Using Geometric Modeling for Archiving and Searching 3D Archaeological Vessels

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Abstract - *This paper presents a method for archiving and searching 3D Native American ceramic vessels using geometric modeling techniques. Archaeological vessels are scanned and defined as a set of three-dimensional triangulated meshes composed of points, edges and triangles. Our work includes modeling the data with parametric surfaces, extracting features to raise the level of abstraction of data, and organizing vessel data based on XML schema. A visual query interface on the Web was developed that permits users to sketch or select sample vessel shapes to augment text and metric search criteria to retrieve original and modeled data, and interactive 2D and 3D models.*

Keywords: Geometric Modeling; XML; 3D Shape; Feature Extracting; Archaeological Vessels; Content-based 3D Search

1 Introduction

The understanding of 3D structures is essential to many scientific endeavors. Recent theoretical and technological breakthroughs in mathematical modeling of 3D data and data-capturing techniques present the opportunity to advance 3D knowledge into new realms of cross-disciplinary research. 3D knowledge plays an important role in archaeology. Archaeologists study the 3D form of Native American pottery to characterize the development of cultures. Quantitative methods of reasoning about the shape of a vessel are becoming far more powerful than was possible when vessel shape was first given a mathematical treatment by G. Birkhoff [1]. Conventionally, vessel classification is done by an expert and is subjective and prone to inaccuracies. The measurements are crude and in some case eyeballing is the method of choice.

In this paper we describe geometric modeling techniques used in our research to describe 3D archaeological vessels from the Classic Period (A. D. 1250 – 1450) of the prehistoric Hohokam culture area of the Southwest (Salt/Gila River Valleys) near present-day Phoenix, Arizona, extract features from geometric models to raise the level of abstraction of data, and develop a web based Visual Query Interface (VQI) to archive and search vessels. Our research involves obtaining shape information from the scanned three-dimensional data of archaeological vessels, using 2D and 3D geometric models to represent scanned vessels, extracting features from geometric models and storing the feature information in database for Web-based retrieval. This paper is structured as fellows. Part two describes archaeological vessel features from the point of view of archaeologists. Part three introduces geometric modeling for vessels. Some feature recognition methods used to extract archaeological vessel features are presented in part four. The VQI for archiving and searching archaeological vessels on the Web are described in part five. Conclusions and further research direction can be found in part six.

2 Features of Archaeological Vessels

Features have different definitions in different application domains. In this paper, features of archaeological vessels mean form feature. Traditionally, much attention has been paid to extract form features from mechanical parts. One hypothesis of this feature extraction problem is that all form features are face oriented. A form feature is defined as a set of faces with distinct topological and geometrical characteristics [2]. Three kinds of traditional methods to extract form features: (i) rule-based method, (ii) graph-based method, and (iii) neural net method also mainly deal with "face features", regions of interest in a part model. Form features in our project have an extensive application domain. Further more, form features are not limited to faces. Feature information can be divided into four categories: Points, Curves, Regions and Volumes. Following is our feature classification.

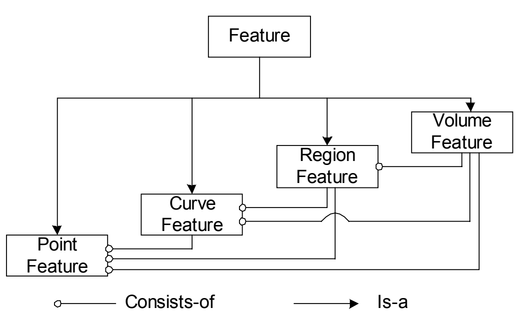

Figure 1. Feature classification

2.1 Features of Vessel Profile Curves

Mostly archaeological vessels are (approximately) surfaces of revolution, and studying contour shape will suffice to gather shape information about the whole object. According to archaeological definition [1] there are four kinds of feature points on profile curves to calculate dimensions and proportions of vessels. They are End Points (EPs), Points of Vertical Tangency (VTs), Inflection Points (IPs) and Corner Points (CPs) found on the vertical profile curve of a vessel:

- *End Points* - points at the rim (lip) or at the base (i.e. top and bottom of vessels).
- *Points of Vertical Tangency* - points at the place where is the maximum diameter on spheroidal form or minimum diameter on hyperbolic form.
- *Inflection Poinst* - points of change from concave to convex, or vice versa.
- *Corner Point*s - points of sharp change on a profile curve. See Figure 2.

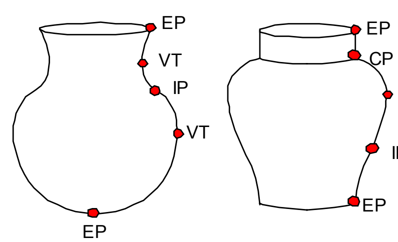

Figure 2. Feature points of vessel profile curves

2.2 Features Common to All Vessels

Next four features are common to all vessels:

- *Orifice* - the opening of the vessel, or the minimum diameter of the opening, may be the same as the rim, or below the rim.
- *Rim* - the finished edge of the top or opening of the vessel. It may or may not

be the same as the orifice. It may have a larger diameter.

- *Body* - the form of the vessel below the orifice and above the base.

- *Base* - the bottom of the vessel, portion upon which it rests, or sits on a surface. The base may be convex, flat, or concave, or a combination of these. See figure 3.

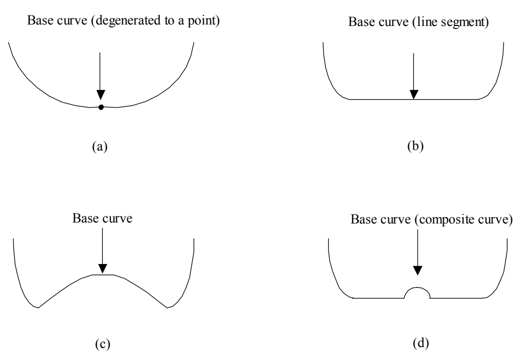

Figure 3. Four kinds of bases. (a) Convex base. (b) Flat base with zero curvature. (c) Concave base. (d) Composite base

2.3 Formal Description for Features

From above definition for characteristic points and common features for all vessels, we can formalize feature representation of vessels as below.

<Point Feature> :=<End Point Feature> |< Point of Vertical Tangency Feature> |< Inflection Point Feature> | <Corner Point Feature>;
<Curve Feature> := <Rim Curve Feature> |< Orifice Curve Feature> |< Base Curve Feature>;
<Rim Curve Feature> :=<End Point Feature>< End Point Feature>;
<Orifice Curve Feature> :=<Corner Point Feature> <Corner Point Feature>;
<Base Curve Feature> := <End Point Feature> |<End Point Feature>< End Point Feature>
<Region Feature> :=< Neck Region Feature> |< Body Region Feature> |< Base Region Feature>;
<Neck Region Feature> := <Rim Curve Feature><Orifice Curve Feature>;
<Body Region Feature> := <Orifice Curve Feature>< Base Curve Feature>;
<Base Region Feature> := <Base Curve Feature>;
<Volume Feature> :=< Unrestricted Volume Feature> |< Restricted Volume Feature>.

We use Extensible Markup Language (XML)[3] to represent information of vessels. XML is the standard format for structured document/data interchange on the Web. Like HTML, an XML document holds text annotated by tags. However, unlike HTML, XML allows an unlimited set of tags, each indicating not how something should look, but what it means. This characteristic is invaluable to information sharing. We design an XML schema to represent geometric information, feature information and measured value of archaeological vessels. Feature information is extracting from geometric information and is organized according to the feature formalism in the XML schema. Also feature information is used to index vessels stored in a database.

3 Geometric Modeling for Vessels

3.1 3D Geometric Models

(1) Polygonal Meshes

After scanning an archaeological vessel via a 3D laser scanner (Cyberware 3030), we can get a polygonal mesh that is constituted of faces, edges and vertices. The polygonal mesh is used as a raw data for further analysis. Polygon Meshes M are 3-tuples, i.e. M = (*V*, *E*, *F*) where *V* is vertex set, *E* is edge set, and *F* is face set**.**

(2) Surface Models

One of representing or modeling surfaces is via parametric surfaces such as B-Spline or NURBS. Surface models are generated by fitting points of polygonal meshes with least squares approximation. We use such representation to enable us to rebuild models, analyze properties such as curvatures, make quantitative measurements as well “repair” incomplete models. A NURB surface can be represented as

$$\vec{P}(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{i,j}\vec{d}_{i,j}N_{i,k}(u)N_{j,l}(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{i,j}N_{i,k}(u)N_{j,l}(v)} \quad (1)$$

where $\vec{d}_{i,j}$, i = 0, 1, …,m; j = 0,1,…n are control points, $w_{i,j}$ are weights, $N_{i,k}(u)$ and $N_{j,l}(v)$ are B-Spline basis functions. When weights equal 1.0, it reduces to a non-uniform B-Spline surface.

3.2 2D Geometric Models

Contour shape information plays an important role in analysis of archaeological vessels. We use two kinds of models, chain codes and NURB curves to represent profile curves of archaeological vessels. Using 2D geometric models can make problem simple, and reduce 3D problem to 2D problem.

(1) Chain codes

In order to get a 2D profile curve from a vessel, archaeologists use a cutting plane to intersect the vessel (polygonal mesh) and can get intersection points, then connect all the points according to some order, and get the chain code.

(2) NURB Curves

NURB curves are generated by fitting points of chain codes with least squares approximation. Since curvature has useful information such as convexity, smoothness, and inflection points of the curve needed by vessel analysis, we adopt cubic NURB curves to approximate profile curves of vessels

$$\vec{P}(u) = \frac{\sum_{i=0}^{n} w_i \vec{d}_i N_{i,k}(u)}{\sum_{i=0}^{n} w_i N_{i,k}(u)} \qquad (2)$$

where $\vec{d}_i$, i = 0, 1, …,n are control points, w_i are weights, $N_{i,k}(u)$ are B-Spline basis functions. Details are in [4].

3.3 Signed Curvatures for Profile Curves

One of the important characteristics of a curve is the curvature. The curvature is very useful for analysis and classification of vessel shape. In 3D space the curvature of curves is unsigned. However, for planar curves in 3D space, we can convert positive curvatures into signed curvatures [4, 5], see Figure 4.

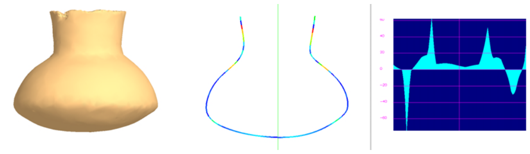

Figure 4. A vessel, its profile curve and signed curvature plot of the curve

4 Feature Recognition

Automated feature recognition and classification from a boundary-representation model, such as a polygonal shell or solid model, was first attempted in mid-1970s, with related work in the 1960s. The techniques are grouped into four categories: rule-based, graph-based, neural-based, and hybrid [6-8]. The rule-based approach uses artificial intelligence techniques to develop a set of "If…Then…Else" feature rules. The work includes pattern-matching techniques. Graph-based systems require matching the feature graph to the appropriate subgraphs in a solid modeler database. Neural-nets have the advantage in shape recognition in that they can be taught using exemplars and can recognize partial features using floating point outputs. Hybrid systems have been studied in an effort to supplant the shortcomings of generic approaches to feature recognition. Recently researchers [9] used curvature region (CR) approach for feature recognition in solid models. The CR approach categorizes features into two primitive shape classes: protrusions and depressions, and use curvature information to get the primitive shape feature from the solid model.

Curvatures are characteristic in this paper too. Mostly pots are rotation volumes, and contour shape can represent characteristic for pots. One of geometric features of a contour is its curvature. Feature points can be extracted from the contour by analyzing its curvatures. For example IPs can be located where the curvature changes from negative to positive or vice versa. CPs and EPs can also be researched from analyzing curvature plot of contour curves.

4.1 Extracting Point Features

We have classified Archaeological vessel features into hierarchic representation. Region features, such as body features, base features, can be determined by curve features. Further, Curve features can be determined by point features. So extracting point features is key here. We have developed several algorithms for that.

(1) Algorithm for extracting end point features
Input: a profile curve represented by B-Spline curve and chain code respectively.
Output: end point features
1. end point 1 ← start point of chain code; end point 2 ← end point of chain code;
2. center point ← center point of chain code;
3. find the base section around center
4. *if* base section is flat or concave *then*
   total end point number ←4; end point 3 ← left terminate of base section;
   end point 4 ← right terminate of base section;
   else { base is convex}
   total end point number ←3; end point 3 ← center;
5. calculate feature information for each end points, include space coordinates, parameter value, position on the chain code, and so on;

(2) Algorithm for extracting corner point features
Input: a profile curve represented by B-Spline curve and chain code respectively.
Output: corner point features
1. calculate curvature value for each points on chain code;
2. find points with local maximum (minimum) curvature value as candidates for corner points;
3. *for* all candidates
   if angle at the candidate point < a predefined value *then*
   the candidate point is a corner point.
4. calculate feature information for each corner points, include space coordinates, parameter value, position on the chain code, and so on;

As for inflection features and point of vertical tangency features, they are easy to find because it is to find inflection point and point of vertical tangency by analyzing curvature value and tangent lines.

When computing the angle between points (x_l, y_l), (x_0, y_0) and (x_r, y_r) in algorithm (2), we find the angle are sensitive to sample error. In order to reduce the error due to sampling, instead of taking (x_l, y_l) and (x_r, y_r) as points of the curve, the coordinates of these points are calculated by averaging the coordinates of a group of neighbors to perform a less noise prone resampling.

Let us consider the mid point (x_0, y_0) of n contiguous points in a chain code of a curve, where n is an odd number, and let p = n/2 + 1 be the point (x_0, y_0). Thus, the initial point of the angle (x_l, y_l) is calculated from the n/2 + 1 previous point as

$$x_l = \frac{\sum_{i=1}^{p} x_i}{n/2+1}, \quad y_l = \frac{\sum_{i=1}^{p} y_i}{n/2+1} \quad (3)$$

and similarly for the end point of the angle (x_r, y_r)

$$x_r = \frac{\sum_{i=p}^{n} x_i}{n/2+1}, \quad y_r = \frac{\sum_{i=p}^{n} y_i}{n/2+1} \quad (4)$$

4.2 Some Results for Point Features

Figure 5 (a) and (b) show end point extracting results under convex base case, and concave base case respectively. Dark green points are end points, and light green points are inflection points. Figure 5 (c) shows the result of finding corner points in red points.

5 Visual Query Interface (VQI)

After getting point features we continue finding curve features and region features based on feature hierarchical definition. Then we use XML to represent the result. The purpose of using XML to represent information is that we can develop a distributed and web based visual query interface for archiving and searching 3D archeological vessels. Embedding data in XML adds structure and web accessibility to the inherent information of archeological vessels. Figure 6 describes the flow chart of the Web-based VQI.

The query process in VQI combines a sketch-based interface and searches by traditional text and metric data. Representative vessel shapes can be selected from the supplied palette and modified, or a freeform profile sketch can be created in the interface window. Text and numeric fields support parallel query of descriptive and derived data within the

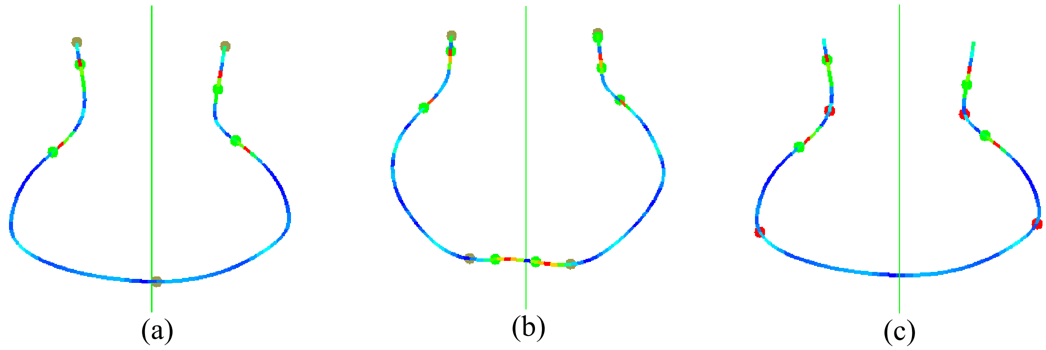

Figure 5. Point feature extracting

databases. Query results from database are stored in XML format, and are visualized via a pre-designed Extensive Stylesheet Language (XSL) file.

6 Conclusions and Future work

We present a method for archiving and searching 3D objects, Native American ceramic vessels using geometric modeling techniques. We have (i) modeled raw data of 3D archaeological vessels with parametric curves and surfaces, (ii) extracted features to raised the level of abstraction of data, (iii) organized vessel data based on XML and (iv) developed a visual query interface on the web for sharing information.

During our research we have found some problems that need solving in the future. First we observe that vessels are handmade, and some vessels are of irregular shape. It is impossible to use profile curves to describe the shape of these vessels. We often get broken vessels because they are "historical" objects. Completely refitting broken vessels is difficult task. All of these need our further work.

7 Acknowledgements

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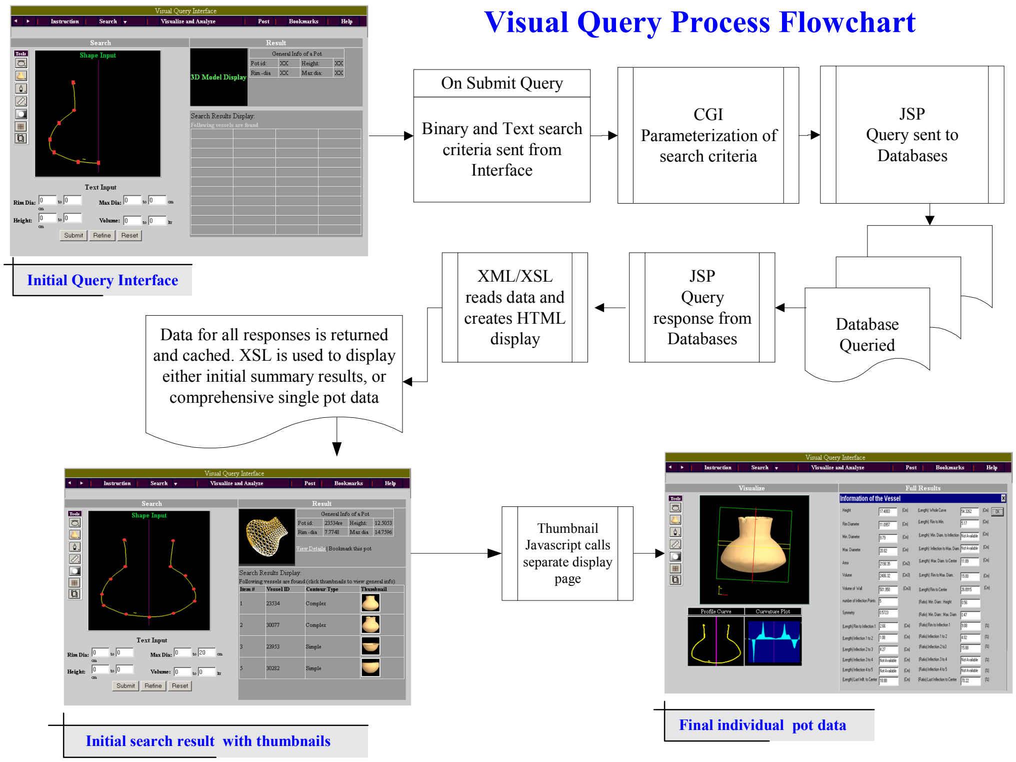

Figure 6. A Web-based visual query interface

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