3D FACE RECOGNITION FROM RANGE IMAGES BASED ON CURVATURE ANALYSIS

Suranjan Ganguly[1], Debotosh Bhattacharjee[2] and Mita Nasipuri[3]

Department of Computer Science and Engineering, Jadavpur University, India
E-mail: [1]suranjanganguly@gmail.com, [2]debotoshb@hotmail.com, [3]mnasipuri@cse.jdvu.ac.in

Abstract

In this paper, we present a novel approach for three-dimensional face recognition by extracting the curvature maps from range images. There are four types of curvature maps: Gaussian, Mean, Maximum and Minimum curvature maps. These curvature maps are used as a feature for 3D face recognition purpose. The dimension of these feature vectors is reduced using Singular Value Decomposition (SVD) technique. Now from calculated three components of SVD, the non-negative values of 'S' part of SVD is ranked and used as feature vector. In this proposed method, two pair-wise curvature computations are done. One is Mean, and Maximum curvature pair and another is Gaussian and Mean curvature pair. These are used to compare the result for better recognition rate. This automated 3D face recognition system is focused in different directions like, frontal pose with expression and illumination variation, frontal face along with registered face, only registered face and registered face from different pose orientation across X, Y and Z axes. 3D face images used for this research work are taken from FRAV3D database. The pose variation of 3D facial image is being registered to frontal pose by applying one to all registration technique then curvature mapping is applied on registered face images along with remaining frontal face images. For the classification and recognition purpose five layer feed-forward back propagation neural network classifiers is used, and the corresponding result is discussed in section 4.

Keywords:
Curvature Analysis, 3D Image, Image Registration, Face Recognition, FRAV3D Database

1. INTRODUCTION

Face detection and recognition has been the key areas of interest over the years. Now a day's 3D face has got the researchers' attention due to its huge applicability for biometric measurement over 2D face. The advantages of 3D face over 2D face are discussed in Table.1. 3D faces can even generate the complete texture information regarding a particular face in case of some scanners.

Table.1. Comparison based on the different problem domain

Different Problems of Face Recognition	Can be solved using 2D Images		Can be solved using 3D Face Images
	Optical	Thermal	
Illumination Variation	No	Yes	Yes
Pose Variation	No		Yes
Variation in Expression	No	Yes	Yes
Disguises	No		Yes
Aging Problem	No		No
Variation in Temperature	No	Yes	Yes

For 3D face recognition purpose, a challenging issue is to recognize accurately frontal posed face images along with registered face images. For the face, which is oriented across any direction, it should be perfectly registered for correct reorganization purpose. The goal of our proposed algorithm is to take an input 3D image across any pose orientation, register it (if it is necessary) then recognize it with proper training and testing of the features by an ANN. The geometrical approach i.e. curvature information [1] is used in this method. The proposed algorithm has been experimented on the FRAV3D database [2]. Before performing the curvature analysis, this technique uses registration methods described by P. Bagchi et al. in [10].

The rest of the paper has been organized as follows. In section 2, we have discussed some of the related works made in the field of 3D face registration and recognition. In section 3, we have discussed our proposed algorithm. Experimental results have been discussed in section 4. And finally, in section 5, conclusions and future scope have been discussed.

2. RELATED WORK

In this section, some significant works have already been made in the field of 3D face registration, and recognition is discussed. In [3], the authors have registered the face with the assumption that the nose tip has the maximum value across Y axis, and they have registered the face across X axis by fitting a plane across the nose-tip along Y-axis. But, the nose-tip may not have a maximum value across Y-axis (for pose variation in 90 degree angle). In [4], the authors have registered the images considering facial symmetry. Here also the authors have assumed, the maximum distance of the nose tip is from the curve ends and then registration is performed using the nose-tip. In [5], the authors have used a joint shape and texture image to generate a set of region template detectors. The problem is that, in their paper, they have not dealt with pose variations across all possible orientations. In [6], the authors have detected face after registering those by 45° angel rotation of the un-registered face models. But the computation of the angle is not stated. In [8], a method for face recognition has been performed but majority of the faces were with occlusions and expressions. In comparison to that a majority of the faces used for 3D face recognition in the stated work, are across pose. In [9], authors proposed expression invariant 3D face recognition algorithm. In comparison to that, this proposed method considered both pose and expression invariant face for recognition purpose.

In this paper for registration purpose, the algorithm [10] calculates rotational and translational parameters for accuracy. The registration technique that is proposed is focused on one to all registration technique. This technique describes that the pose variation of the input face images is registered with all the images in frontal pose from the FRAV3D database by selection of the best registered image. After registration, some image pre-processing

technique is applied and then curvature is computed and feature is calculated and finally, recognition technique is applied.

3. PROPOSED TECHNIQUE

The proposed method for 3D face recognition is subdivided into five subdivisions, and that is described in Fig.4.
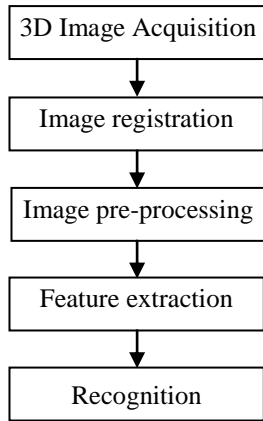
3D Image Acquisition

Image registration

Image pre-processing

Feature extraction

Recognition

Fig.1. Flow diagram of proposed algorithm

3.1 FACIAL IMAGE ACQUISITION

The present technique uses FRAV3D database [2] for face recognition. In FRAV3D database, there are 106 subjects each having 16 different captured pose. Out of 16 different pose, 8 images are with frontal pose; 4 images have pose variation across Y-axis and from remaining 4 images, 2 images each having pose variation across X-axis and Z-axis respectively. The Fig.2 given below, shows samples of produced depth images correspond to the 2D visual image in Fig.3 that has been chosen from the FRAV3D.
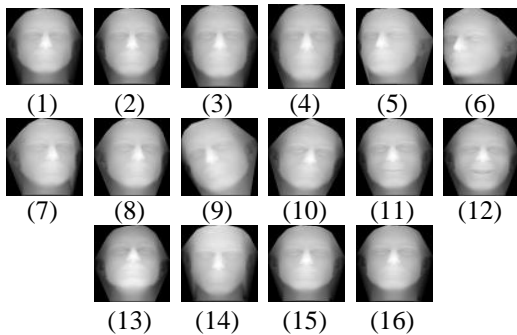

(1)   (2)   (3)   (4)   (5)   (6)
(7)   (8)   (9)   (10)   (11)   (12)
(13)   (14)   (15)   (16)

Fig.2 Generated range images

(1)   (2)   (3)   (4)   (5)   (6)
(7)   (8)   (9)   (10)   (11)   (12)
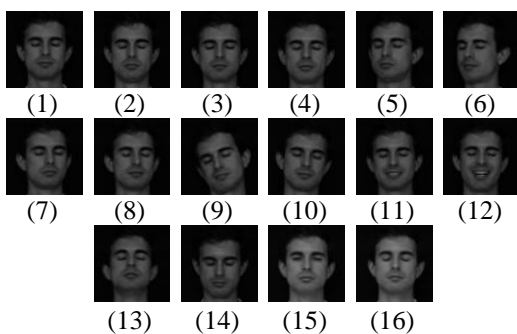(13)   (14)   (15)   (16)

Fig.3. 2D visual images

Image Description of Fig.2 and Fig.3 from FRAV3D database

Images 1-4 for frontal pose with neutral pose;
Images 5-6 for pose variation along positive Y axis;
Images 7-8 for pose variation along negative Y axis;
Images 9 for pose variation along positive Z axis;
Images 10 for pose variation along negative Z axis;
Images 11-12 for frontal pose with expression;
Images 13 for pose variation along positive X axis;
Images 14 for pose variation along negative X axis;
Images 15-16 for Frontal pose with illumination;

3.2 FACIAL IMAGE REGISTRATION

Registration process is termed as to translate and rotate the facial image from pose variation about X, Y and Z axes to frontal pose. After face image acquisition, the nose tip feature is localized from range image for registration by rotating and translating as discussed in by P. Bagchi et al. in [10]. After registration the registered faces with respect to X, Y and Z axes are shown in Fig.4.

(a)   (b)   (c)
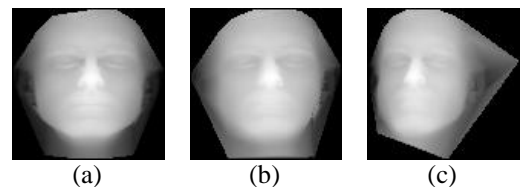
(a) Registered with respect to X axis of Fig.2(13)
(b) Registered with respect to Y axis of Fig.2(5)
(c) Registered with respect to Z axis of Fig.2(9)

Fig.4. Registered faces

3.3 IMAGE PRE-PROCESSING

In the previous section, the registration technique is done by computing the translation and rotation parameter. It is noticed that registered face images from the pose variation along Z-axis, both in positive and negative direction, is translated more compared to other registered face images. Fig.5 describes this problem and it is needed to be processed to isolate face region only for better recognition purpose. In Fig.6, localized face region is shown from registered face image and for the localization purpose 'maximum depth in the nose tip' is considered. At first, nose tip is detected by selecting maximum depth from entire registered face image. From detected nose tip position, a fixed number of height and width is calculated to extract the face region, discarding unwanted portion from registered face image. Fig.7 describes the maximum depth of the nose tip from the generated range image. A 6×6 window is set near nose region and then depth values are shown.
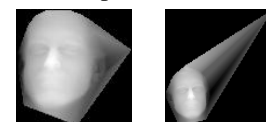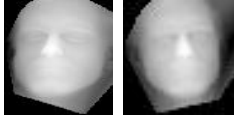

Fig.5. Registered face image

Fig.6. Localized face image

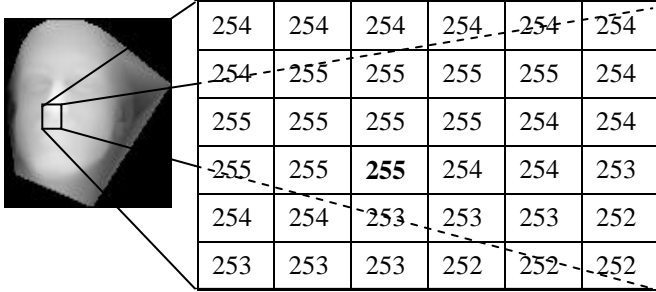| 254	254	254	254	254	254
254	255	255	255	255	254
255	255	255	255	254	254
255	255	**255**	254	254	253
254	254	253	253	253	252
253	253	253	252	252	252

Fig.7. Depth values near nose tip

Normally 3D face images may have a spike, holes and other noises. After successful registration and face isolation, as stated above, all the face images are smoothed by median filtering. Median filter [19] is used to remove noise reduction from image. It is a non-linear technique and effective in impulsive noise. For this work, a 3×3 block is considered to remove noises and spikes from range images. Fig.8 describes the smooth image along with noisy face image of Fig.2(2). This smoothing technique is applied to all the face images of all the classes.
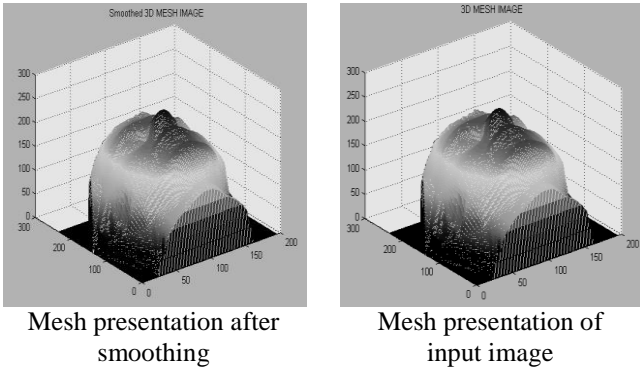

Mesh presentation after smoothing

Mesh presentation of input image

Fig.8. Image smoothing

3.4 FEATURE CALCULATION

A feature is the distinct attribute or aspect of something for any object by which it can easily be distinguished from one another. It is very common that, within a class, there will be more similarity in features and among the classes there should be much difference among different classes feature, i.e. there is large intraclass similarity among features and interclass dissimilarity among them. For the proposed system to work accordingly, following steps are performed:

- Curvature Analysis
- Elliptical Crop
- Feature Computation

3.4.1 Curvature Analysis:

Curvature measurement [12] is the amount by which an object deviates from being flat or straight in the case of a line. But this concept can be defined in different ways depending on

the geometry of the object. There are two significant types of curvatures. One is an extrinsic curvature, and another one is intrinsic curvature. Mean and Gaussian curvature [11] [13] presents the extrinsic and intrinsic geometric properties of the surface respectively. The best approximating circle that may lie either to the left or to the right of the curve can be used to form a signed curvature measurement. The curvature will have a positive sign if the circle lies to the left and negative sign if the circle lies to the right of the curve. This sign curvature is the normal section curvature of the curve at the given point of interest. In the tangent planes, to the surface at various points, it is possible to compute the normal section curvature in all the directions. Then, there will be a maximum value and a minimum value among these values. Gaussian Curvature is the product of these maximum and minimum values and Mean curvature is the average of these maximum and minimum values. There is also the significance of a sign in Gaussian curvature values. The positive Gaussian curvature value means the surface is either a peak or a valley; the negative value means the surface has a saddle points and also a zero value means the surface is flat. For this work, Gaussian, Mean and Principal Maximum curvature values are considered.

The two principal curvatures [11] [1] at a given point of the surface are the eigen values of the shape operator at that point. They measure how the surface bends by different amounts in different directions at that point. The principal curvatures at p, denoted by k_1 and k_2, are the maximum and minimum values of this curvature. The product of k_1 and k_2 of the two principal curvatures is the Gaussian curvature and denoted by K, and the average of $\frac{(k_1 + k_2)}{2}$ is the mean curvature [11] [13] and denoted by H.

$$K = \frac{f_{uv}f_{uv} - f_{uv}}{\left(1 + f_u^2 + f_v^2\right)^2} \quad (1)$$

$$H = \frac{1}{2}\left(\frac{f_{uu} + f_{vv} + f_{uu}f_v^2 + f_{vv}f_u^2 - 2f_uf_vf_{uv}}{\left(1 + f_u^2 + f_v^2\right)^{3/2}}\right) \quad (2)$$

$$K_{1,2} = H \pm \sqrt{H^2 - K} \quad (3)$$

where,

$$f_u = \frac{\partial f}{\partial u}, f_v = \frac{\partial f}{\partial v}, f_{uu} = \frac{\partial^2 f}{\partial u^2}, f_{vv} = \frac{\partial^2 f}{\partial v^2}, f_{uv} = \frac{\partial^2 f}{\partial u \partial v} \quad (4)$$

and the information for calculating the curvatures values are given as $X = (u, v, f(u, v))$.

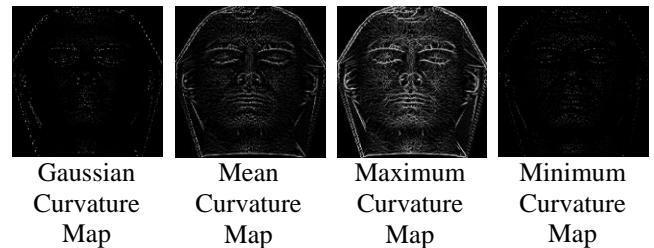The Fig.9 shows different curvature analysis performed on Fig.2 (16).

Gaussian Curvature Map	Mean Curvature Map	Maximum Curvature Map	Minimum Curvature Map

Fig.9. Different curvature maps

3.4.2 Elliptical Crop:

Normally it is studied that human faces are of elliptical shape. To extract only the face region from the entire image elliptical shape is drawn by computing the centroid, major axis and minor axis on range images. The range images are resized into fixed size of 100×100 before elliptical cropping is done for simplification. Fig.10 shows the elliptically cropped and resized curvature images of Fig.9.

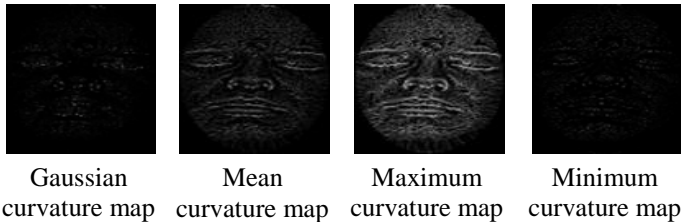| Gaussian curvature map | Mean curvature map | Maximum curvature map | Minimum curvature map |

Fig.10. Elliptically cropped images from curvature maps

3.4.3 Feature Computation:

To classify and recognize facial images of different classes' facial images successfully, at first Singular Value Decomposition (SVD) is applied on both selected pair-wise curvatures.

SVD [14-15] method can transform matrix 'A' into product USV^T, which allows us to refactoring a digital image in three matrices. The using of singular values of such refactoring allows us to represent the image with a smaller set of values, which can preserve useful features of the original image, but use less storage space in the memory and thus it serves as a compression process.

The factors or values of the diagonal matrix of S are all non-negative, and all are arranged in decreasing order. If A is a matrix of size $m \times n$ (i.e. m number of rows and n number of columns) and $m \geq n$ then it computes 'n' number of non-negative decreasing order diagonal elements of S and, if $m < n$ then it computes 'm' number of non-negative decreasing order diagonal elements of S. These values are used as features for this work for recognition purpose. For the feature calculations following steps are done:

Step 1: At first all these non-negative values are gathered from different curvature map (Mean, Gaussian, and Maximum) and stored in a single one dimensional matrix from two dimensional matrices and transposed to get row wise arrangement of the corresponding matrix and sorted in ascending order.

Step 2: For the feature vector all non-negative values are not considered, only some percentage (top 10, 12, 15 and 20) of values are considered as described in experiment result section. From these matrices, two pair of curvatures (Mean and Maximum curvature and Gaussian and Mean curvature) is selected and merged row wise. After merging process, they are again sorted and used in feature vector.

These steps are continued for each image from each class.

3.5 RECOGNITION

Classification is a supervised learning. By the term supervised learning, it means that learning with the help of a teacher. In the case of pattern recognition, it can be described with the help of training data consisting of training example, new data will be labelled. For this research work, a five layer feed-forward back propagation neural network has been used for classification purpose.

Artificial Neural Network (ANN) [17] is supervised learning method, and it is a mathematical model inspired from biological neural network. Artificial neurons are the mathematical function. These are the constructive unit of ANN. These neurons are all interconnected and propose to connectionist approach for the computation. ANN can change its structure according to the learning phase, so sometimes it is also termed as adaptive model.

After feature extraction and selection of ranked values of 'S', size of the feature vector is changed. For example if rank value is chose 10 then the size of the feature vector is 20 (10 non-negative values from each of the curvature pair). Thus for each of the face image corresponding vector is formed. Now these total numbers of vectors are divided into two blocks for training and testing. Odd number of images and corresponding features are used for training and others are for testing. Out of five layer neural network, first hidden layer contains 100 neurons; second hidden layer contains 50 neurons and third hidden layer hold 10 neurons. Input layer contains either 20 or 24 or 30 or 40 number of neurons, (for example, selecting 10 non-negative values from each of the curvature pair 20 neurons will be selected) and last layer contain number of classes i.e. 106. Tan-sigmoid transfer function has been used as gradient descent with momentum training function is used to update weights and bias values in this network.

4. EXPERIMENTAL RESULTS

The success rate of the proposed technique for recognition purpose is partially dependent on how much effectively the registration techniques register the face image in the frontal position. Success rate of registration method, described in [10], is shown in Table.2.

Table.2. Success rate of registered face images

Registration Details	Success rate (%)
Across X-axis	79.66
Across Y-axis	79.66
Across Z-axis	67.70

With the mentioned accuracy of the registration on FRAV3D database, the proposed recognition techniques are carried out. Two pair-wise features, that are Mean and Maximum curvature pair and another one Gaussian and Mean curvature, is used to compare the recognition rates in different perspectives:

- frontal pose with expression and illumination variation
- frontal face along with registered face
- only registered face
- considering only individual registered face from pose variation along X, Y and Z axes

These are considered to use the excellent benefits of 3D face image to use as biometric measurement. The first two aspects are considered for general purpose. The 3rd one is chosen

considering if for some reason very less frontal face image of any subject is stored in a database. Then for security measurement it may happen that only registered face images from pose variation are used to train the system and use it for biometric security system. The 4th one is considered if, for some accidental or medical reason, it is not possible to capture the frontal face images as well as face facial movement is not possible then it may occur. These are the great advantages to use 3D face over 2D optical face image for recognition purpose.

The experiment is also conducted by selecting two curvature pairs, H-K curvature. Gaussian-Mean (H-K) curvature has a significant role. With the help of H-K classification table, it is possible to estimate face description like nose region eye corner etc as described in [18]. It is also observed that P_{max} i.e. Maximum curvature holds maximum information, as described in Fig.9 and Fig.10, which is paired with Mean curvature.

A description of the study is given in the Table.3 and Table.4 as stated above, for Mean-Maximum curvature and Gaussian-Mean curvature pairs. In Fig.11, an observation is made for the different recognition rates coming from two curvature pair consideration for our proposed algorithm.

Table.3. Recognition rate for frontal pose with expression and illumination variation

Ranked non-negative values of 'S'	Mean-Maximum curvature	Gaussian-Mean curvature
	Classification Rate (%)	
Top 10	86.51	78.66
Top 12	80.83	75
Top 15	80.83	73.32
Top 20	76.66	68.55

Table.4. Recognition rate of frontal face along with registered face

Ranked non-negative values of 'S'	Mean-Maximum curvature	Gaussian-Mean curvature
	Classification Rate (%)	
Top 10	76.08	67.33
Top 12	73.08	57.50
Top 15	66.23	52.21
Top 20	58.67	49.66

Table.5. Recognition rate of registered face

Ranked non-negative values of 'S'	Mean-Maximum curvature	Gaussian-Mean curvature
	Classification Rate (%)	
Top 10	46.23	36.75
Top 12	45.83	36.62
Top 15	42.22	33.38
Top 20	39.67	32.96

Table.6. Recognition rate of individual registered face from pose variation along X, Y and Z axes

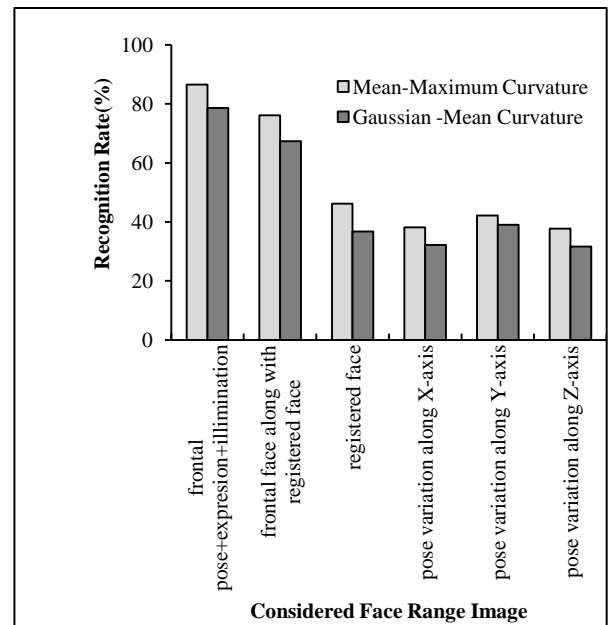| Ranked non-negative values of 'S'	Mean-Maximum curvature	Gaussian-Mean curvature	Registered Face Images from Pose variation
	Classification Rate (%)		
Top 10	38.12	30.10	along X axis
Top 12	36.67	32.21	
Top 15	35.66	29.87	
Top 20	31.8	25	
Top 10	40.3	37.89	along Y axis
Top 12	42.14	37.45	
Top 15	39.66	38.97	
Top 20	33.33	35	
Top 10	37.7	31.33	along Z axis
Top 12	35.83	31.6	
Top 15	32	30	
Top 20	31.33	29.89	

Fig.11. Summary of recognition rates from proposed algorithm

5. CONCLUSION

Here, in this work a novel approach on curvature based 3D face recognition technique is proposed for FRAV3D database. A set of experiment is also carried out on the same for recognition purpose. In this paper, only two curvature pair is considered for study purpose but in future different combination can be experimented from four types of curvatures that may lead to better recognition rate. We have also intended to test the proposed algorithm on other 3D face databases.

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