

ACCURATE 3D FACE REGISTRATION BASED ON THE SYMMETRY PLANE ANALYSIS ON NOSE REGIONS

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ABSTRACT

Three-dimensional face registration is a critical step in 3D face recognition. This paper presents a fully automatic registration method with high accuracy and robustness to facial expressions for aligning frontal 3D face data. In our method, the nose region, which is relatively more rigid than other facial regions in Anatomy sense, is automatically located and analyzed for computing the precise location of a symmetry plane. We then proceed on to find a stable reference point and a nose line from the global information of the nose region. In this way, the six degrees of freedom as well as a unified coordinate system can be determined for each face. Extensive experiments have been conducted on the FRGC V1.0 benchmark face dataset to evaluate the accuracy and robustness of our registration method. Firstly, we compare its results with manually marked points on the visualized face data. Secondly, we test its application in a 3-D face verification system. Preliminary experiment results show that this approach can efficiently reduce the intra-class distance and performs even better than the manual registration method in face recognition.

1. INTRODUCTION

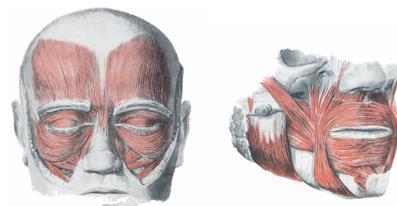
3D face data acquired by 3D scanners can explicitly represent the features of a person's face regardless of the viewpoint and lighting variations. Thus, research in 3D face recognition has received significant attention especially in recent years [1][2]. The purpose of 3D face registration is to align different 3D face data into a common coordinate system. Registration is a crucial and indispensable step as the accuracy of this step will greatly influence the performance of the whole face recognition system.

In this paper, we propose an accurate 3D face registration method by creating an intrinsic coordinate system for each 3D face data. To achieve this purpose, the six degrees of freedom (6DoF): Θ_x , Θ_y , Θ_z and the origin (x_0, y_0, z_0) , should be included into the consideration for each set of 3D face data. Where Θ_x , Θ_y and Θ_z are the rotation around the x axis, y axis and z axis respectively. Previously, an effective method, based on the symmetry plan analysis on the whole 3D face region, for determining Θ_y and Θ_z of a 3D face data has been proposed by Pan et al. [3]. This algorithm and its variations have been adopted by many other researchers in their face registration work [4][5][6]. This class of methods holds the assumption that human face is bilaterally symmetric. Nevertheless, small pose variations, different hair style and facial expressions can all lead to violations of such an assumption. In fact, we have found that the symmetry plane results for multiple facial scans from the same person are not always stable for the above reasons.

Based on the above analysis, we are inspired to find a more rigid part on the human face for the symmetry plan analysis. Compared to the whole face region, the nose region has several advantages intuitively. Firstly, human nose, which consists mostly of cartilage, is more rigid than mouth, eyes and cheeks, all of which consist mainly of tissues. Secondly, human nose does not change significantly under most facial expressions. Thirdly, the data in the nose region is usually complete and is seldom occluded by hair or beard. In view of these observations, we propose to use nose region for a more stable symmetry plane locating in our work.

In Section 2, we start our analysis by introducing evidences from anatomy to support our assumption that the nose region is the relative more rigid part than other facial parts on human being's face. Section 3 presents the main methodologies proposed in our 3D face registration framework. We then investigate the performance of our proposed registration method with the Face Recognition Grand Challenge (FRGC) dataset V1.0 [7] in Section 4, in which we also compare our work with two other registration methods: one based on symmetry plane analysis on the whole face region, and the other based on manually marked fiducial points. Section 5 is the conclusion.

2. EVIDENCES FROM ANATOMY



(a) Upper face muscle. (b) Lower face muscle.

Figure 1: Facial muscles.

The anatomy of muscles can serve as a direct tool for analyzing facial expressions. Figure 1 depicts the muscles of the face. From this figure, we can clearly see that, compared to other parts on human face, the amount of muscles located on the nose region is the least. In anatomy, Facial Action Coding System (FACS) [8] is a *de-facto* standard for "coding" every conceivable human facial expressions. The basic measurement units defined in FACS are Action Units (AUs). A single AU may consist of more than one muscle. Nearly all anatomically possible facial expressions can be decomposed into specific AUs that produce the expressions [8]. And there are totally 32 AUs defined in FACS. In Table 1, we summarize the number of AUs reside on major parts of human face. We can observe that there is only one AU related to the

nose region, and the associated movement defined in FACS is called nose wrinkler. By contrast, the muscles associated with other facial regions all contribute to more than one AUs. As such, the nose regions can be viewed as a more rigid object than any other parts of the face and are almost invariant under many facial expressions. In addition, the good face recognition performance achieved by Chang et al. [9] using multiple nose regions under varying facial expression further supports our belief.

	Forehead	Eyebrow	Eyes	Nose
AUs	>2	>5	>5	1
	Checks	Mouth	Lips	Chin
AUs	>5	>5	>10	>5

Table 1: The number of AUs located on major parts of human face.

3. THE AUTOMATIC REGISTRATION PROCESS

3D face data used in this paper are from the FRGC V1.0 (Spring 2003) dataset. We adopt the FRGC, which contains 943 frontal facial scans from 275 individuals in which the head pose of 3D data in this dataset are basically all frontal.

Figure 2 illustrates the framework of our proposed automatic 3D face registration method. The first stage is to extract a facial region from a set of raw 3D face data automatically. The basic idea of this step is to locate the four boundaries of the face region coarsely, and then the cropped face region is refined on the yz -plane for discarding such unwanted points as hair, ear and neck regions. The second stage is to compute the symmetry plane of the extracted 3D face region for the purpose of finding the nose region. The third stage is to locate the symmetry plane for the nose region. In the final stage, an intrinsic coordinate system is created for the 3D face data.

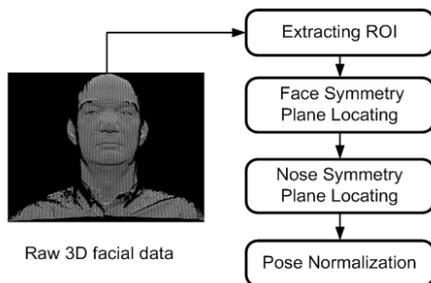


Figure 2: Proposed automatic 3D face registration framework.

3.1 Symmetry plane locating

In this section, we will start with the work for computing the symmetry plane for the extracted face region firstly. Then this symmetry plane will be utilized to locate the nose region and serve as the initial symmetry plane for it. Finally, a more accurate symmetry plane of the nose region will be detected for registration purpose.

The symmetry plane location methods adopted in [4][5][6] are all similar to each other, and can be viewed as variations of the method proposed by Pan et al.[3] which we have also adopted here for this work. Pan's method is a two stages, coarse to fine method. Firstly, Principle Component Analysis (PCA) is applied on a set of 3D face data to roughly locate an initial symmetry plane. Secondly, this plane is used

as the mirror plane for constructing the mirrored 3D data for the original 3D face data. Thirdly, an Iterative Closest Point (ICP) algorithm [10] is employed to get a refined registration between original 3D face data and mirrored 3D data. Finally, plane fitting is applied on the corresponding points from the two aligned surfaces to get the final symmetry plane. When using this method, we should notice that the original ICP algorithm in the third step converges monotonically to a local minimum and hence is a good estimate of the initial transformation between point sets.

When applying PCA to locate the initial symmetry plane, we find there are some cases when this method fails, as shown in Figure 3(a). In [4] and [5], the authors assume that a human facial surface's height is typically taller than its width. Moreover, their semiautomatic methods on ROI extraction also ensure the validity of their assumption. Hence when PCA is applied to 3D facial data, the direction of the first principle eigenvector always approximates the vertical dimension of the facial surface. However, there is no assurance that the vertical dimension generated by PCA is always longer than the horizontal dimension when a facial region is cropped using our ROI extraction method for every face data. If these inaccurate symmetry planes are used as initial estimates, the ICP algorithm will probably not converge.

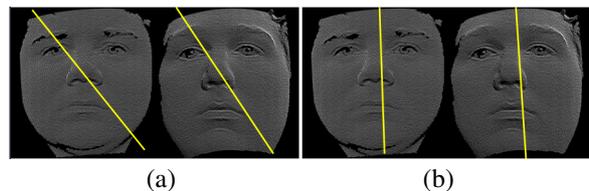


Figure 3: (a) Improper initial symmetry plane locating results by PCA. (b) Initial symmetry plane locating method proposed by us.

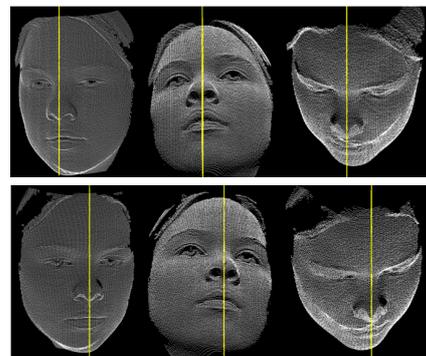


Figure 4: Unstable symmetry plane locating results on two 3D facial scans from the same person. When fixing Θ_z of these two face data, Θ_y difference between them exceeds 10 degree by roughly estimation.

Since the head pose for 3D face data used in our work are all near frontal, this prior knowledge could be utilized here to design a simpler initial symmetry locating method instead of the PCA method. As an alternative, we calculate the location of the centroid for all points on the 3D face firstly. Then, the plane which is parallel to yz -plane and passes through the centroid is taken as the initial symmetry plane, as illustrated in Figure 3(b). In order to speed up the following ICP algorithm, we down sample the 3D face data to a specific degree.

In our implementation, the number of points is down sampled to 500.

In our experiment, we found that the symmetry plane locating method does not perform stably when applied to multiple scan data belonging to the same person. This is because the complete face is not really a symmetric object. Reason is that we use this algorithm, which is originally designed for a symmetric object, on an asymmetric object, as shown in Figure 4. To overcome this intrinsic shortcoming, the essential solution is to find a more rigid part on human face and apply the symmetry plane locating algorithm to it.

Based on the analysis in Section 2, the more rigid object we find on the face is the nose region. To accurately locate the nose region, we relocate the symmetry plane horizontally so that it passes through the nose tip. The algorithm is outlined as follows:

1. Locate the nose tip and nose bridge on the intersection curve running between facial surface and the symmetry plane, through curvature analysis.
2. Construct three transverse planes which are perpendicular to the symmetry plane at the nose tip for the extraction of three intersection curves.
3. Locate the nose tip through curvature analysis on each curve, see Figure 5(c). And the centroid of all these detected nose tip candidates is used as the new location for the nose tip.
4. Construct a new symmetry plane as the plane parallel to the original symmetry plane but passes through the new nose tip.
5. Locate the new nose bridge as the intersection curve lying between the facial surface and the new symmetry plane, through curvature analysis, as depicted in Figure 5(d).

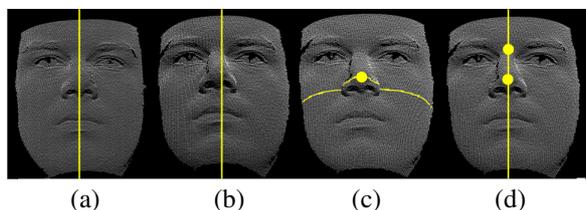


Figure 5: (a)~(b) Symmetry planes (based on complete faces) for two different 3D facial scans from the same person divide the face asymmetrically. (c) Locating the nose tip. (d) Refined symmetry plane.

Since the refined symmetry plane passes through the nose tip now, we can use it to locate the nose regions for each 3D face data for a more accurate symmetry plane locating. The procedure for locating the symmetry plane for nose regions is presented as follows:

1. Define the refined symmetry plane for the whole face region as the initial symmetry plane for the nose region.
2. Employ the 3D points lying inside the rectangular region right above the detected nose tip as input data for further refinement of the location of the symmetry plane for the complete face, as illustrated in Figure 6.
3. Down sample the number of points in the rectangular region before entering the ICP step. In our implementation, the number of points is down sampled to 200.
4. Adopt Pan's method [3] for locating the final symmetry plane for the complete face. Notice the problem cases in Figure 4 are now solved as shown in Figure 7.

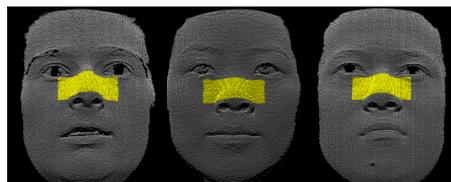


Figure 6: The nose region used for symmetry plane locating.

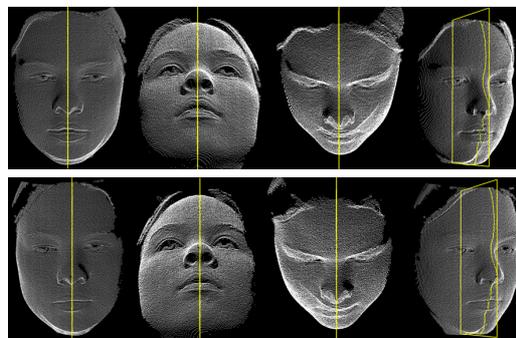


Figure 7: Refined symmetry planes located on 3D facial data.

3.2 Pose normalization

After refining the symmetry plan, Θ_y and Θ_z of the face can now be determined. Thus, we have identified two parameters in the 6DoF. The next step is to resolve Θ_x of the face and find a robust reference point as the origin. Let 'symmetry profile' stands for the intersection curve between the 3D face data and the symmetry plane, along which locations of the nose tip and the nose bridge can be identified through curvature analysis, as seen in Figure 8(b) and 9(b). Although the nose tip or the nose bridge is a natural candidate for the origin; there are chances that their positions cannot be stably extracted due to factors like spikes or holes. Figure 8(a) and 9(a) are two facial scans from the same person. Because of a big spike in the data around the nose tip as shown in Figure 8(a), the detected nose tip is inaccurate, see Figure 8(b). If we use this nose tip as the origin, the registration result will not be satisfactory as illustrated in Figure 9(c). To deal with this problem, we propose a more stable reference point locating strategy, based on the observation that the segment between the nose tip and the nose bridge on the symmetry profile can often be treated as a straight line.

1. Extract the points between the located nose tip and nose bridge from the smoothed symmetry profile.
2. Fit a least square straight nose line with the extracted points, as depicted in Figure 8(c). The angle between the nose line and y axis is Θ_x of the face.
3. Collect those points on the smoothed symmetry profile whose distances to the nose line are smaller than a pre-defined threshold. The centroid of these points is used as the final reference point as shown in Figure 8(c) and will be adopted as the origin later. In this way, all of the 6DoF for each 3D face data are now resolved.

A coordinate system can thus be defined for each 3D face based on the position of the reference point, the nose line, together with the symmetry plane. This operation can also be interpreted as a pose normalization process, considering that the coordinate system thus defined is pose invariant. To define such a coordinate system, firstly, the symmetry plane is

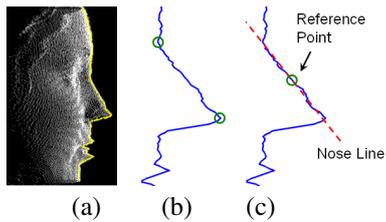


Figure 8: (a) Several "spikes" appeared on 3D face data. (b) Inaccurate nose tip and nose bridge localization results on symmetry profile. (c) The nose line.

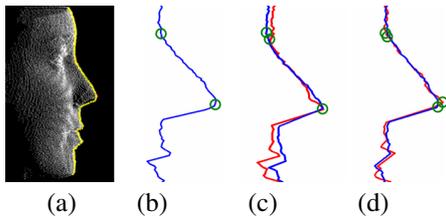


Figure 9: (a) Facial scan from the same person as Figure 8(a). (b) Located the nose tip and the nose bridge. (c) Using the nose tip as the origin, the enclosed area between 8(b) and 9(b) is 240.8. (d) Using our method, the area is decreased to 82.2.

used as the yz -plane for the new Cartesian coordinate system. Secondly, the position of the reference point is adopted as the origin. Finally, the angle between the y axis and the nose line is set to a certain degree θ . After such intrinsic coordinate system is built for each 3D face, data in the whole dataset can now be aligned into a common coordinate system. Figure 10 shows some results after this pose normalization process. And the effectiveness of this method is illustrated in Figure 9(d).

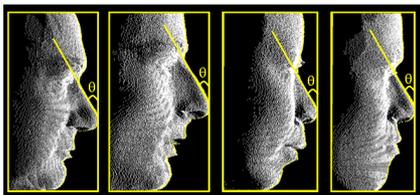


Figure 10: Side view of four already registered 3D facial data.

4. EXPERIMENT RESULTS

In order to evaluate the performance of the automatic 3D face registration method proposed in this paper, manually marked facial points are used here for comparison. Totally eight fiducial points are chosen because of their anatomical distinctiveness, so that they are capable of capturing the shape and size variations of a human face. Figure 11(a) shows these points. The manual job was carried out by a team of 6 graduate students with biometrics training. And each 3D face data is marked by two people to avoid individual bias. The average value of two manually marked locations is taken as the effective location of a fiducial point.

In our experiments, we used two intersection curves, obtained directly from aligned 3D face data, as the feature for face matching. One curve which is the intersection between facial surface and yz -plane is called a symmetry curve. The other curve which is the intersection between facial surface

and xz -plane is called cheek curve. Figure 11(b) shows them. The area enclosed by the same type of curves extracted from different faces is utilized as the distance measure.

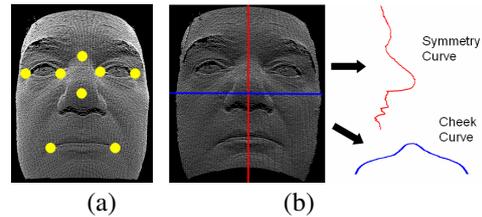


Figure 11: (a) The eight manually marked fiducial points. (b) Two extracted curves for face recognition.

3D face data are registered in three different ways. The first one, termed Nose Symmetry Plane (NSP) method, uses our automatic registration method as introduced in section 3. The second registration method is based on the symmetry plane analysis on the whole face region in which Θ_y and Θ_z from the 6DoF are determined for each 3D face. Like the first method, a reference point is adopted as the origin and a nose line is used for determining Θ_x of a face. The nose tip now serves as the origin and the nose line is constructed by passing a line through the nose tip and the nose bridge. We call this method Face Symmetry Plane (FSP) method. The last method applies Procrustes algorithm [11] on the manually marked fiducial points for registration purpose.

If a person is regarded as one class, then multiple facial scans from the same person should belong to the same class. An important criterion to judge a registration method is to check how good it can achieve on decreasing the intra-class distance. Our first experiment is to evaluate the intra-class distance for the different registration methods. One-to-one matching between multiple facial scans for the same person was conducted using the FRGC V1.0 dataset. The results are listed in Table 2 in which we can see that, Arithmetic Mean and STD for the NSP method are the smallest among the three registration methods. This clearly indicates that our proposed automatic registration method is more accurate than the other two registration methods.

Registration Method	Cheek Curve	Symmetry Curve
NSP	80.0 ± 47.4	92.5 ± 47.8
FSP	117.8 ± 84.3	93.4 ± 55.6
Manual	101.4 ± 58.7	103.8 ± 50.0

Table 2: Statistics of the intra-class distance by different registration methods.

The objective of the second experiment is to compare the performance of different registration methods in face recognition. All 3D face data in FRGC V1.0 dataset are used for one-to-one matching in verification experiment. The corresponding Receiver Operating Characteristic (ROC) curves when using the symmetry curve and cheek curve as matching features are shown in Figures 12 and 13. We summarize the EER scores gained by the different registration methods and list them in Table 3, in which the lowest EER scores for the symmetry curve and the cheek curve are both obtained using the NSP method. Since this method has the smallest intra-class distance in experiment 1, there is no surprise it can perform the best in face recognition experiment. Moreover, when compared with the FSP method, the improvements in the EER scores from 7.1% to 5.5% for the symmetry curve

and from 12.0% to 8.9% for the cheek curve clearly reflect that significant enhancements in matching results occur when we change the symmetry plane analysis strategy from the whole face region to the nose region.

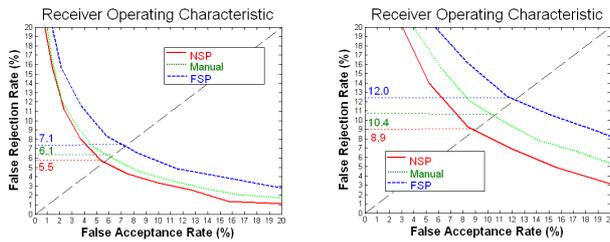


Figure 12: The ROC curve for using the symmetry curve. Figure 13: The ROC curve for using the cheek curve.

Registration Method	Symmetry Curve	Cheek Curve
NSP	5.5%	8.9%
FSP	7.1%	12.0%
Manual	6.1%	10.4%

Table 3: Statistics of the intra-class variation by different registration methods.

When observing failed cases in the FSP method, the main problem lies in the instability of the located symmetry plane for the same person. And this problem has been satisfactorily resolved in the NSP method, see Figure 14. Problems in the manual registration method mainly come from facial expression changing and mouth corner localization error because of beard, see Figure 15. This observation also validate that our automatic registration method is more robust to expression or appearance changes than landmark based registration method.

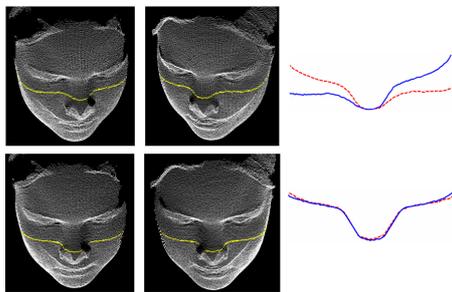


Figure 14: The first row shows two aligned 3D face data by the FSP method. The area between the two cheek curves is 1038. The second row shows results from the NSP method. The area between the two cheek curves is 63.8.

5. CONCLUSIONS

In this paper, we have provided a fully automatic registration method to create an intrinsic coordinates system for 3D face data. Different from previous works using the whole face region for locating the symmetry plane of a face, we use the nose region to conduct our work because the nose region is relatively more rigid than other parts of a face and is almost expression invariant in Anatomy sense. In addition, that the reference point and nose line are computed using the global information on the nose region also contributes to a higher registration reliability.

To verify our claims, the FRGC V1.0 benchmark 3D face dataset was utilized for evaluating the performance of our method in registering 3D facial datasets. Results suggest our

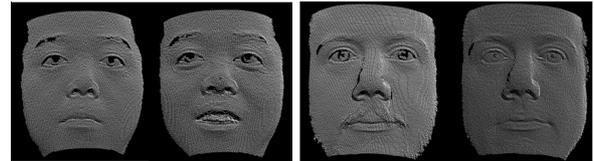


Figure 15: False rejected faces in manual registration method. (a) Facial expression variations. (b) Face samples with and without beard.

superiority not only when it is compared with the symmetry plane located using the whole face but also in cases when manual registrations are used.

Considering that only one single profile has been used as the feature, the face recognition result achieved using our automatic registration method is quite promising. We are in the process of applying additional more discriminative features and expect even lower EER scores. We view our contribution as proposing a fully automatic, accurate and robust registration method for near frontal 3D face data, and verifying the nose region as a more promising candidate for symmetry plane locating research. Applications for this accurate registration method should not be restricted only to 3D face recognition study, but spread over wide areas such as medical systems, computer animation and virtual reality etc.

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