Geometric Modeling of Indian Archaeological Pottery: A Preliminary Study

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Abstract

Three-dimensional visualization of pottery sherds and vessels through AutoCAD and WiseImage has demonstrated that the technique holds promise in digital archiving of pottery traditions in India. To develop this work further, HNB Garhwal University, Srinagar, India has collaborated with Harcourt Butler Technological Institute, Kanpur, India, and the Indian Institute of Technology, Kanpur, to develop mathematical models for Indian archaeological pottery assemblages In this study, we have taken the two-dimensional pottery profiles from four different cultural phases in Indian archeology—Ochre Color Pottery (OCP), Painted Gray Ware (PGW), Black and Red Ware (B&R), and Northern Black Polished Ware (NBP)—to examine the geometric definitions in the form of polynomial equations. These mathematical definitions are generated mainly from curves using modern scientific tools of MATLAB and I-DEAS, which can be customized for achieving the objectives that will be mentioned in this discussion. The geometric analysis of pottery will be very helpful in scientifically understanding the classification system of Indian pottery, and will open a new line of enquiry into shape modeling of Indian archaeological ceramics.

1 Introduction

In India, the intervention of computing technology for three-dimensional (3D) modeling of archaeological pottery shapes has been attempted in recent years by the senior author (Nautiyal et al. 2000; Nautiyal et al. 2004). This work has expanded the scope of research to explore the new aspects of shape analysis and geometrical modeling. A review of other recent work shows that geometric modeling and shape feature analysis have increased in importance considerably as the amount of research has increased due to rapid advances in the area of CAGD (Computer-Aided Geometric Design) (Farin 1996). As a result of these advances, a significant amount of research has been done in the area of archiving and documenting pottery fragments. Schurmans et al. (2001) described various new computing methods for 3D digitization, archiving, and geometric modeling of pottery collections from the American Southwest, and their accessibility via the Internet. Kampel et al (2001) constructed a computer-aided documentation system for archaeological segments that leads to semi-automatic classification and reconstruction of pottery fragments. Any archaeological pottery or vessel can be best described by its shape or the flow of its curves (Stylianou and Farin 2002). Thus, on a fundamental level, any archaeological material can be mathematically defined and represented. The shape of vessels has been mathematically defined many times in the past, but a better understanding of shapes of these archaeological ceramics was proposed by Simon et al. (2002) based on geometric modeling techniques and feature extraction. In addition, Simon et al. described an XML-based information model for archaeological pottery collections.

In this paper, we propose a new approach based on geometric and mathematical modeling of various parameters of curves obtained from two-dimensional (2D) profile drawings of sherds from the site of Atranjikhera, India (Gaur 1983), as well as of the image of a full pot obtained from different views through a CCD (charge-coupled device) camera. We address two problems in this work: 1) finding mathematical expressions of the existing traditional pottery types belonging to different cultural phases in order to develop an intelligent system to retrieve, heal (repair holes or patches in the point cloud data), and extract geometrical features with high accuracy; and 2) exploring new computing tools for understanding the complexities of typological changes in Indian archaeological pottery shapes.

2 Schematic Variations in Indian Ceramics in Different Cultures

Pottery remains in archaeological sites represent the largest proportion of all the material and artifacts recovered in India. In the Indian context, the archaeological pottery from the Protohistoric to Historic periods reflects different cultural phases (Gaur 1983). The ceramic traditions have been classified into five groups, namely Ochre Colored Pottery (OCP), Painted Grey Ware (PGW), Black Slipped pottery (BSW), Northern Black Polished Ware (NBP), and Black and Red Ware (B&R Ware) (Figure 1). In all these ceramic traditions, the different types of vessels include basins,

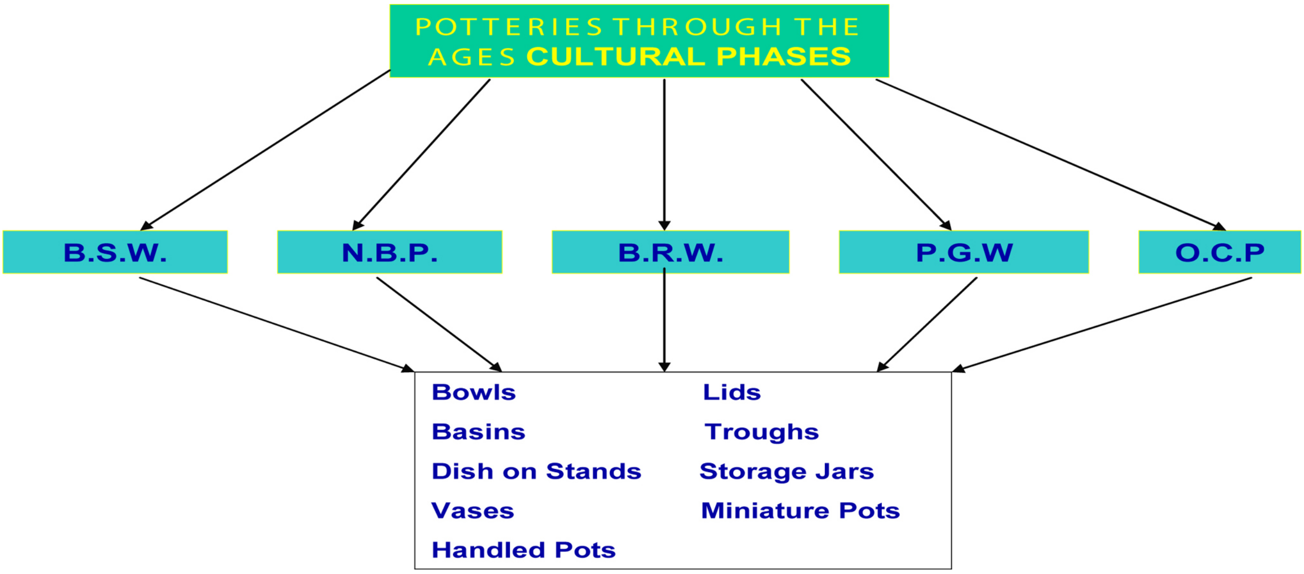


Figure 1. Diagram representing pottery types in different cultural phases in India.

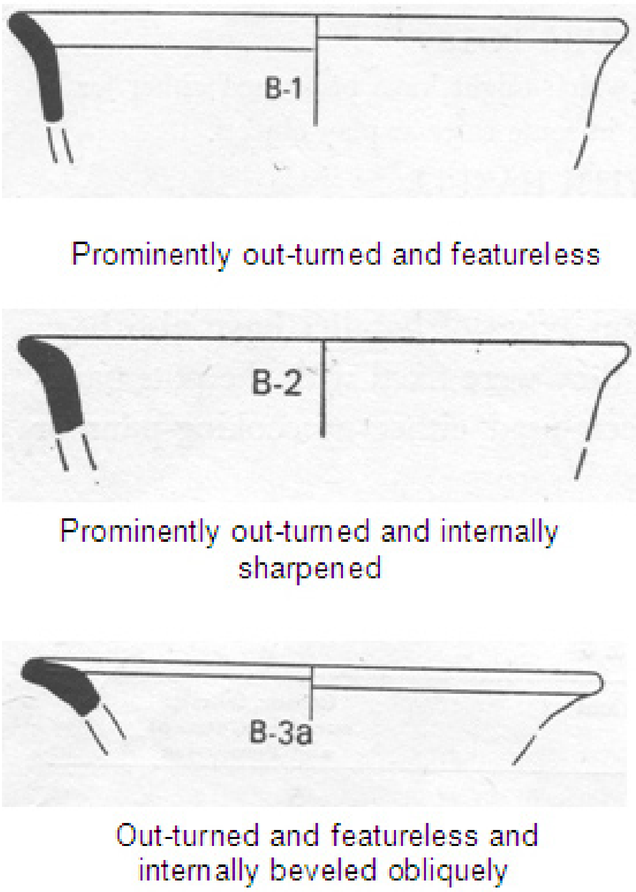


Figure 2. Typological variants of the Indian pottery types.

bowls, lids, troughs, dishes on stands, storage jars, vases, miniature pots, and handled pots, as shown in Figure 1.

The existing classification of Indian ceramics is primarily made on the basis of rim and neck type, which are documented through the 2D profile. The current classification system of the pottery types from one of the cultural phases, OCP, is shown in Figure 2. Our work mainly deals with geometrically modeling these pottery fragments, and obtaining mathematical definitions of the neck and rim portion of sherds belonging to different cultural phases so that the phases can be identified scientifically.

3 Methodology for the Geometric Modeling of Pottery Curvature

The process for geometric modeling of pottery curvature is described in the flow diagram in Figure 3, and these different stages are also discussed and illustrated in Figures 4a-14a.

3.1 Image Acquisition

The 2D image of the pot which we are considering here as an exemplar for subsequent modules can be acquired in the following ways (see Figures 4a-4c):
a) Through a CCD camera where the image of the pot under consideration is taken in different views and then all the views are fused together,
b) Through the 2D profile sketches,
c) Through the drawings by a draftsman.

3.2 Image Registration

The registration operation contains the following operations.

- **Scaling**. The acquired 2D image of the pottery is normalized in standard size by the use of 2D scaling. In this process the object may be compressed or expanded.
- **Rotation**. In the rotation phase, the scaled object is two-dimensionally rotated in order to align the acquired image with respect to X-axis.
- **Translation**. The aligned image is translated so as to fit in the positive X-axis.

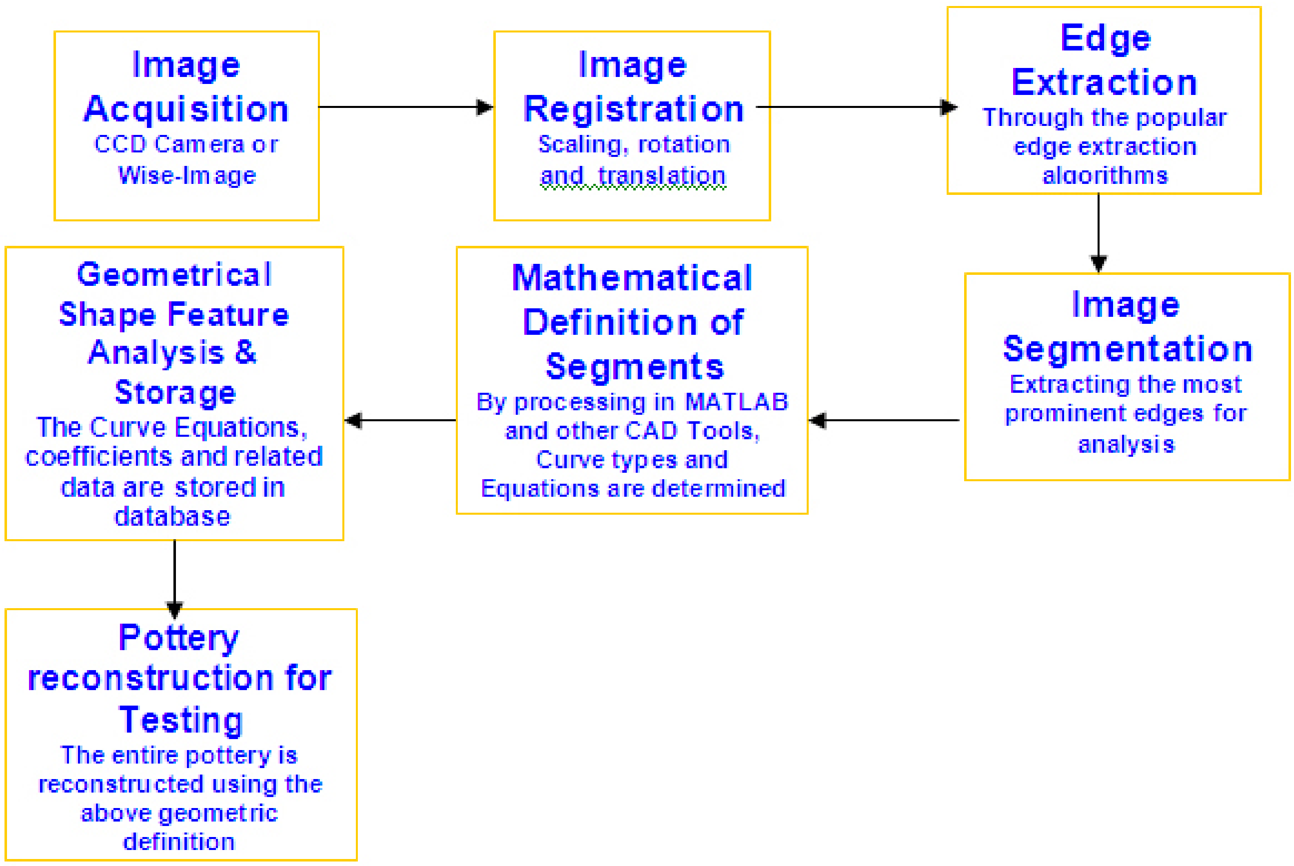


Figure 3. Approach for the geometrical modeling of pottery curvature.

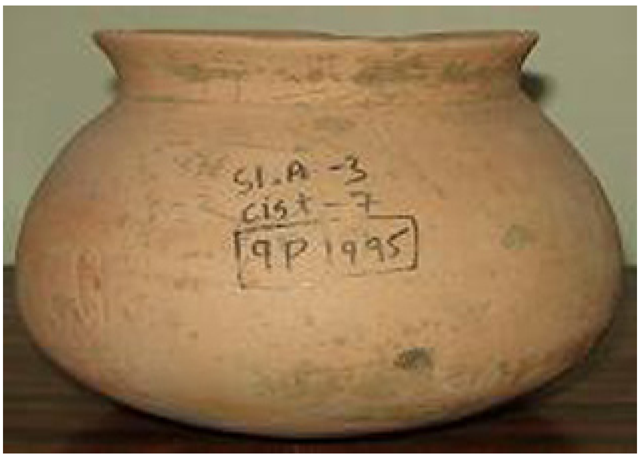


Figure 4a. Image acquired through a CCD camera.

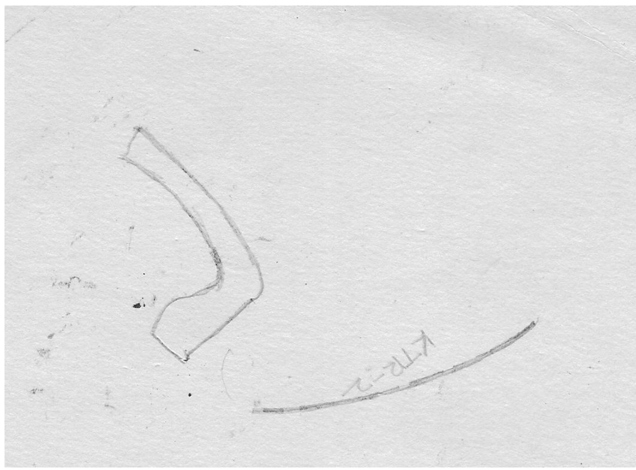


Figure 4c. Manual drawings drawn by draftsman.

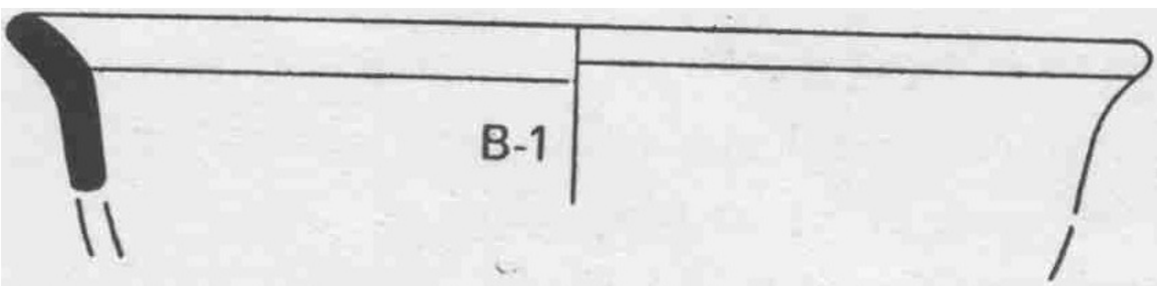


Figure 4b. A 2D profile sketch

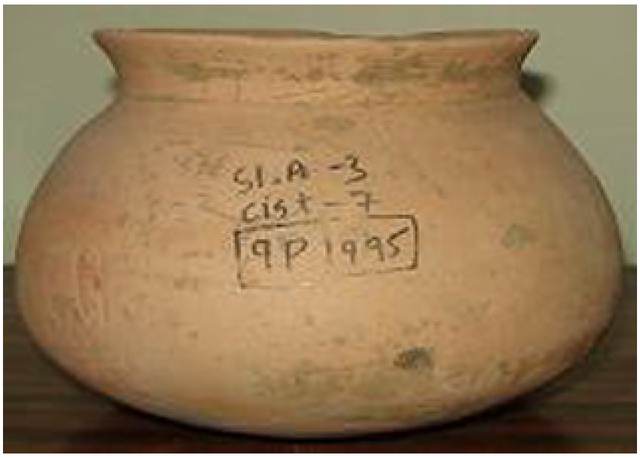


Figure 5a. CCD camera Image of pot.

Figure 5b. The extracted edges through the use of the Sobel filter.

3.3 Edge Extraction

Once the image is registered, its edges are extracted using a standard image processing edge extraction algorithm such as Sobel, Canny, etc**.** (See Figures 12.).

3.4 Segmentation

The most extensive edges are further segmented into smaller parts for further analysis and mathematical modeling. The following illustration shows the segmentation of the extracted edge of the left half of the pot shown in Figure 5. This segmentation is obtained by calculating the changes in curvature at the neck and rim region of the pot and then computing the point of inflection from the extracted edges (Figure 6).

3.5 Mathematical Modeling of Segments

The mathematical definition of each segment is obtained by processing the segments in MATLAB and CAD tools to obtain the curve types (Figures 7a-11a) and the equations for these curves (Figure7b-11b).

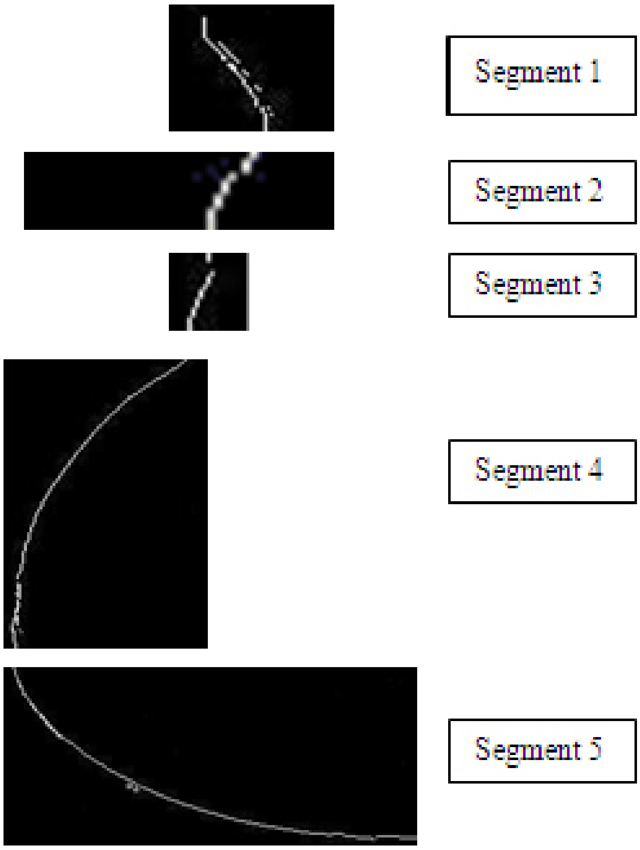


Figure 6. Domain Segmentation of the left half of the vessel.

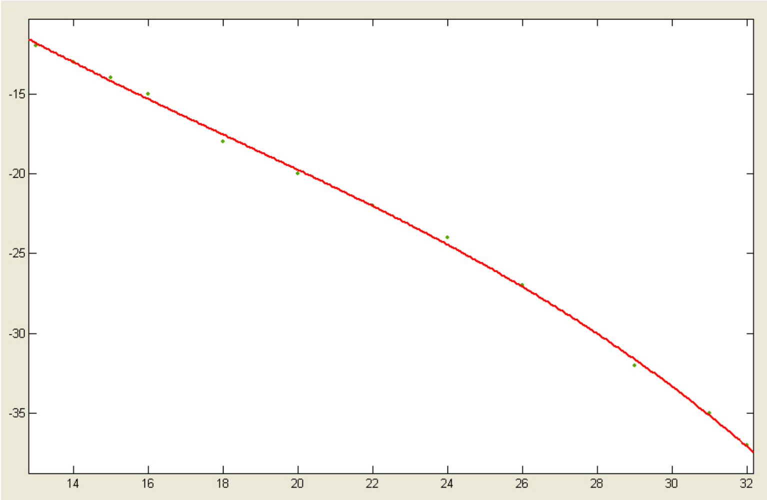
3.6 Geometrical Shape Feature Storage

The equations which have been extracted by the image capturing exercise basically represent the mathematical expression of the particular curve of the rim and the neck. The constants p1, p2, p3, and p4 in the equation have been extracted from the curve-fitting analysis. These are the differentiating factors of the pottery shapes. The values of the coefficients have been scaled accordingly in order to get the plots of the equations within the visible ranges.

The archaeological classification is supported by the corresponding mathematical equations. The equations are more or less similar for the different pottery types; the only difference lies in the coefficients of these equations. The corresponding set of coefficients (strictly taken from the indicated interval of the values), plot and depict the approximate outline of the concerned shape of the ceramics belonging to a specific culture. The curve equations, with their respective coefficients, and the related data obtained as the result of previous step are all stored in a database.

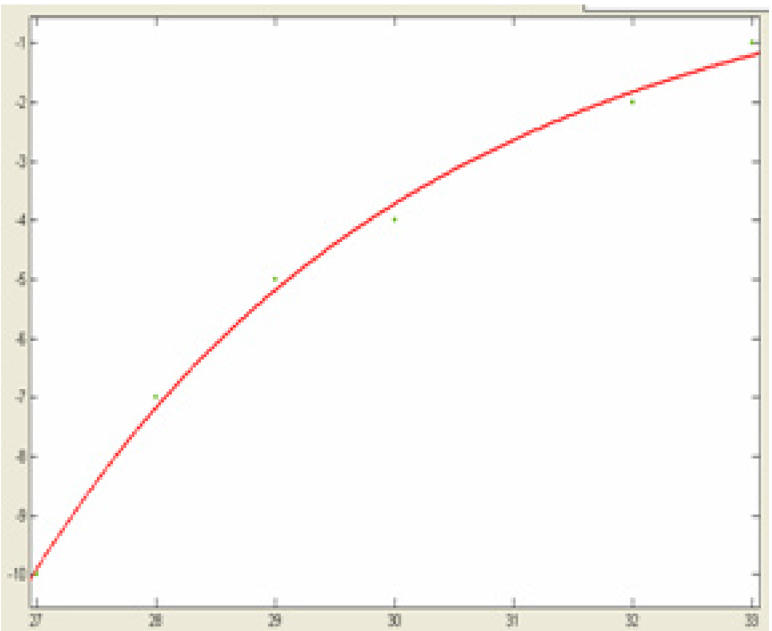
3.7 Pottery Reconstruction for Testing

The input image can be acquired through three methods, as discussed in section 3.1, suggesting that we are able to extract the exact edges irrespective of the technique being used, derive the mathematical definitions by retrieving their coefficients, and store this information in the database (Figures 6a,b-10a,b). For testing purposes, if we extract these coefficients from the database, we can generate the



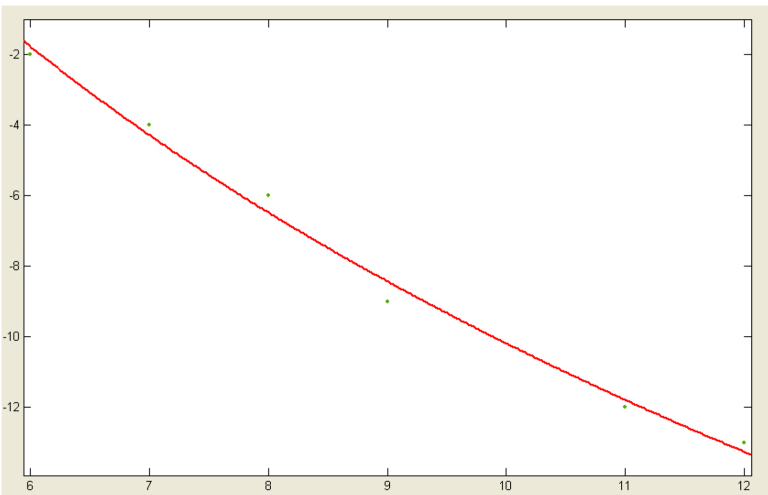
F(x) = p1*x^3 + p2*x^2 + p3*x + p4
p1 = -0.001593 (-0.003012, -0.0001751)
p2 = 0.08727 (-0.008616, 0.1831)
p3 = -2.691 (-4.767, -0.6146)
p4 = 11.9 (-2.43, 26.23)

Figure 7. a. Curve fit to Segment 1, b. mathematical modeling done to Segment 1.



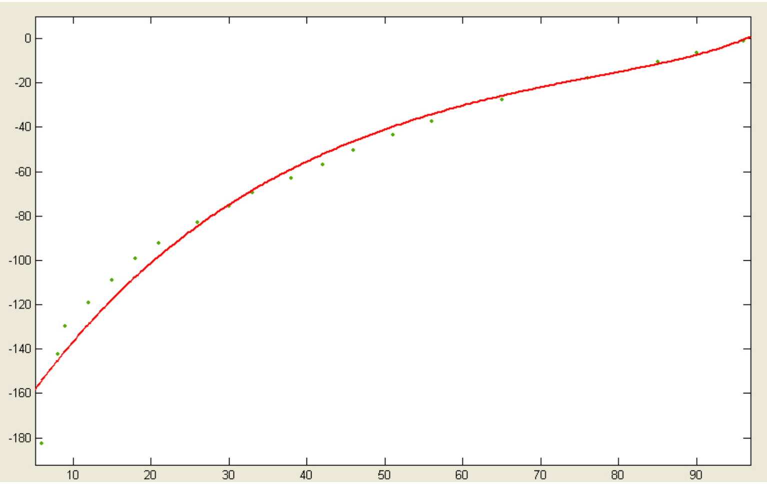
f(x) = a*x^b+c
a = -2.315e+012 (-3.454e+013, 2.991e+013)
b = -7.913 (-12.2, -3.623)
c = 1.021 (-1.916, 3.958)

Figure 8. a. Curve fit to Segment 2, b. mathematical modeling done to Segment 2.



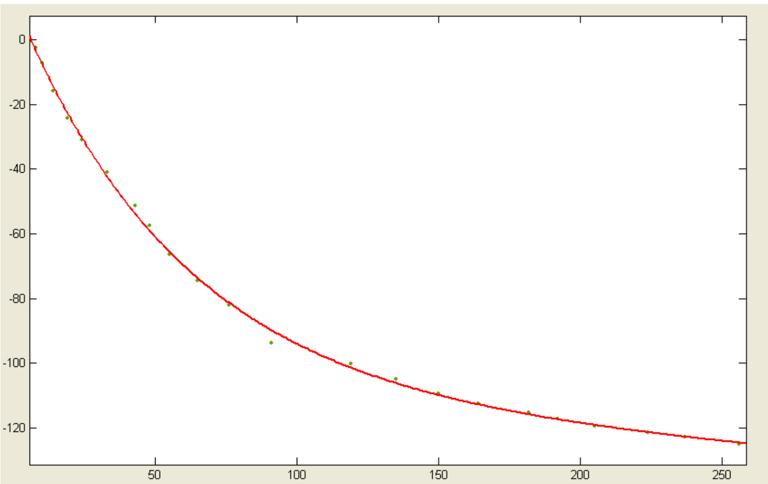
f(x) = a*x^b+c
a = -217.5 (-6493, 6058)
b = 0.06617 (-1.605, 1.737)
c = 243.1 (-6090, 6576)

Figure 9. a. Curve fit to Segment 3, b. mathematical modeling done to Segment3.



f(x) = a*exp(b*x) + c*exp(d*x)
a = 0.0001768 (-0.007873, 0.008227)
b = 0.1137 (-0.3677, 0.5951)
c = -184.5 (-200.5, -168.4)
d = -0.03006 (-0.03456, -0.02557)

Figure 10. a. Curve fit to Segment 4, *b. mathematical modeling done to Segment 4*



f(x) = a*exp(b*x) + c*exp(d*x)
a = -110.4 (-125.4, -95.34)
b = 0.0005211 (-3.701e-005, 0.001079)
c = 122.9 (109.6, 136.2
d = -0.01707 (-0.02005, -0.01408)

Figure 11. a. Curve fit to Segment 5, *b. mathematical modeling done to Segment 5.*

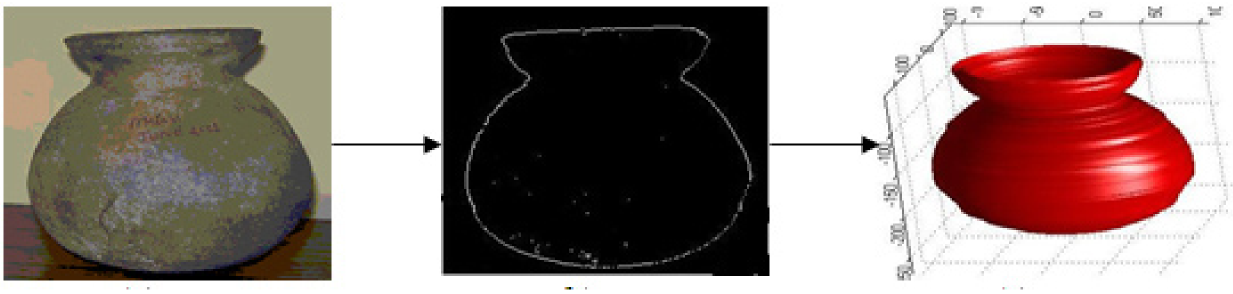


Figure 12a. Input media is digital image acquired through CCD camera, b. extracted edges, c. reconstructed pot.

exact replicas of shapes (as far as we can assume) of the pottery types of a particular period. The software packages of MATLAB and I-DEAS have been used in the present study.

4 Results and Conclusions

Our preliminary work mainly deals with geometrical modeling of Indian archaeological pottery to give definitions to the various pottery shapes acquired through different media. This is very helpful in understanding the classification system of Indian pottery in the most scientific manner. It can also help to improve the existing pottery definition in a mathematical perspective in order to make an accurate classification with a representative prototype for each period. We have obtained encouraging results as far as the analysis and comparison of shape features of pottery sherds pertaining to different periods is concerned. Additionally, we tried to test our definitions by reconstructing the entire pottery shapes from the parameters we had saved in our database, and we could do the healing and reconstruction of broken pottery vessels with the maximum possible accuracy. Many challenges still lie ahead to systematically classify the pottery types because the existing method is based on observations from an individual item and, therefore, suffers from various inconsistencies.

In order to build up a robust classification system, we have to take into account the computation of consistency or inconsistency of pottery making throughout Indian history, and seek to understand the influence of wheel dynamics on the pottery shape. Though the present study is preliminary in nature, it may provide a foundation to develop a method of pottery classification on the basis of geometrical modeling. Therefore, the authors believe that a detailed analysis of a larger number of samples may provide a better understanding of this problem. Currently, we are also in the process of making an interactive GUI to make the archaeological computing user friendly and of broader interest

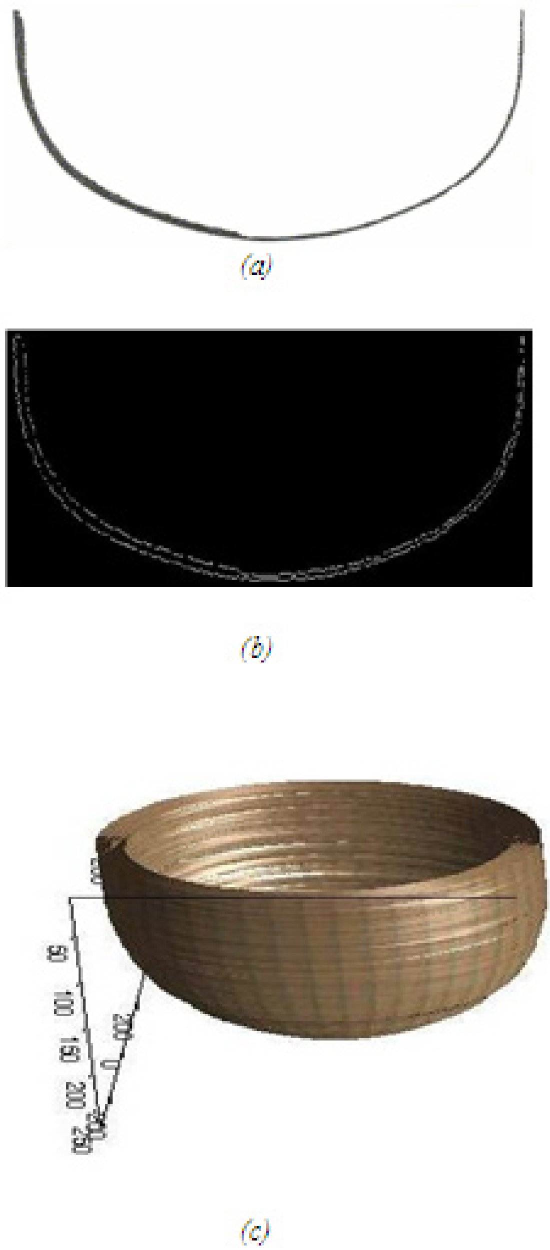


Figure 13. a. Bowl sketch with definition: vertically and internally sharpened, rounded sides to a sagger base, b. detected edges, c. regenerated 3D model through mathematical definition.

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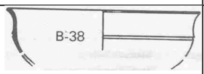
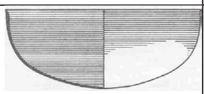
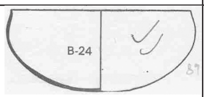
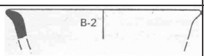
PER-IOD	REPRESENTATIVE MEMBER	CLASSIFI-CATION SYSTEM	MATHEMATICAL MODEL	VARIATION OF COEFFICIENTS	First Derivative	Second Derivative
NBP		1. Vertical and internally sharpened, 2. Almost vertical and internally sharpened, 3. Flaring Featureless and slightly sharpened	1. Exponential [a*exp(b*x)] 2. Exponential [a*exp(b*x) + c*exp(d*x)] 3. Quadratic polynomial [a*x*x+b*x+c]	1. ‘a’ belongs to (7.156, 8.284), ‘b’ to (-0.191, 0.238). 2. ‘a’ belongs to (6.344, 8.097), ‘b’ to (-0.344, 0.985), ‘c’ to (4.113,7.341),’d’ to (-0.142, 0.452). 3. ‘a’ belongs to (4.326, 9.341), ‘b’ to (-23.378, -8.262), ‘c’ to (1.735, 7.382).	1. Exponential [a*b*exp(b*x)] 2. Exponential [a*b*exp(b*x) + c*d*exp(d*x)] 3. Quadratic polynomial [2*a*x+b]	1. Exponential [a*b*b*exp(b*x)] 2. Exponential [a*b*b*exp(b*x) + c*d*d*exp(d*x)] 3. Quadratic polynomial [2*a]
BRW		1. Prominently outturned 2. Externally thickened 3. Internally beveled	1. Exponential [a*exp(b*x)] 2. Exponential [a*exp(b*x) + c*exp(d*x)] 3. Exponential [a*exp(b*x) + c*exp(d*x)]	1. ‘a’ belongs to(5.798, 9.768), ‘b’ to (-0.659, 1.767). 2. ‘a’ belongs to (5.344, 18.767), ‘b’ to (-1.924, -0.462), ‘c’ to (4.569,8.498),’d’ to (-2.167, 1.672). 3. ‘a’ belongs to (6.736, 11.864), ‘b’ to (3.640, 8.971), ‘c’ to (7.765, 9.754), ‘d’ to (-1.867, 1.876).	1. Exponential [a*b*exp(b*x)] 2. Exponential [a*b*exp(b*x) + c*d*exp(d*x)] 3. Exponential [a*b*exp(b*x) + c*d*exp(d*x)]	1. Exponential [a*b*exp(b*x)] 2. Exponential [a*b*exp(b*x) + c*d*exp(d*x)] 3. Exponential [a*b*exp(b*x) + c*d*exp(d*x)]
PGW		1. Outturned 2. Sharpened Internally	1. Quadratic polynomial [a*x*x+b*x+c] 2. Exponential - [a*exp(b*x) + c*exp(d*x)]	1. ‘a’ belongs to(6.7954, 9.989), ‘b’ to (-0.983, 1.421), ‘c’ to (-1.7609, 1.879). 2. ‘a’ belongs to (4.877, 14.797), ‘b’ to (-1.348, -0.7987), ‘c’ to (7.656,9.488,’d’ to (-5.167, -3.675).	1. Quadratic polynomial [2*a*x+b] 2. Exponential - [a*b*exp(b*x) + c*d*exp(d*x)]	1. Quadratic polynomial [2*a] 2. Exponential - [a*b*b*exp(b*x) + c*d*d*exp(d*x)]
OCP		1. Prominently Outturned 2. Internally Sharpened	1. Exponential - [a*exp(b*x) + c*exp(d*x)] 2. Exponential - [a*exp(b*x) + c*exp(d*x)]	1. ‘a’ belongs to (8.677, 17.567), ‘b’ to (-2.786, -0.7865), ‘c’ to (7.7657,9.876),’d’ to (-7.4687, -2.768). 2. ‘a’ belongs to (7.567, 14.297), ‘b’ to (4.572, 9.759), ‘c’ to (7.748, 11.698), ‘d’ to (-2.579, 8.786).	1. Exponential - [a*b*exp(b*x) + c*d*exp(d*x)] 2. Exponential - [a*b*exp(b*x) + c*d*exp(d*x)]	1. Exponential - [a*b*b*exp(b*x) + c*d*d*exp(d*x)] 2. Exponential - [a*b*b*exp(b*x) + c*d*d*exp(d*x)]

Figure 14. This chart shows the different cultural periods, one representative member, the classical definitions given to such respective profiles, and the mathematical model given by new method.

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