

Computer Vision Aided Pottery Classification and Reconstruction

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Abstract

In the field of archaeology, there is a dearth of computer based automation tools for performing the tedious task of pottery classification. Archaeologists also lack the support of computer vision aided tools, which would enable them to visualize, in 3D, an entire pot from a broken shard. This paper presents the features and inner workings of a computer vision based tool that aids archaeologists in pottery classification and reconstruction. By utilizing the image of a pot's profile, the tool provides several functionalities, some of which include classification of complete and partial profiles with respect to a dynamic user defined database, construction of 3D models of pots and extension of partial profiles by appending user defined splines.

Key Words and Phrases: Pottery classification, pottery reconstruction, splines, pot profiles

1. INTRODUCTION

Archaeology has not been fully influenced by the power and wide application of computer based automation tools. Hence, archaeologists spend a majority of their time performing tasks which are repetitive in nature. Pottery classification is an example of such tasks. When done manually, this tedious task takes hours to perform, as the profile to be classified must be compared with all available profiles in the database. The accuracy of this method is also questionable, as it is dependant upon the experience and expertise of the archaeologist. A

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system that performs virtual reconstruction of complete vessels and partial fragments has been reported in [1]. It utilizes a silhouette based method for complete vessels and a profile based method for fragments. Methods of acquiring 3D data for fragments have been discussed at great length but not enough emphasis has been laid on the algorithms and techniques utilized in virtual reconstruction. An accuracy of 50% has been reported for profile extraction and subsequent matching, which is an enhancement over the manual method but is still not up to the mark. An automatic and efficient vessel reconstructing and drawing system is presented in [2]. It allows the alteration of pot profiles via the addition of user defined splines. This system utilizes mesh models of the fragment taken from a 3D scanner. The authors have reported an enhancement of 60% over manual methods. However, this system requires manual intervention during various stages of the reconstruction process and the time taken to create a 3D model is in the order of minutes. A tool to assist archaeologists in their work of analysis and reconstruction of archaeological objects from their fragments has been reported in [3]. The authors have proposed an environment for computer aided reconstruction of archaeological objects and a method to estimate the quality of an association based on a surface area evaluation. A unique approach towards classifying pottery is presented in [4]. This system of classification is based on 3D models of the shards acquired by a 3D scanner using structured light. The 3D model is oriented by the use of plane-fitting and Hough inspired methods and the classification is done by comparing the extreme points and the primitives. An automated method for assembly of pots from thousands of shards is reported in [5]. Matching of fragments is done by aligning them geometrically into configurations based on matching break curves, estimated axis and profile curve pairs for individual fragments. The common problem in all of the reported works is the extent of manual intervention. Such interventions are currently extensive and exist during every phase of the 3D reconstruction process. The time taken by these methods of

classification is often in the order of minutes. This may be a considerable improvement when compared to the manual methods but there is still room for improvement. The computer vision tool presented in this paper classifies a pot's profile in seconds with an accuracy of 97%. Within the same time duration, it also constructs a 3D model from the profile and also allows the user to manipulate the constructed model by dynamically changing its radius and orientation. A partial pot profile can also be extended via the addition of user defined splines. The 3D model of this extended profile can also be visualized and manipulated. Furthermore, in contrast to the earlier works discussed, this tool does not require the user to have any special knowledge of the functioning of the tool. It also does not require the use of any commercial software for the construction of a 3D model.

2. POTTERY CLASSIFICATION AND RECONSTRUCTION TOOL

The Pottery Classification and Reconstruction Tool, enables classification of both complete and partial pot profiles with great accuracy. It provides the user with a 3D model of a pot generated from an image of the pot's profile. This model can be manipulated by altering its radius and orientation in the 3D space. This enables an archaeologist to visualize and study the whole pot rather than relying on the pot profile for analysis. The tool's profile editor enables the addition of user defined splines to partial profiles. These extended profiles can also be visualized with the help of a 3D model. This section discusses some of the main features of the tool such as profile outline and control points extraction, classification of complete pot profiles, classification of partial pot profiles, pot profile editor, pot profile and spline databases and construction of 3D models of pots.

2.1 Profile Outline and Control Points Extraction

To facilitate the classification and reconstruction of a given pot's profile, it's outline and control points must be extracted from the image. Hence, upon loading an image of a profile the user is presented with it's outline and control points. Figure 1 shows the outline extracted from an image of a pot profile.

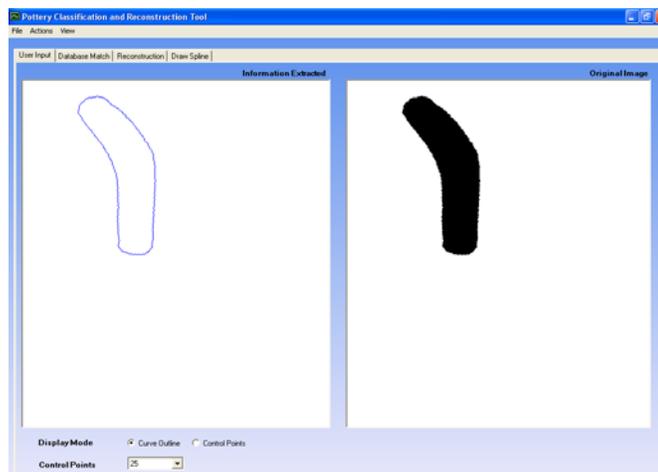


Fig. 1. Extraction of a profile outline

Points on the outline of a curve where there is an abrupt change in slope are termed as control points. Highlighting these points on the outline of a profile aids the archaeologist in analyzing it. The number of control points can be varied and the corresponding changes can be viewed simultaneously. The classification and reconstruction of profiles is directly based upon the number of control points chosen. Hence, it allows the archaeologist to view the effect of altering the number of control points on these two operations. Figure 2 shows the extraction of control points on the outline of a profile.

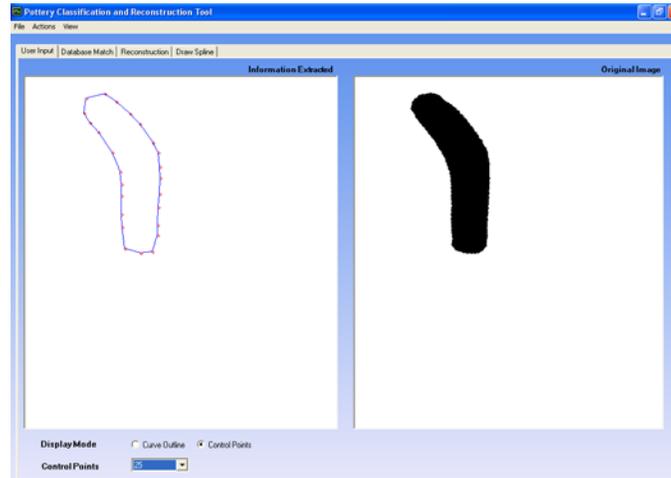


Fig. 2. Extraction of profile control points

2.2 Classification of Complete Pot Profiles

Archaeologists spend a lot of time classifying profiles which is a repetitive and tedious task. This tool enables the archaeologist to classify a profile based on a dynamic user defined database of profiles. After classification, the profiles most resembling the input profile are reported along with their names and values indicating the magnitude of difference from the original profile. The user can toggle between these profiles and can also compare each of the results by superimposing them onto the original profile. This method of classification is based on the Fourier Transform and hence is invariant of all affine transformations. Figure 3 shows the primary result of a classification process.

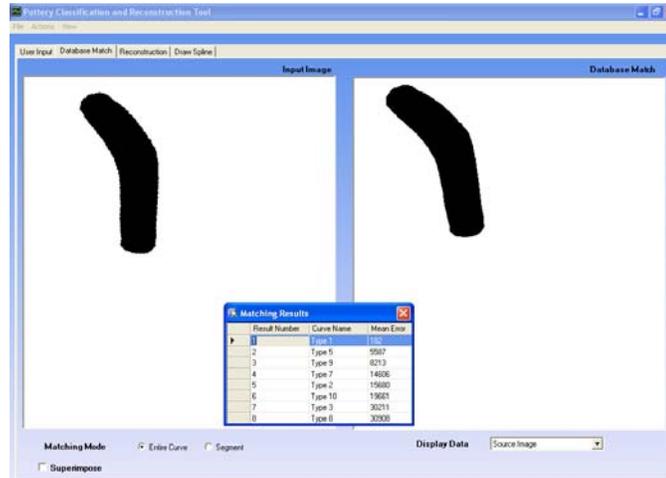


Fig. 3. Result of classification of a pot profile

2.3 Classification of Partial Pot Profiles

There are primarily two scenarios where in an archaeologist shall utilize this feature. The first scenario is when the input profile is of a shard and the complete profile to which it belongs must be located. Shown in Figure 4 is a profile of a shard which is found to be a part of a complete profile found in the database.

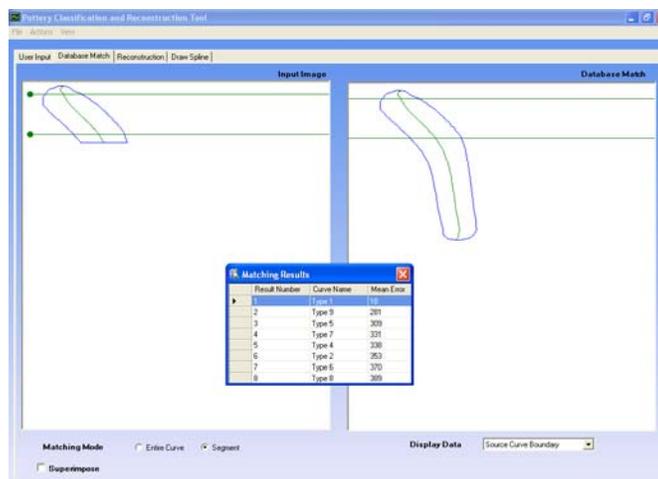


Fig. 4. Classification of partial pot profiles

The second scenario is when the user wants to find profiles that have a certain section in common, irrespective of their overall differences. Figure 5 shows the similarity found between sections of two different profiles. As in the case of complete profile classification, a group of profiles most resembling the input profile are reported along with their names and a value indicating the difference in magnitude from the original profile. Partial profile classification is achieved by applying the Fourier Transform on profile skeletons, the details of which are discussed in further sections.

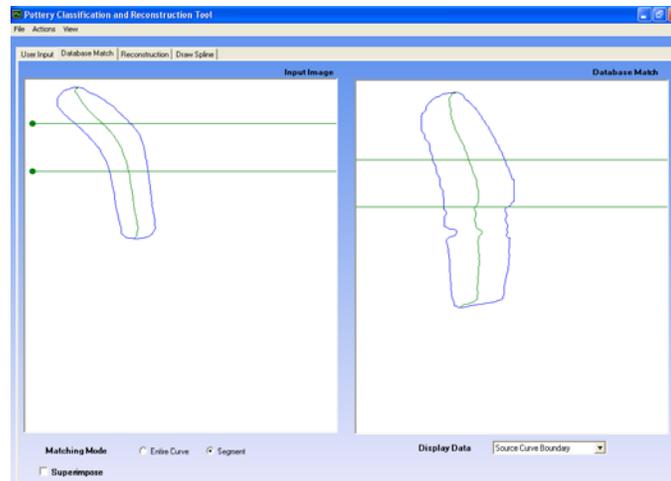


Fig. 5. Classification of sectional pot profiles

2.4 Pot Profile Editor

The pot profile editor enables the alteration of pot profiles via the addition of user defined splines. The tool's pot profile editor is shown in Figure 5. A spline can be created by altering control points (shown as green dots along the splines length) in number and in location. A previously saved spline can also be loaded from the database. Splines can be appended to any point along the boundary of an existing pot profile and, corresponding changes to the pot profile and the 3D model of the pot can be viewed simultaneously. Archaeologists can utilize this feature for altering profiles of complete pots and also for extending profiles of fragments i.e. incomplete pot profiles.

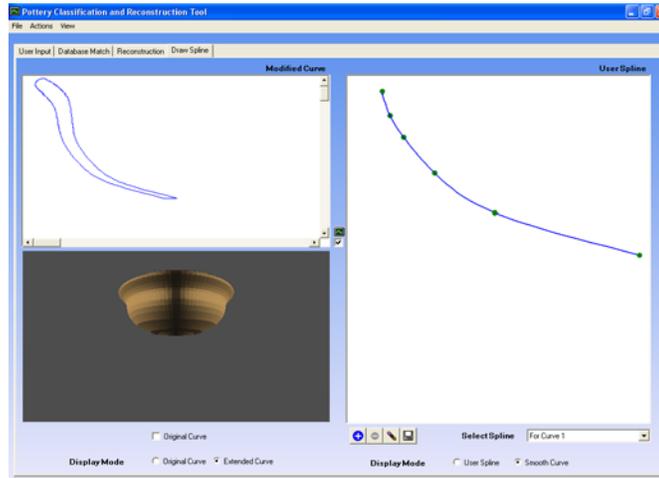


Fig. 5. The pot profile editor

2.5 Pot Profile and Spline Databases

The classification of partial and complete pot profiles is done with respect to a dynamic user defined database of profiles. To add a new profile to the database, an image of the profile is provided to the tool for computations. Following which, that profile is added to the database and instantly becomes available for comparisons. There also exists a separate database of user defined splines. After creation of a spline in the pot profile editor, it can be added into this database. This enables the archaeologist to apply the same base to several different pot profiles without having to redraw the spline.

2.6 Construction of 3D Models of Pots

The construction of 3D models is based on the assumption that all pots have been created on a potter's wheel and are hence symmetric about the Y axis. With the help of this assumption and the pot profile data the tool creates an interactive 3D model of the pot. However, since the tool receives a 2D image of the pot's profile as input, it is impossible to predict the radius of the pot. To counter this, the radius of the constructed pot can be varied and the corresponding changes can be viewed simultaneously. The orientation of the pot can also be

altered enabling the user to view the pot from all angles. 3D models can be constructed from the input pot profiles as well the extended pot profiles. Furthermore, utilizing the spline database discussed in the previous section, a variety of splines can be attached to a 3D model and a single spline can be attached to a variety of models. Figure 6 shows the construction of a 3D model of a pot.

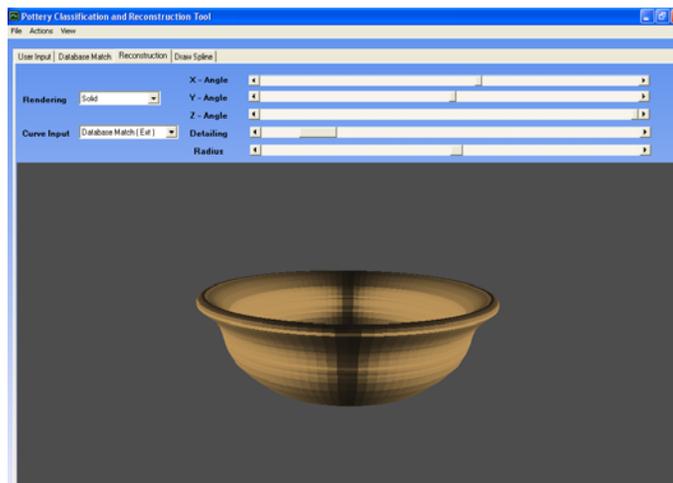


Fig. 6. A 3D model created from an input pot profile

3. OUTLINE OF ALGORITHMS

This section gives a brief description of the main algorithms which were used to create the Pottery Reconstruction and Classification Tool. The main algorithms which have been discussed are extraction of profile outline, extraction of profile control points, classification of complete pot profiles, classification of partial pot profiles and construction of 3D models of pots.

3.1 Extraction of Profile Outline

The extraction of a profile outline may seem like a trivial task, but there are several complications which arise when the pot profile is in the form of an image. Firstly, at pixel

level the edges of the profiles have jagged edges. Secondly, these edges need not be uniformly joined and may have breaks in between them. Figure 7 illustrates both these complications in a zoomed image of a pot profile. Thirdly, the orientation of the profile within the image is not fixed; hence the algorithm must be applicable to all orientations and sizes.



Fig. 7. A zoomed view of a pot profile

To counter all these complications the entire image is treated as a large maze and a crawler is utilized to trace the outline of the profile. The crawler is a name for the sub routine whose function is to trace the outline of the profile. This crawler upon locating the first non white pixel in the image starts to follow the boundary pixels of the profile until it again reaches the first pixel. Any pixel which has one or more white pixels as its neighbors is defined as a boundary pixel. Each of the eight traversable directions (in the maze) is assigned a priority according to which the crawler moves. Along with the search direction it also keeps track of the last few boundary pixels in order to avoid back tracing. Figure 8 shows the resultant outline after applying a crawler to the profile shown in Figure 7.

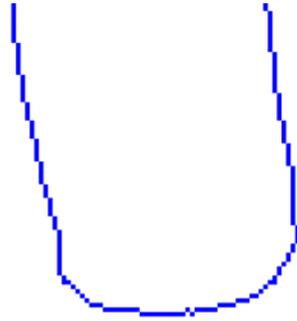


Fig. 8. A zoomed view of the outline of the pot profile in figure 7

3.2 Extraction of Profile Control Points

Control points are computed along the boundary of a pot profile to reduce the computations involved in the process of reconstruction and classification. Control points are chosen on the pot's profile by removing the irrelevant shape features and keeping the relevant ones. This is achieved by iteratively comparing the relevance measure of all points on the profile. For each of these iterations, the vertex that has the lowest relevance measure is removed and a new segment is established by connecting the two adjacent points. A higher relevance value signifies that the vertex has larger contribution to the shape of the curve. The details of this method have been discussed in [6]. Figure 9 shows a comparison between a pot profile created using all available points and the same pot profile created using 25 control points.

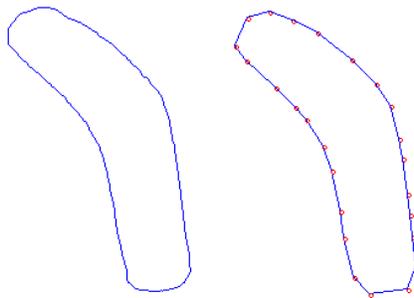


Fig. 9. A complete pot profile compared with its 25 control points

3.3 Classification of Complete Pot Profiles

For the purpose of classification, each pot profile is treated like a closed curve and the Fourier Transform is applied to the closed curve to obtain a power spectrum. After normalization, this power spectrum is invariant to all affine transformations. After computing the normalized power spectrum a similarity measure is computed between the input profile and each profile in the database. This similarity measure compares the first few values in the power spectrum (as the main energy of the power spectrum lies in these values) and computes an error value which represents the difference between the two profiles. Finally, the results are displayed in the increasing order of error values. Thus, a pot profile which has been distorted via an affine transformation such as translation, rotation, scaling, shearing or a combination of the above can still be successfully classified to its corresponding profile within the database. The details of computing the power spectrum and similarity measure are found in [6].

3.4 Classification of Partial Pot Profiles

Classification of partial pot profiles does not differ from the classification of complete profiles in the method of comparison but in the application of that method. The complexity involved in classifying partial profiles is much higher. Thus, to reduce the number of comparisons and to ensure a correct classification of the partial profile the Fourier Transform is applied to the skeleton of the profiles involved. Firstly, the skeleton of the partial profile is extracted and its normalized power spectrum is computed. Following which, each of the database profile skeletons are broken into fragments of the size of the input profile and their normalized power spectrums are computed. Similarity measures are then computed between each of the power spectrums of the fragments and the input profile to obtain error values. The results are then displayed in the increasing order of error values.

3.5 Construction of 3D Models of Pots

It is assumed that all pots have been created on a potter's wheel and are hence symmetric about the Y axis. Since it is impossible to compute the radius of a pot via a 2D image, an arbitrary value is chosen initially and this radius can later be edited interactively while the pot is being visualized. For the construction of a 3D model the control points on the pot profile need to be mapped into a spatial arrangement. To achieve this, a central axis is selected and the distance of each control point from that central axis is computed. Using this distance, the control point is mapped to be the boundary point for the pot's 3D model and is iteratively rotated around the Y axis to create a layer of the model. This process is repeated for every single control point. This generates a 3D arrangement of boundary points of the pot, which are then rendered using OpenGL.

4. Conclusion

We have presented a Pottery Classification and Reconstruction Tool which performs with great speed and accuracy, the task of classifying pot profiles. This task takes several hours if performed manually and the results of this method also depend upon the experience and skill of the classifier. The tool also enables the archaeologist to visualize and manipulate 3D models of pots which are created from 2D images of pot profiles. It also enables the classification and extension of partial pot profiles. We have discussed some of the earlier works in this field and pointed out their limitations of manual intervention and lack of speed. The same have been overcome in our tool. The tool's entire process of classification and reconstruction is extremely straightforward and user friendly and it empowers the archaeologist to conduct analysis of pottery in a novel and refined manner.

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