Feature Extraction from 3D Data for the Modeling of Any Input Artifact/Sculpture to Support Its Identification

Vandana Dixit Kaushik, Rahul Gupta, Anand Singh, Ashish Kumar Vasisth, Krishna Kumar Verma, Vinay Pathak

Department of Computer Science & Engineering
Harcourt Butler Technological Institute
Kanpur, U.P, India
vandanadixitk@yahoo.com

Abstract

This paper attempts to study the various distinctive facial features present on Indian sculptures of different periods and then develop a method for automatic extraction of some features like shape of nose, nose line, etc., and then define such features geometrically. The geometric modeling further aids in automatic identification of 3D objects, and it can be extended to the identification of these sculptures/artifacts for their period of origin. For automation of facial feature extraction we are using Multi View Modeling through Z-Component Analysis. This algorithm uses the heuristic approach that takes the changes in z component of 3D coordinates into account and finds the point of maximum z, that is "nose tip" (in a normalized 3D image). Similarly, we calculate remaining control points on a sculpture's face with the help of an existing algorithm. The results of feature extraction and geometric modeling are encouraging.

1 Introduction

The biggest problem faced by the archeologists and art historians in India is to ascertain the period of origin of any sculpture. A large number of ancient sculptures and artifacts, after archaeological excavations, are lying unattended in museums all over the world. One of the well-known techniques to date these sculptures is radiocarbon dating, which is a specialized technique and can be used in a controlled environment in the presence of an expert. However, it is not sufficient to cater to million-year-old history, and it cannot be used to directly date stone sculptures. So, art historians have to identify manually the period to which any sculpture belongs based on their iconographic features and other related properties, such as the drapery and jewelry worn by the sculptured figure. There are lots of challenges in cataloging three-dimensional (3D) artworks (Levoy and Molina 2000), but the recent advances in laser rangefinder technology and digital imaging techniques reveal that many 3D scanners (optical and laser) are available today that enable us to scan almost any object, from small artifacts to life-sized artifacts, including large sculptures (Boehler and Marbs 2002).

Not only this, but various new algorithms in biometrics, especially related to face recognition and face identification, show that biometrics can be used to identify any individual human face (Zhao et al. 2003). Biometric identification techniques have made it possible to extract features like shape of eyes, curvature of eyebrows, nose, lips, etc., and also to define such features geometrically. Geometric modeling further aids in automatic identification and regeneration of our precious cultural heritage and, thus, can be extended to the identification of sculptures for their period of origin. For this, the main step leading to identification of sculptures is Feature Extraction. In archaeological research, 3D knowledge, including shape information and feature information, is vital (Razdan et al. 2001). The main characteristic of the sculpture's face is that it is a 3D elastic surface. This means that the 2D projection of a face is very sensitive to the illumination, head pose, and facial expressions. Trying to make face-recognition algorithms insensitive to these and other factors is one of the main areas of current research.

These recent technological breakthroughs in mathematical modeling of 3D objects and data acquisition techniques brings a new opportunity to explore 3D modeling of facial features, which can be extended to giving precise geometric definition to Indian sculptures of various periods. In this paper, we propose a simple and robust algorithm based on *Z-Component Analysis* that is not sensitive to pose and illumination and can be used for automatic extraction of facial features such as nose, nose line, eyebrows, etc. from 3D data obtained through digital scanning. These features will further aid in giving mathematical definition to any human or sculpture face.

The following sections cover in detail the objectives behind this paper, the methodology adopted for 3D feature extraction using z-component analysis—which is further divided into many sub-sections—followed by results and conclusions.

2 Objectives

History reveals that Indian culture and its vast heritage are home to some very ancient and precious sculptures. Archaeological excavations have brought to light that these sculptures can be traced to different periods, like Kushan Period, Gupta Period, Post Gupta Period, etc. (Huntington and Huntington 1985). All of the sculptures of different periods have unique facial features characteristic of a specific period. Apart from these, concrete differences in facial

Table 1. Differences in Facial Features of Kushan Period and Gupta Period Sculptures.

Kushan Period	**Gupta Period**
Eyebrows are straight.	Eyebrows tend to take a sharp curve & extend up to ears. The two curves near the nose do not meet, but make a broad "L-shaped" angle.
Ear Lobes do not touch the shoulders	Ear Lobes are elongated.
A circular mark (urna mark) between two eyes on the forehead is very common in Buddha images.	Urna mark has completely vanished from the forehead in Buddha images.
Very raw features, such as broad nose, etc.	Idealistic features, such as straight nose etc.

biometric features of two periods (Joshi 2004) are given in Table 1 and the example sculptures are shown in Figures 1 and 2, respectively.

Based on these distinctions, it can be proposed to identify various facial features from sculptures of different periods because biometric identification techniques have made it possible to extract facial features (e.g., shape of eyes, curvature of eyebrows, nose, lips etc.) and to define such features geometrically.

3 Methodology

The overall methodology is divided into a number of sub-sections, which generally take place in the following sequence: 3D Object Acquisition, Analysis of 3D Object File, Registration, Normalization, Point Cloud Reduction, Point Cloud Subdivision, Feature Extraction, Mathematical Modeling, Parameter Processing, and Database Generation. The 3D object acquisition step is actually carried out in parallel with all other steps.

3.1 3D Object Acquisition

The very first operation includes the 2.5D scanning of a sculpture using an ATOS optical scanner, followed by digital image processing techniques such as edge detection, segmentation, and noise removal, to acquire a fine, 3D-mesh, geometric model. Figure 3 shows the output of the scanning process after noise removal and hole filling.

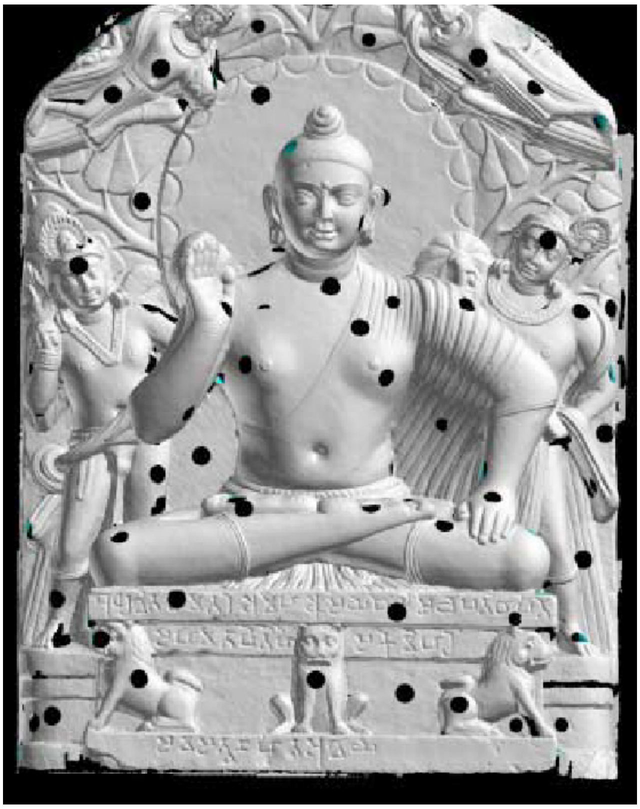


Figure 1. Gupta Period sculptures example: Sitting Buddha.

Figure 2. Gupta Period sculptures example: Standing Buddha.

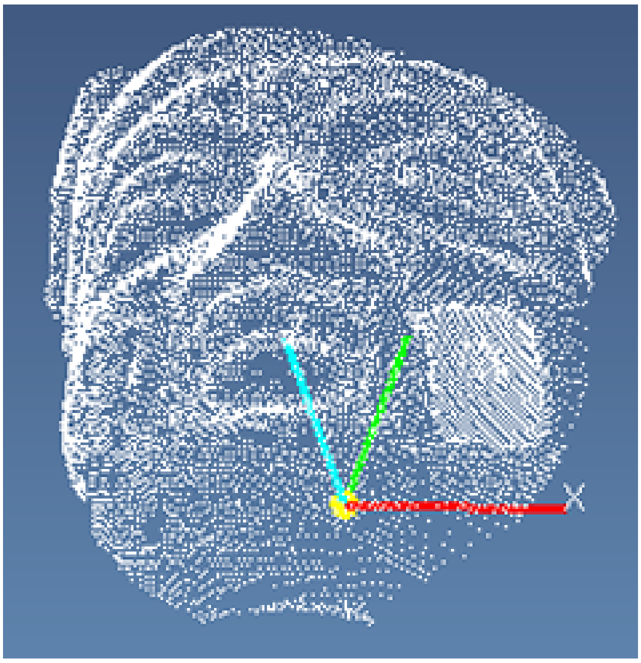


Figure 3. Triangulated 3D face mesh of the face of Lord Natraj.

3.2 Analysis and Registration of 3D Object File

The data generated by scanning requires the analysis of the file, including the study of different file formats (like *.stl, *.asc, *.ast, *.obj etc) and their inter-conversion in order to make them platform-independent and suitable for modern computation tools. We work mainly with the*.asc file of the scanned object.

Registration operation contains the following operations.

Making of a face equator line. The Equator Line of the 3D face is very helpful to start the automatic registry of object, and the selection of the correct Equator Line is very important. The definition of Equator Line is the backbone of model registration process. The Equator Line can be defined as follows.

Let R be the set of data fields containing the information (coordinate value of X, Y, Z and orientation of normal in terms of coefficients like X_{Normal} ,Y_{Normal}, Z_{Normal}) on different points. Rx, Ry, and Rz are the collections of X, Y, and Z coordinates of points in the point cloud data.

$$R = \{R_x, R_y, R_z, R_{xn}, R_{yn}, R_{zn}\}$$
$$R_x = \{X_1, X_2, X_3, \ldots\ldots, X_n\}$$
$$R_y = \{Y_1, Y_2, Y_3, \ldots\ldots, Y_n\}$$
$$R_z = \{Z_1, Z_2, Z_3, \ldots\ldots, Z_n\}$$
$$Z_{max} = Z_k, \text{ where } Z_k > (Z_i \square R_z),$$
$$\square \text{ i but } i \neq k, \text{ where } 1 \leq I \leq n.$$
$$P_T = (X_k, Y_k, Z_k)$$
$$Y_{min} = Y_l \text{ where } Y_l > (Y_j \square R_y), \square$$
$$\text{j but } j \neq l, \text{ where } 1 \leq j \leq n.$$
$$P_B = (X_l, Y_l, Z_l)$$

The Equator Line connects the P_T and P_B. Figure 4(a) shows the Face Equator line, the use of which will allow the entire face to be oriented.

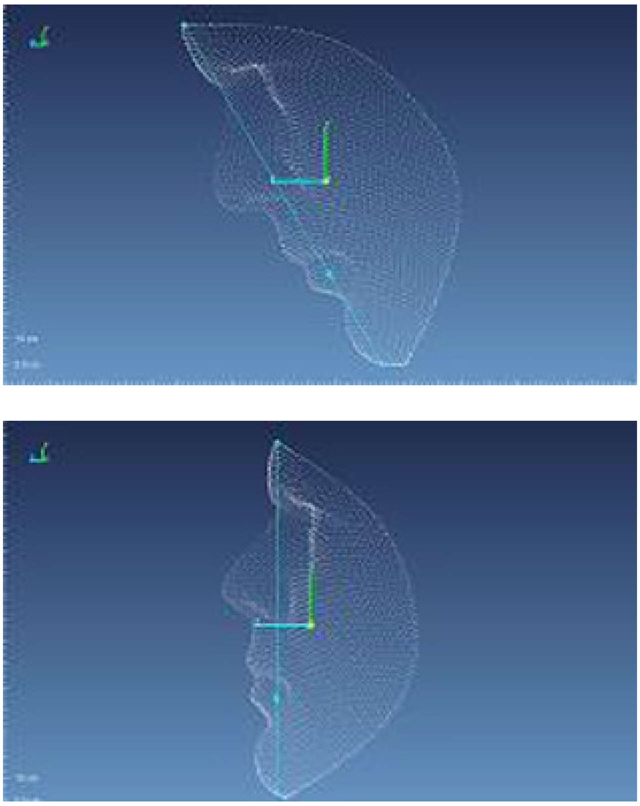


Figure 4. 3D face image registration. (top) Face Equator Line. (bottom) 3D rotated face.

Orientation of 3D Object. Now the 3D object can be three-dimensionally rotated with respect to the positive X, Z, and Y axes with the help of the equator line. Figure 4b shows the oriented face, which completes the registration process.

3.3 Normalization of Registered Object

The normalization of the registered 3D object is mainly achieved by bringing the object to a standard size. This normalization of a 3D image without a human being is a challenging task. It has sub-procedures of rotation, translation, and scaling in a series, i.e., rotation, translation, and scaling in all three dimensions as first, second, and third operations, respectively.

3.4 Reduction and Subdivision of Point Cloud

To increase speed and performance, and to decrease the complexity of algorithm, it is very necessary to reduce the large point cloud data to a small point cloud in such a way that no important facial information is lost. For this, we try to remove the less prominent regions of the point cloud so that the higher, prominent region (a region where the probability of finding the facial features is higher) comes into the picture. By setting the limiting criteria in x, y and z, we

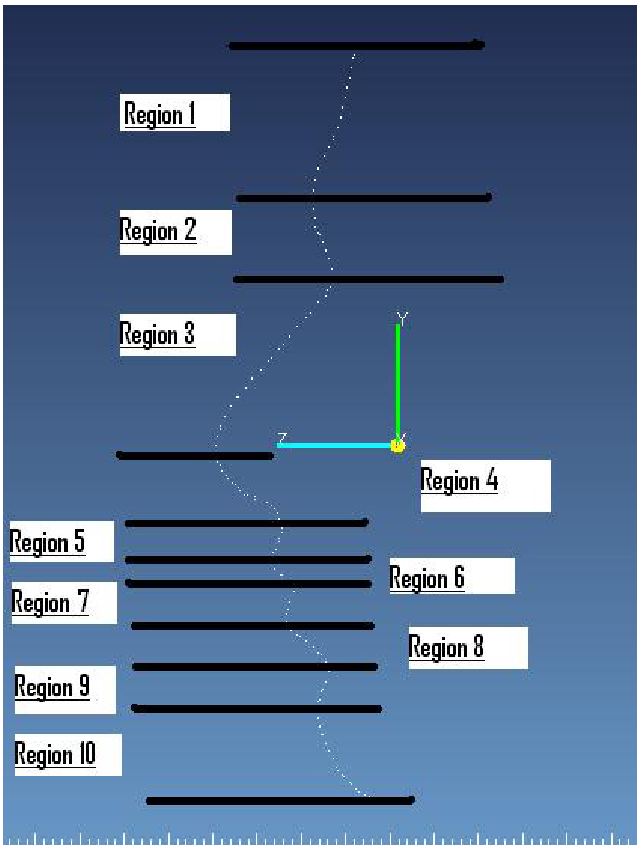


Figure 5. Max Z curve and its subdivision.

obtain the prominent region as per the following process:

X={xr};
Y={yr};
Z={zr};
Where, xl <= xr < = xu
Yl <= yr < = yu
Zl <= zr < =zu

From the feature extraction point of view, the point cloud subdivision is essential. It reduces the computation and increases the efficiency of the algorithm because the entire face line can be divided into various regions based on the location of features; therefore, searching of features in the localized space becomes easy. Further mathematical modeling of various features can be efficiently done. For subdivision of the point cloud, the normalized image is further processed for extraction of vertical max Z curve. This curve divides the human face into left and right subparts symmetrically. The max Z curve is shown in Figure 5. Subdivision is helpful to search the facial features in a local point cloud, which increases the searching power of algorithm.

3.5 Feature Extraction

Because there is variation in the facial features, we are extracting various features like nose line and nose shape, and trying to get the equation of the curve for each case as well as the value of coefficients. Figure 6 and Figure 7 show the extracted face line and nose shape, respectively.

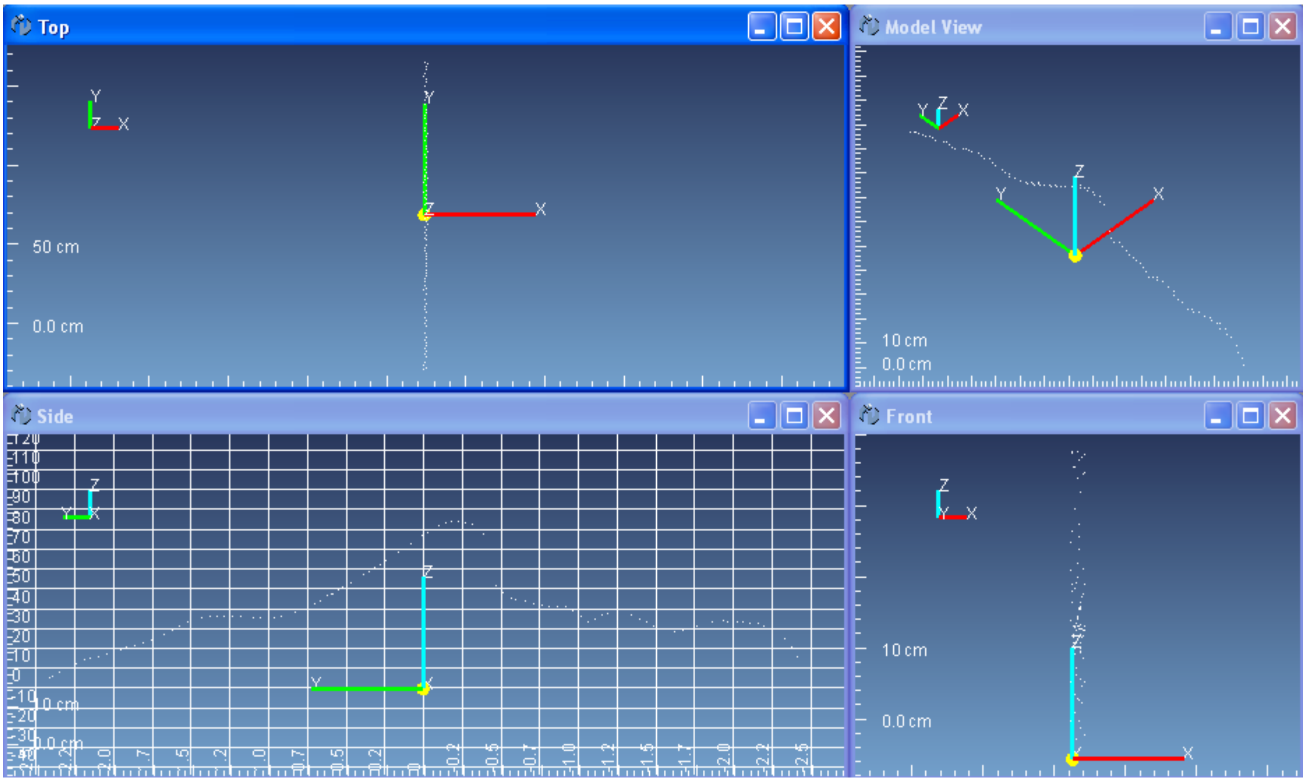


Figure 6. Face Line extracted from face of Lord Natraj.

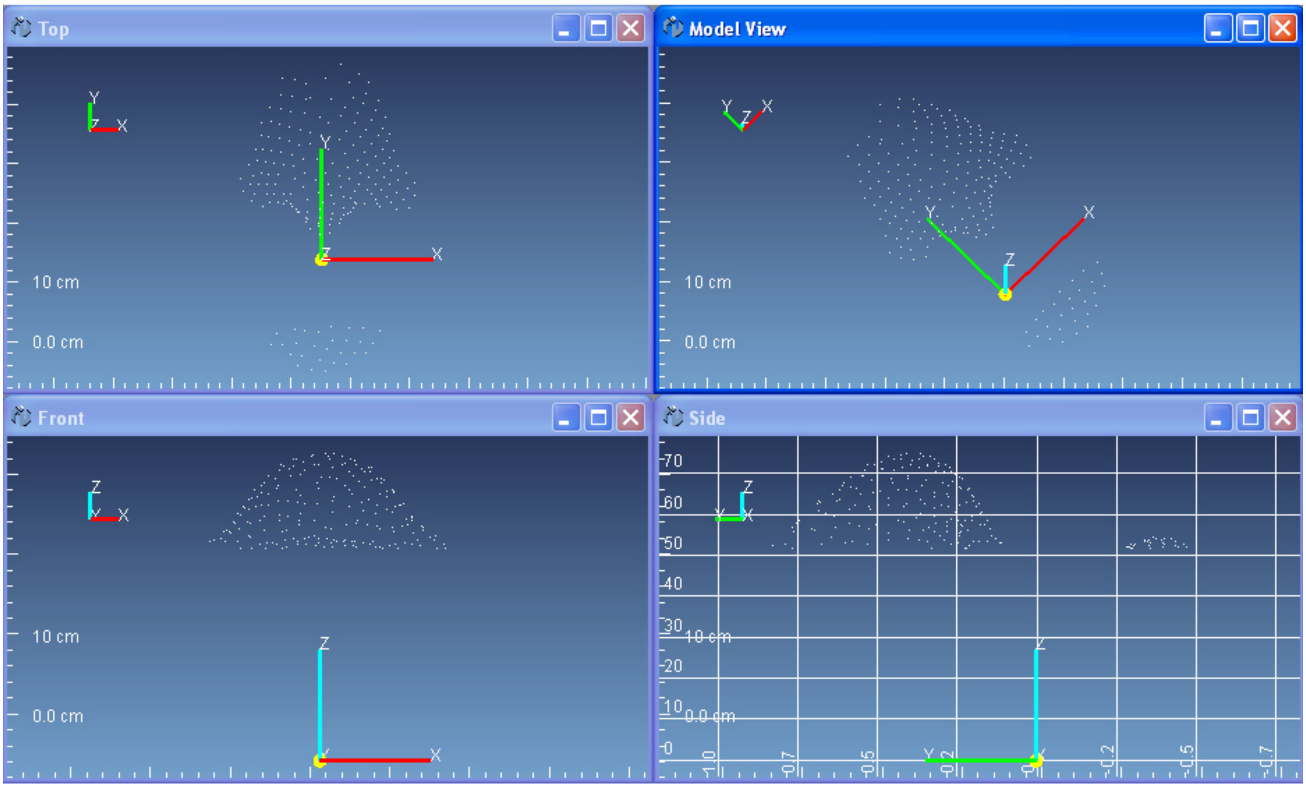


Figure 7. Nose shape extracted from face of Lord Natraj.

3.6 Mathematical Modeling of Feature Points

The mathematical definition of any object or image explains the correct identification of it. We used the mathematical definition of facial features in terms of 2D curve-fitting using a curve-fitting tool of MATLAB. The Figure 8 shows curve fitting of a nose line from the front, while Figure 9 shows the curve fitting on the max Z curve.

The Corresponding equation is:

Linear model Poly1:
$f(x) = p1*x + p2$
Coefficients (with 95% confidence bounds):
p1 = -0.00525 (-0.1438, 0.1333)
p2 = 0.5264 (-0.6536, 1.706)
Goodness of fit:
SSE: 8009
R-square: 3.072e-005
Adjusted R-square: -0.005464
RMSE: 6.634

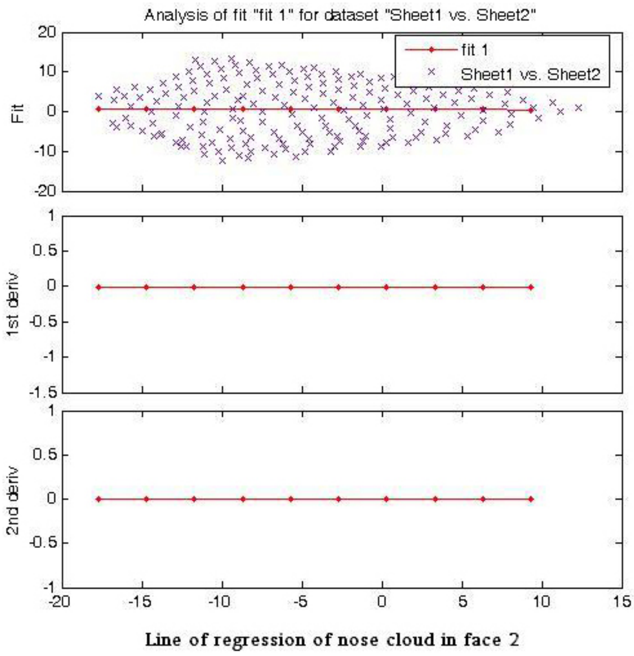


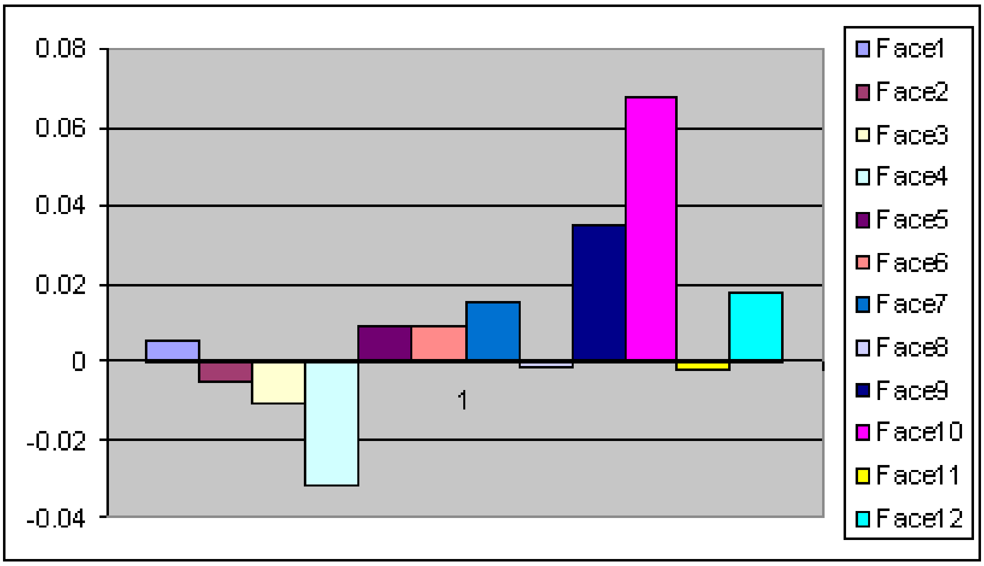
Figure 8. Line of regression fitted on nose cloud of face 2, i.e, on face of Lord Natraj.

3.7 Parameter Processing of Model

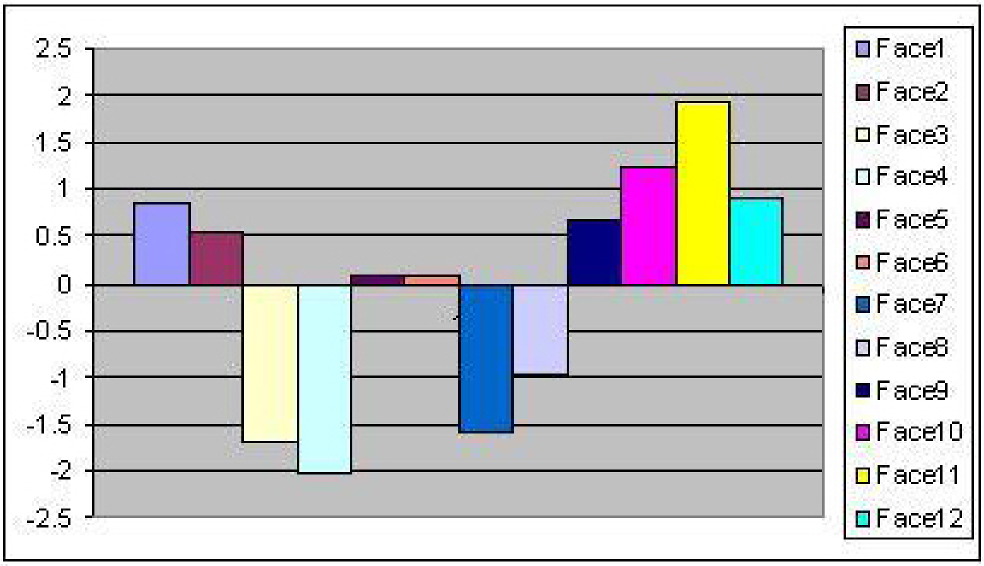
The parameters of any 2D and 3D curve or surface explain the whole nature of curve or surface. Here the parameters refer to various coefficients of curve, coefficients of 2^{nd} & 3^{rd} derivatives of curve, with position and orientation of origin of our rectangular coordinate system. The selection criteria of correct and important parameters are critical. We devised our own selection criterion for parameter selection, and the final selected parameters were saved in the database.

3.8 Database Generation

There is a large information set regarding a 3D face model. Thus, the selection of a good database environment is needed for proper repository storage. The fetching, processing, comparing, and storing are the main operations performed on a large amount of data. So, a good query is



Variation in 1st landmark points in different 12 faces



Variation in 2nd landmark points in faces

Figure 9. Variation graph for two extracted features from 12 sculpture faces.

very helpful to ease the above operations. A good query reduces the complexity and fetching time, and increases the performance in terms of efficiency and turnaround time. To the point cloud information we fit the curve and find the equation of the curve (this equation can be of any degree), and from this equation we can find coefficients that are specific to the given equation. Because there is variation in the features, we can take many facial features (eyes, nose, curvature of eyebrows, existence of eyeball, size and shape of ears, etc.) together and get the equation of the curve for each case, and then acquire the coefficient values. Now we can store these coefficients in our database as a parameter along with other information. Proper scaling and translation is also required in order to deal with different objects.

When a sculpture comes in for testing, we repeat Step 1 to Step 3 and find the coefficient parameter. Then we use pattern recognition and pattern matching techniques between inputted sculptures and our database in order to get the information about the age and culture of the inputted sculptures. If the parameters (i.e., coefficients of a given sculpture) match with some parameters in the database, then the age and culture of that sculpture can be determined. This work to create the database and the matching techniques required to find the age to which any sculpture belongs is in progress.

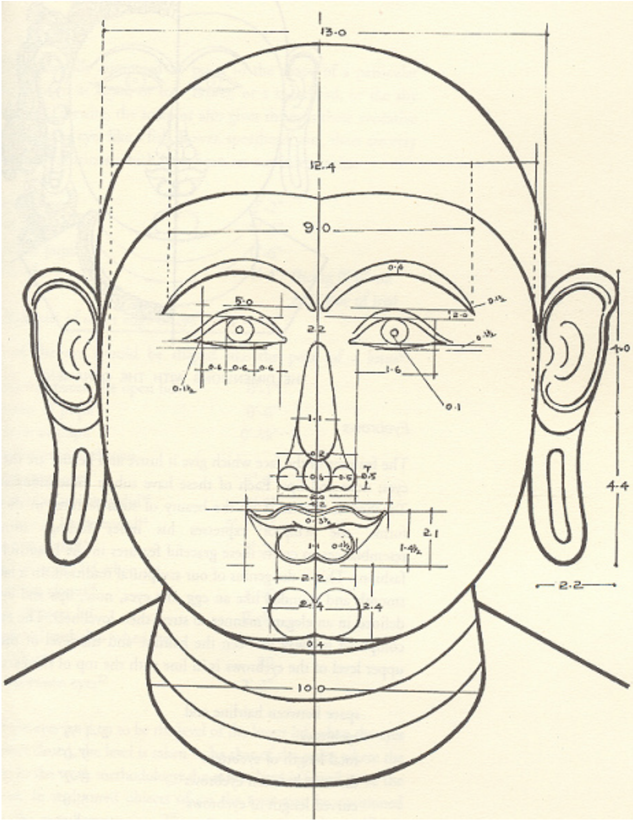


Figure 10. Detailed measurements on face of Lord Buddha.

4 Results and Conclusions

After comparing the coefficients of the regression line of 12 different sculpture faces, we get the following variation graphs. These variations in regression lines will be helpful to us in deducing the variation patterns of various landmark facial features of sculptures that pertain to different periods, for example Kushan Period, Gupta Period, and so on.

A detailed measurement scheme and iconography for different styles of deities is also available as shown in Figure 11. Thus, an automated system can be developed based on these measurements, which will help in ascertaining the unique style or posture used for making any deity/idol. If some idol's sculpture is retrieved in an excavation, these measurements will help in conforming the style or posture of that sculpture.

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