to be established or the measurements will not be in the same coordinate system. As the object pieces are usually small, a metric grid can be used as the reference coordinate system upon which the object parts are placed as shown in Figure 1. The imaging can then take place and coordinates of edge points of the object parts can be obtained through standard photogrammetric procedures. The points should be selected at the critical points with sufficient density to represent the object shape. The distance between the points can be defined through a given threshold if the edges are not straight. The maximum variation of slope between consequent edges is defined as in Equation 1.

$$M = (s_{max} - s_{min})/L \tag{1}$$

Where $M$ = Maximum variation of slope (%), $s_{max}$ = maximum slope (%), $s_{min}$ = minimum slope and $L$= edge length (cm).

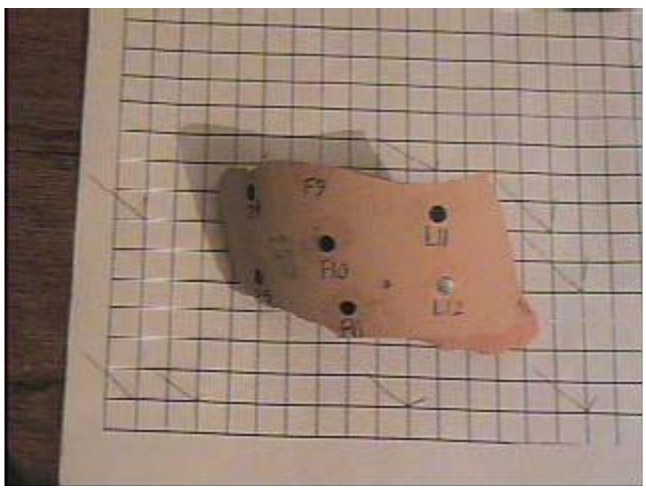


*Figure1. A sample image taken for photogrammetric measurements.*

## 3 Establishing the Relation Between Object Parts

Once the points on the edges of the object parts are measured, the shape of each part can be formed. The next problem, however, is to find which part, or so-called model, is adjacent to which. This can be done in a number of ways, including:

- Comparison of the objects using the gray values obtained from the images taken at the photogrammetric stage
- Direct comparison of object shapes based on the photogrammetric measurements
- Comparison of mathematical relations among the measurements

In the following, each of the above techniques is discussed in detail.

## 3.1 Comparison of the objects using their gray values

Provided that object parts are of the same material and quality, the comparison of their colour values may be used to find relating parts. However, this is not the case for archeological objects. This is because of the great age of these objects and the conditions in which they have been covered in the ground. Obviously, parts may have been covered by different soils and in differing physical conditions, leading to different effects on the object parts. These in turn may result in different colours for various parts of the object. For these reasons, this technique was not applied in this project.

## 3.2 Direct comparison of object shapes based on the photogrammetric measurements

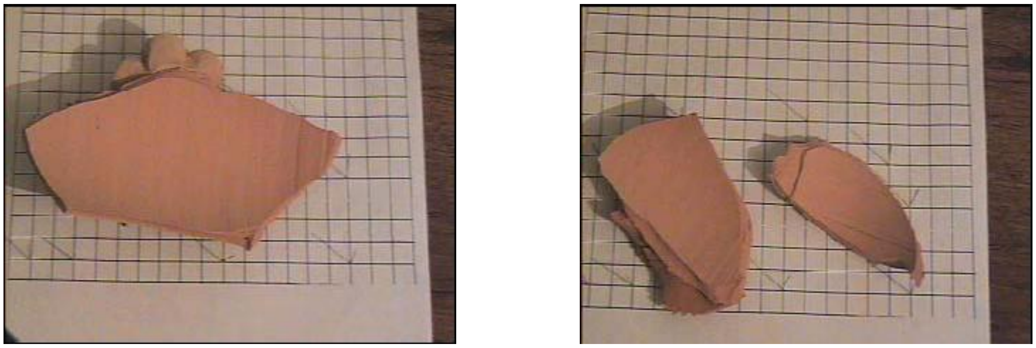
The direct comparison technique was also not used in this project. This is due to the fact that archaeological parts are fairly fragile and are mostly damaged after so long a time. As a result, the shapes of object edges are different from those of the original object; thus they cannot be matched with sufficient accuracy. However, the overall shape of the object can be used as a rough estimate to reduce the number of matching candidates (Jimenez, 1998).

## 3.3 Comparison of mathematical relations among the measurements

In this section, the different parameters studied to establish mathematical relations between adjacent edges are described. These include: edge length, thickness, the angle between consequent edge lines, twist and curvature.

*Edge length*

For this, the edges with almost equal lengths were extracted and compared with each other. The experiments carried out here showed that this technique is erroneous. In other words, the lengths of parts with known adjacency were different, leading to errors in the comparison. This suggested simultaneous comparison of a number of lengths. However, owing to the fact that the archeological shapes are damaged, the accuracy of this parameter in estimating a correct relation between adjacent candidates did not give satisfactory results. An example of a problematic match is shown in Figure 2, where the object on the right is broken into two different pieces, thus making it difficult directly to compare the length of the edges of the object in (a) with those of (b).



*(a)* *(b)*

*Figure 2. An object (a) and its corresponding parts (b)*

*Thickness of selected points over border of boundary parts*

Selected boundary points (vertices) are by chance, and over conjugate boundaries these points are different and also the thickness of the points is different. As a result, this parameter can be used to make a connection if it is certain that the selected point in one border is one that is available over a related border in another part. However, this selection is impossible because separate points may not come from two related parts, so this parameter was not used to make any connections.

*Angle of the corners and continuous directions of part's border*

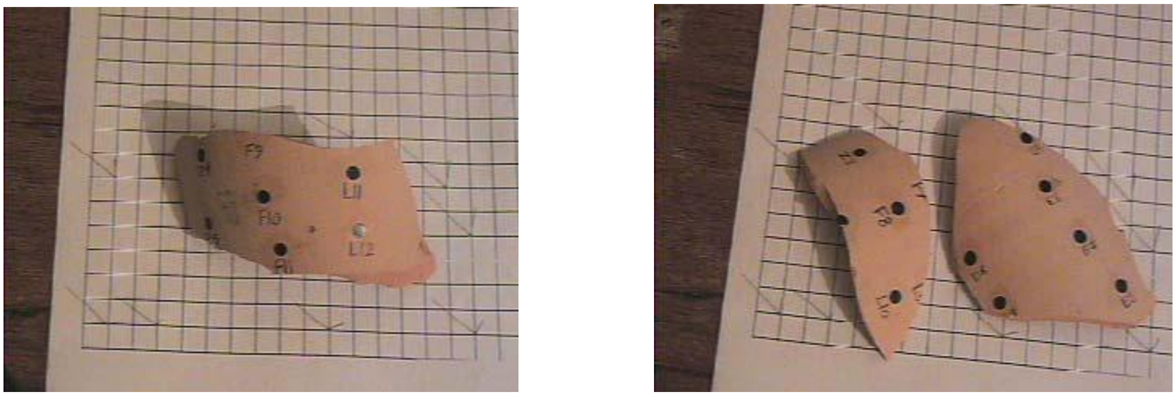
The total corner angle should be 360 if corners are connected together. Researches show that the possibility of dropping and destroying the points is high because of the sensitivity of the points to small impacts rendering them damaged, mostly, over time. So these angles are not suitable to make a connection. Therefore, comparing angles between two continuous vectors is not a reliable parameter for making a connection between parts because if a border point is forward or backward, the related border is incorrect.

*Twist and its radius*

Twist is the curve track change in 3D space, and the spatial curve radius which corresponds to this track change is called the radius of twist, whose value is measured by continuous integrals. In this research, because a continuous track change was unavailable, an approximate track was defined by unreliable points so that a value related to the same parameter could be calculated. Studies have shown that this parameter is not measurable in most points of two related borders because twist parameter is affected by height changes of the point: in borders where changes in the z coordinate of continuous points are small, this parameter, c, cannot be used.

*Curvature and its radius*

Curvature is the track change of the border curve, and the circular radius corresponding to this track change is called the radius of curvature. Various tests show that calculating this parameter in related borders gains the same values. In Table 1 and Table 2 for Figure 3(a) and Figure 3(b) respectively, curve radii of two related borders are shown. The curve radius of the two borders has only a small difference, so this parameter was selected as one producing a strong probability of related borders. Because of the different place of the corner points over the two curves, the curve at the same points is determined by two values (left and right limits). So the tables are replaced by two values for curvature.



*(a)* *(b)*

*Figure 3. Two related borders.*

Table 1. Observation of figure 3(a).

| Left limit | Radius of curvature |
|---|---|
| 4.25 | 5.18 |
| | 20.72 |
| | 6.55 |
| | 10.16 |
| 8.73 | 3.50 |

Table 2. Observation of figure 3(b).

| Left limit | Radius of curvature |
|---|---|
| 6.80 | 5.93 |
| | 19.96 |
| | 6.34 |
| | 10.38 |
| 5.40 | 4.96 |

## 4 How to Determine Threshold Limit to Accept or Reject Relation Between Parts

It should be noted how the threshold limit of accepting and rejecting the differences is determined. If the threshold is small, much time can be wasted, and with a big threshold, identifying the correct border is difficult. So the threshold limit is selected according to the accuracy required for reviewing the effect of the border's length.

Knowing which borders to connect, three points were considered and given 3D coordinates: transfer, circular and change parameters were measured to connect together the pieces. To see the object and the colour and quality of the parts properly, the parts were put together, and also, to show how to connect the repaired parts to the main piece, an animation was prepared as shown in Figure 4.

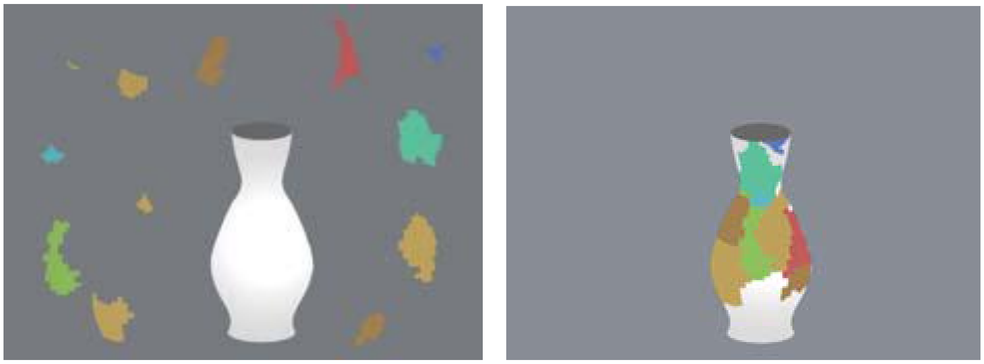


*Figure 4. 3D animation of parts before and after connection.*

## 5 Conclusion and Recommendation

According to the aforementioned properties for an optimum system for 3D modelling, the cost required for photography and producing 3D models is less than for other methods. After preparing 3D models of historical artefacts, possible relations between parts should be determined. Comparing geometric parameters was selected as a suitable method after studying three comparison methods including: comparing the angles of boundary points, comparing boundary shapes, and comparing geometric parameters. Studies have shown that applying close range photogrammetry and curvature radius is a good method for repairing historical artefacts. To have a reliable method, different kinds of historical artefacts should be tested. It is recommended that real artefacts are tested given the advantages offered by this research.

## References

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