Precise Face Recognition Algorithm Based on Equal Contour Line Description

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Abstract **— In order to improve face recognition rate using geometric and neighborhood information, a local descriptor is proposed in this paper for 3D face recognition. In this method, equal geodesic contour line of the face is extracted and re-sampled and a local descriptor that does not rely on coordinate information is extracted by the analysis of cloud distribution information of local points on the contour line. Local characteristics are weighted and rules are integrated between the corresponding points of the tested face and library set face and ultimate recognition result is obtained by using nearest neighbor classifier. Performance of the algorithm is verified in FRGV v2.0 and experimental results show the method has good recognition performance. Improvement measures are also proposed to solve the problem that the geodesic contour line is easily affected by expression in the bottom part area of human face and experimental results show the improvement method is effective.**

Keywords - face recognition; neighborhood; local descriptor; equal geodesic contour line; corresponding point

I. INTRODUCTION

Face recognition, an important biological characteristic recognition method, is featured with less interference for users and good acceptability and has wide application prospect in the biological authentication. 3D face recognition mainly recognizes human face according to 3D geometric shape of the face and it is free from post and lighting. With rapid technical development of 3D scanning, 3D face recognition would draw more and more attention. At present, there are many researches about 3D face recognition and they are mainly divided into method based on overall characteristics and method based on local characteristics. However, the extraction of overall characteristics would be affected by post change easily and method based on overall characteristics cannot cope with the hair and beard. Method based on local characteristics uses characteristics of local part of face to recognize the face. The method treats the different areas of face differently according to their characteristics so the method has advantage over the overall method in expression and occlusion problems. Therefore, the face recognition based on local descriptors of facial geometric information and neighborhood information is proposed in the thesis from two perspectives. Firstly, equal geodesic contour line equidistant to the nasal tip point would be extracted after post correction, the local neighborhood information of each point on the re-sampled contour line is extracted to form local descriptor and finally local descriptor is weighted and rules are integrated between the corresponding points of tested face and library set face. Eventually, the ultimate recognition result is obtained by nearest neighbor classifier. System model is shown in Figure 1. Experiment shows the algorithm in the thesis has great performance in recognition rate and calculation complexity.

II. PRETREATMENT AND CONTOUR LINE EXTRACTION

A. *Pretreatment of Face data*

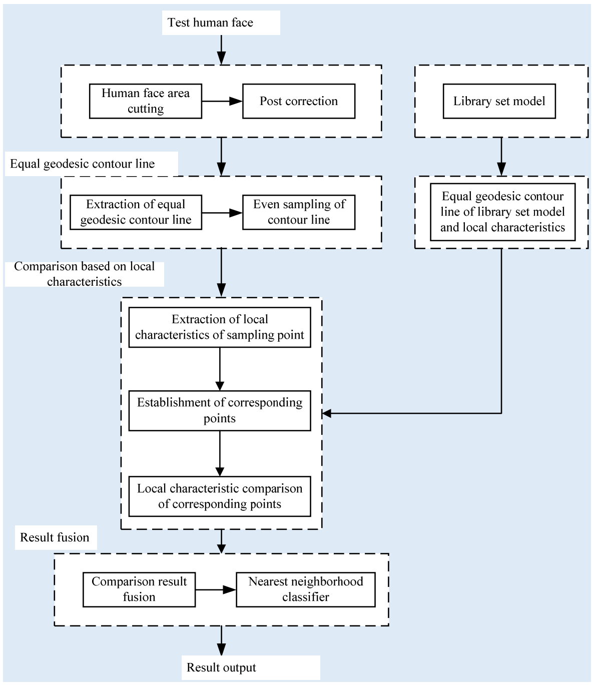
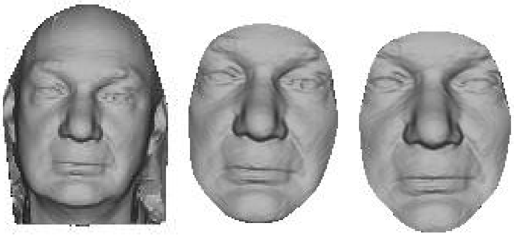


Figure 1. System module diagram

Face data obtained by 3D scanner include all the posts and include areas like ear, hair and neck. To extract characteristics precisely and improve subsequent matching precision, human face shall be cut and post shall be corrected to obtain strict human face area.

Method in the literature [1] of the thesis normalizes human face post. Firstly, position nasal tip according to face shape index [7] characteristics and geometric constraints and then the human face area included in the sphere with center point of nasal point and radius *r* is the one to be cut. 3D face point cloud data can generally be the actual size of face and human face area is generally concentrated in the sphere with center point of nasal tip and radius of 90mm. therefore the human face area is cut when $r = 90mm$. Original face and the cut face are shown in Figure 2 (a) and (b).

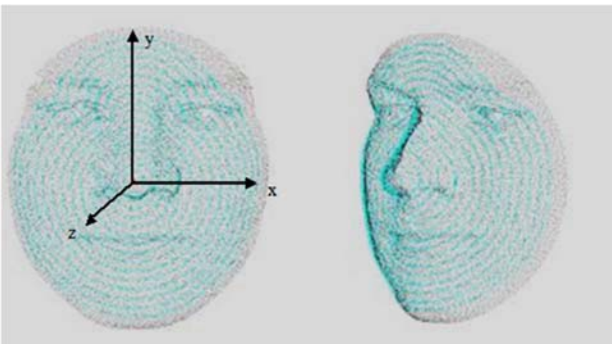
Analyze principal components (PCA) of the point cloud of cut human face and three orthogonal principal directions are obtained. Coordinate system is established on the three principal directions and the human face in the coordinate system has the same front post. The coordinate system is also called post coordinate system (PCS) [8]. Nasal tip point is the origin of PCS and point cloud data of cut human face are transferred into PCS and human face post correction is completed, as shown in Figure 2(c).



(a) Original face (b) Cut face (c) Human face in PCS
Figure 2. Human face cutting of post correction

B. Extraction of Equal Geodesic Contour Line

Shortest distance between two points on the curved surface is geodesic distance. It is believed that the geodesic distance doesn't change with change of facial expression [9]. We use Dijkstra and the method mentioned to calculate the geodesic distance between random points on human face point cloud.



(a) Front view (b) Side view
Figure 3. Equal geodesic contour line

After the geodesic distances between all the points on human face to nasal tip point, compose an equal geodesic contour line c' with the points whose distances to the nasal tip point is within $[\gamma-\delta, \gamma+\delta]$. In fact, c' is a closed belt area composed of a series of points. The width of belt area can be changed by setting different δ (δ >0). $\delta = 1.4mm$ in the thesis. According to different *r* values, different equal geodesic contour lines can be obtained. Number and position selection of equal geodesic contour line have great impact on the representation of contour line. To better present the shape of human face, $\gamma = \{5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80,85\}$. Extract 17 equal geodesic contour lines c_i' ($i = 1,2,...,17$) at the same interval in human face area. These 17 equal geodesic contour lines basically cover the entire human face area as shown in Figure 3.

C. Sampling of Equal Geodesic Contour Line

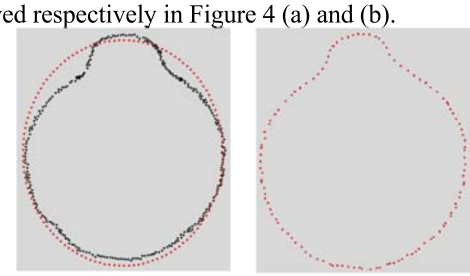
Number of equal geodesic contour lines extracted accordingly on different human faces varies according to the method presented in the section above but characteristics of corresponding points on the corresponding curves shall be compared in the recognition. Therefore, equal geodesic contour lines shall be re-sampled before characteristic matching.

It can be observed in Figure 3 that projection of equal geodesic contour line in the plan of principal axis coordinate system xOy approximates an ellipse. With nasal tip point as center point, projection difference *a* of equal geodesic contour line on *x* axis is minor axis and the projection difference *b* of equal geodesic contour line on *y* direction is major axis. As a result, an ellipse is obtained and equation is:

$$\begin{cases} x = \frac{a}{2}\cos(t) \\ y = \frac{b}{2}\sin(t) \end{cases} \tag{1}$$

Where, $t = [0, 2\pi]$. Points of different numbers can be sampled on the ellipse by discrete sampling t. For each sampling point on the ellipse, the nearest point on the equal geodesic contour line is the sampling point of geodesic contour line. All the sampling points of geodesic contour line compose geodesic contour line c_i ($i = 1,2,...,17$) after sampling.

The sampled equal geodesic contour line has the same sampling point number and the same sequencing as corresponding ellipse according to the method above. Equal geodesic contour lines before and after the sampling are displayed respectively in Figure 4 (a) and (b).



(a) Pre-sampling equal geodesic contour line (b) Post-sampling equal geodesic contour line
Figure 4. Sampling of equal geodesic contour line

III. LOCAL DESCRIPTOR MATCHING

A. Extraction of Local Descriptor

Take any point g ($g \in c_i$) on the re-sampled equal geodesic contour line as center and make a sphere with rl=10mm. Human face area is included in the sphere and this area is the neighborhood of point *g*. Calculate the major axis of neighbor point cloud *L* by use of PCA and the characteristic vector of the maximum characteristic value is *y* axis and characteristic vector of the minimum characteristic value is *z* axis. Then establish a right-handed coordinate system and the origin of the coordinate system is the centroid of point set. As shown in Figure 5, new coordinate system of point cloud *L* is principal axis coordinate system.

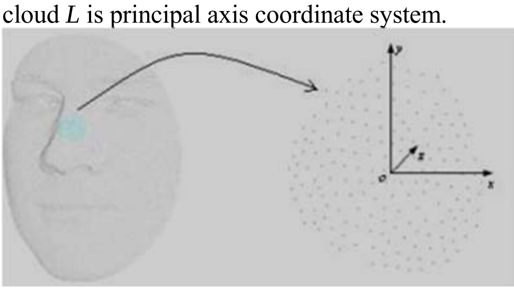


Figure 5. Principal axis coordinate system of point set *L*

Project the point in point cloud L into three axes of principal axis coordinate system and extract the difference f_x , f_y and f_z between the maximum projection value and the minimum projection value in three principal axis directions of point cloud. Where, f_x and f_y reflect the shape distribution of point set *L* on axis *x* and axis *y* and f_z reflects the curvature of the curved surface of point set. Small f_z refers to the flat curved surface *L* and big f_z means L has obvious concave-convex degree.

Besides, area of point cloud *L* is extracted as local characteristic. Firstly, 3D point cloud is meshed. The area sum of all the triangular patches composed by the points in the point cloud *L* is the area *s* of point cloud *L*. $[f_x, f_y, f_z, s]^{\mathrm{T}}$ is the local descriptor extracted at point *g*. The descriptor is unrelated to the rigid motion of object and has good curved shape representation and calculation complexity is small.

Local descriptor of every point of equal geodesic contour line c_i is extract and local characteristics $\boldsymbol{L}_i = [\boldsymbol{l}_1, \boldsymbol{l}_2, \cdots, \boldsymbol{l}_{n_i}]$ of contour line c_i is obtained, where n_i is number of points in the post-sampling the contour line c_i and $\boldsymbol{l}_j = [f_x^j, f_y^j, f_z^j, s^j]^{\mathrm{T}}$.

Extract local characteristics of 17 equal geodesic contour lines in human face successively and all the local characteristics of human face are obtained.

B. Point Correspondence Establishment

Suppose the local characteristics of contour lines c_i^{A} and c_i^{B} corresponding to face A and face B are $\boldsymbol{L}_i^{\mathrm{A}} = [\boldsymbol{l}_1^{\mathrm{A}}, \boldsymbol{l}_2^{\mathrm{A}}, \cdots, \boldsymbol{l}_{n_i}^{\mathrm{A}}]$ and $\boldsymbol{L}_i^{\mathrm{B}} = [\boldsymbol{l}_1^{\mathrm{B}}, \boldsymbol{l}_2^{\mathrm{B}}, \cdots, \boldsymbol{l}_{n_i}^{\mathrm{B}}]$ respectively. The average distance s_i of local characteristics between corresponding point pair of the contour line we calculate is the similarity degree of two contour lines as shown in equation (2):

$$s_i = \frac{1}{n_i}\sum_{j=1}^{n_i}\left\|\boldsymbol{l}_j^{\mathrm{A}} - \boldsymbol{l}_j^{\mathrm{B}}\right\|_2 \tag{2}$$

Where, n_i is the number of points in contour line $\boldsymbol{l}_j^{\mathrm{A}}$, $\boldsymbol{l}_j^{\mathrm{A}}$ is the local descriptor of the *j*th point on human face A, $\boldsymbol{l}_j^{\mathrm{B}}$ is local characteristic of point in contour line c_i^{B} on human face B corresponding to the *j*th point in the contour line on human face A.

Calculate contour line similarity according to equation (2). Firstly, determine pair of corresponding points in contour line c_i^{A} and c_i^{B} of different faces. Corresponding equal geodesic contour lines on different faces have the same number of points after equal geodesic contour lines are re-sampled before. For corresponding contour lines c_i^{A} and c_i^{B} of two faces A and B, first suppose the first point of c_i^{B} is corresponding to the first point of contour line c_i^{A} . According to the contour line sampling rule stated in the thesis, the *j*th point in c_i^{B} is corresponding to the *j*th point in c_i^{A} ($2 \le j \le n_i$). Accordingly, we establish a point correspondence relation. Suppose the first point in c_i^{B} is corresponding to the *p*th point in c_i^{A} ($2 \le p \le n_i$) by the same method and the *j*th point in c_i^{B} is corresponding to the *q*th point in c_i^{A} and *q* can be obtained in the following equation.

$$q = \begin{cases} p + j - 1 & p + j - 1 \le n_i \\ p + j - 1 - n_i & p + j - 1 > n_i \end{cases} \tag{3}$$

We establish n_i types of point correspondence relations according to the method above. A similarity degree of each point correspondence relation can be obtained in equation (2). Considering shape information of human face, the point correspondence relation is reasonable when the characteristic distance is the minimum and at this moment the minimum characteristic distance d_i is the similarity degree of corresponding contour line c_i^{A} and c_i^{B} of face A and B. Smaller d_i refers to the higher similarity of contour lines.

Algorithms like ICP are generally used to calculate point correspondence but these algorithms require searching corresponding points globally, which is time-consuming. For example, for two contours including M points, M^2 searches shall be done to find corresponding points by ICP but M searches are required to find corresponding points by the method in the thesis, which improves calculation speed significantly.

C. Local Characteristic Fusion and Matching

Compare the local characteristics of 17 equal geodesic contour lines extracted from two faces respectively according to the method above and similarity degree d_i ($1 \le i \le 17$) of 17 contour lines is obtained. We fuse the comparison result of different contour lines. Considering central area close to the nose has good stability, set a weight value ω_i for the distance between different contour lines to the nasal tip. The contour line closer to nasal tip has bigger weight value. Calculation of ω_i is shown in the following equation:

$$\omega_i = \exp(-\gamma(i)/\gamma(17)), (i = 1, 2, \cdots, 17) \tag{4}$$

Finally matching results of the 17 equal geodesic contour lines are fused and the human face similarity obtained by local characteristics is shown in the following equation:

$$d = \sum_{i=1}^{17} \omega_i . d_i \tag{5}$$

Characteristics of library set model are extracted only. During the online recognition, local characteristics of test model shall be extracted first and then characteristics of test model are compared with characteristics of library set mode respectively. For the library set of *N* models, *N*-dimensional vector $\boldsymbol{D} = [d_1, d_2, \cdots, d_N]$ to present local characteristic similarity would be obtained. Finally, the library set face corresponding to the minimum element in *D* is the recognition result.

IV. EXPERIMENT RESULT AND ANALYSIS

FRGC v2.0 is a large public face database [11]. 3D face data set therein is the largest 3D face database in the world at present. Face data are 3D point cloud. Face data of 41 persons are selected from FRGC v2.0 database and 241 faces in total are tested. A library set is composed to 41 neutral expression faces in total; the residual faces compose a test set, including 112 neutral expression faces and 88 non-neutral expression faces.

A. Local Descriptor Representation Experiment

6 faces of three persons are compared to verify the effectiveness of the local descriptor, 10 sampling points are selected at random on one contour line of each face and local characteristic of each sampling point is vertical coordinate. Curves of the same color in Figure 6 are the characteristics of the same person and different colors stands for different persons. It can be seen in Figure 6 that local characteristic of sampling point extracted in the these has obvious distinction between different persons and has small difference for the same person, which means the local descriptor mentioned in the thesis has relatively good representation.

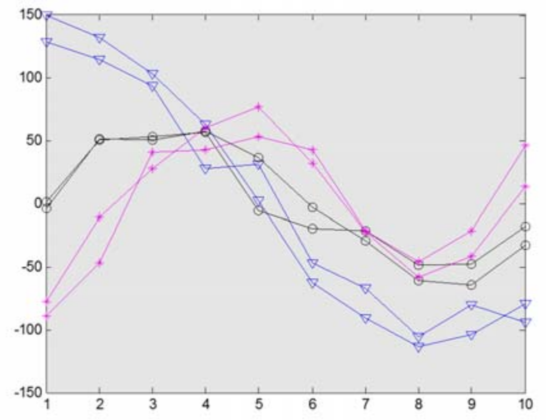


Figure 6. Representation of local descriptor

B. Face Recognition and Verification Experiment

The recognition experiment in the thesis is conducted in three conditions. First condition: comparison of non-neutral face and library set face ((non-neutral vs. neutral); second condition: comparison of neutral face and library bank face (neutral vs. neutral); third: comparison of all faces and library bank face (all vs. neutral). Figure 7 shows CMC (cumulative match characteristic curve) obtained by the algorithm in the thesis. When the level is 1, the recognition rates in three conditions are: 89.8%, 99.1% and 95%.

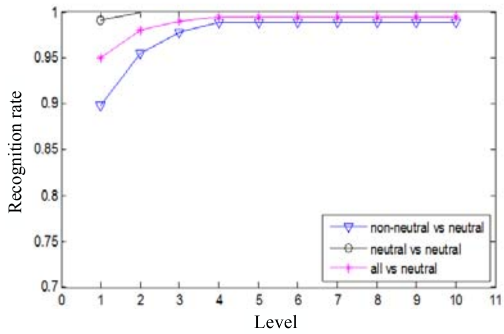


Figure 7. CMC curve

Experiment result shows algorithm can achieve good recognition effect on the premise of no expression and the recognition rate is 99.1%. However, the face has an expression, performance of algorithm would drop dramatically and the recognition rate is only 9.3%. Failures on the premise of expression are analyzed and it is found that recognition failures mostly happened when the subject open his/her mouth. It can be seen from Figure 8 that the extraction of equal geodesic contour line of the upper part of face would have big error when the mouth is opening.

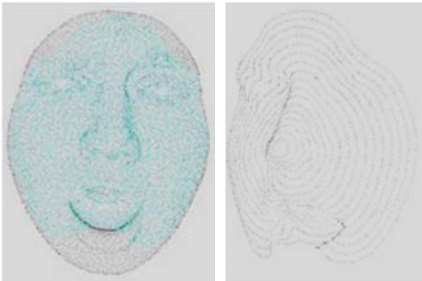


Figure 8. Equal geodesic contour line extracted when mouth is open

Open mouth creates a concave in the mouth area of human face so the topological structure of face is changed. Considering the major reason for recognition failure is that the bottom face of subject is deformed, only the characteristics in the equal geodesic contour line on the upper part can be extracted for experiment. Select a point in the face pose coordinate system whose *y* coordinate>0 as the point in the upper part of face and extract all the local characteristics in the equal geodesic contour line on the upper area and CMC curve as obtained as shown in Figure 9.

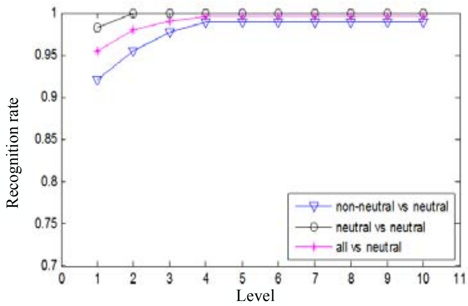


Figure 9. CMC curve

It can be seen from the figure, when the characteristics in contour line on the upper part are extracted for recognition, in the three conditions: non-neutral vs. neutral, neutral vs. neutral and all vs. neutral, the recognition rate is: 92.1%, 98.5% and 95.5% when the level is 1. When the test subject has an expression, recognition rate is improved significantly and good effect is achieved.

Verification experiment is that all the faces in the test set are compared with library set faces (all vs. neutral). Figure 10 shows ROC (Receiver Operating Characteristic) obtained by the algorithm in the thesis. It can be seen from the curve that EER (equal error rate) is 5.67% and good verification result is obtained.

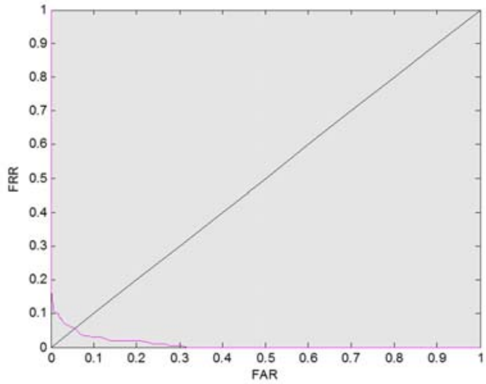


Figure 10. ROC curve

Compare the algorithm in the thesis with the literature [3-6] and result is shown in Table 1. It can be seen from the table that the algorithm in the thesis fully combines the geometric information and neighborhood information of face surface so it has advantage in recognition rate and equal error rate.

TABLE 1. ALGORITHM RESULT COMPARISON

Recognition method	Recognition rate	EER
Literature [3]	-----	5.93%
Literature [4]	94.67%	-----
Literature [5]	-----	8.32%
Literature [6]	93.78%	-----
The thesis	95.5%	5.67%

V. CONCLUSIONS

Local descriptor based on equal geodesic contour line is proposed in the thesis to recognize 3D face. Firstly, 3D face data are pretreated to obtain uniform face area and normalize the pose; then points equidistant to the nasal tip point are extracted to compose equal geodesic contour line according to geodesic distance, the contour line is re-sampled and local descriptor of each sampling point neighborhood is extracted; finally local descriptor is weight, fused and compared after the point correspondence relation between test face and library set face is established and ultimate recognition result is obtained. The algorithm is tested on Face recognition grand challenge v2.0 database and experiment result shows the method has relatively good recognition performance.

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