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A Novel Approach of 3D Face Reconstruction Using Ellipse Fitting

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Abstract

The problem of reconstructing the 3D face using one image captured from a viewpoint arises in many fields of science and engineering, this paper propose the novel approach for reconstructing the 3D face by using ellipse fitting technique from only one 2.5D image. The 2.5D face image is captured from any viewpoint between -45 degree and +45 degree. The cross section across the head is fitted by ellipse, and then the semimajor axis vectors are corrected to the nose tip and ridge by the nose ridge detection algorithm, the nose tip and ridge are localized. The mirror of real face is computed from the symmetry plane passing the nose ridge, the nose tip and the point on the center line of face. Finally, 3D face is reconstructed using the real face and its mirror face. This proposed method has the advantages: 1) the only one 2.5D image from a viewpoint between -45 degree and +45 degree is used; 2) the generic face model is not required in the system. The 135 3D virtual face samples were reconstructed in the experiment. The results show the feasibility of the proposed method.

1. Introduction

Reconstructing 3D face has been a challenging issue in computer vision and recognition in the past decades. The several methods which use the least number of input images from a viewpoint of face for reconstructing the 3D face have been proposed so far. But the existing system which uses a single image can achieve good performance from only the frontal face viewpoint by means of the generic face model [1].

The techniques for reconstructing the 3D face can be classified into three categories.

Firstly, the 3D face is reconstructed from the multi images. G. Pujitha [2] proposed a method using the four 2.5D images captured from different orientations. The corresponding points are selected by manual and mapped by using a least squares estimator. L. Yuan and L. G. Marina [3] proposed a method for reconstructing 3D face model from extracting 18 feature points on 2D facial images in two orthogonal views: one frontal view and one side view. These methods need more than a single frontal image and the precision of depth value depend on the number of input images.

Secondly, the morphable model proposed by V. Blanz [4],[5] can create a face model from a single image. Their system uses both a geometry database and an image database. It can model the faces whose skin colours are covered by their database. Their methods are computationally expensive. To obtain the training set, a large 3D face database is needed.

Thirdly, shape from shading (SFS) [6],[7],[8] deals with the recovery of 3D shape from a single monocular image. Under the Lambertian assumption, the 3D shape of human face can be recovered by using SFS. But most of the 3D face models recovered by SFS are not useful in many applications because they give unreliable depths in facial organs such as the eyebrows, eyes, mouth and nose. H. Yuankui [1] also proposed the generic face model using SFS. But the only frontal image can be used to reconstruct the 3D face.

In existing research, the 3D face reconstruction methods show the sufficient result in case the multi input images or the generic face model with an additional image is used. Based on the symmetry property of face [9], in this paper, we present the 3D face reconstruction by using ellipse fitting. Only one 2.5D image captured from a viewpoint between -45 degree and +45 degree is used. The virtual face is reconstructed using the symmetry plane passing the nose tip and the nose ridge according to the 3D face reconstruction algorithm. This paper is the extended research of the robust method for localizing the nose tip and ridge by using ellipse fitting in [10]. Our 3D face reconstruction method has the advantages: 1) the only one 2.5D image from a viewpoint between -45 degree and +45 degree is used; 2) the generic face model is not required in the system.

The proposed method is described in detail as following section beginning from 2.5D Image Acquisition, Nose Ridge Localization, 3D Face Reconstruction, Experimental Result and Conclusion, finally.

2. 2.5D Image Acquisition

For our 3D face reconstruction algorithm, the one 2.5D head image is used. The input data is captured by using VIVID700 and represented by the point set data. The 2.5D image consists of range data and color data. The range image size is 200x200 pixels, the color image has 400x400 pixels in the same image size. Unfortunately, VIVID700 is not sensitive for the black color like hair because it uses a red laser. This problem was solved by covering the hair with the cap. It seems to be advantages to wear the cap, however it is not correct. An example of a person with gray hair without cap will be shown in the experiment. The input image was captured from a viewpoint around Y axis from -45 degree to +45 degree (see Fig. 1(b)).

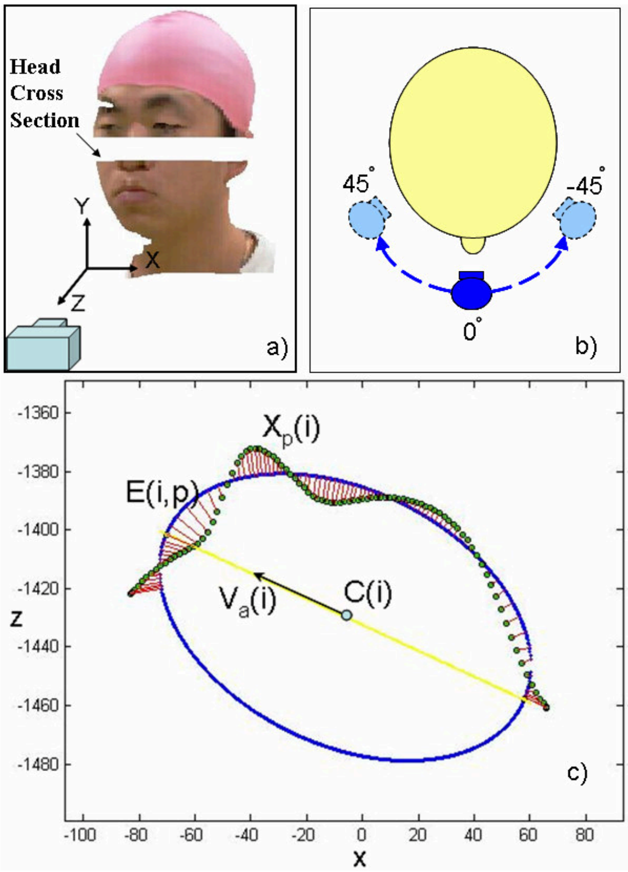

Figure 1. a) Coordinate System Configuration. The black color surface as hair unmeasured by laser light is covered by cap. b) Illustrate the viewpoint for capturing the 2.5D image from the top view of human head. c) Fitting the head cross section data by ellipse fitting technique. The significant parameters were illustrated. The $X_p(i)$ (green points) are the point on the facial surface. The $E(i,p)$ (red lines) are the ellipse fitting error from a point $X_p(i)$ to ellipse. The blue ellipse is the ellipse of fitting.

3. Nose Ridge Localization

In this section, the nose ridge localization algorithm is explained briefly based on the full version in ref. [10].

Based on the definition of body segmentation referred in ref. [10], the head is defined as the body above the chin neck juncture. The chin neck juncture will be selected manually in advance.

3.1. Fitting of Ellipses for Head Cross Section Data

In this subsection, the significant parameters solved by the ellipse fitting technique will be described. From the range image, the head data is split into N cross sections along the Y axis (see Fig. 1(a)). The data on each cross section was fitted by ellipse fitting technique.

Based on the ellipse fitting method referred in ref. [10], the three significant parameters which are illustrated in Fig. 1(c) can be solved.

i) Average Center of Ellipse (C_{Ae}): This parameter is the average value computed from the center of ellipse in all cross sections.

$$C_{Ae} = \frac{1}{N}\sum_{i=1}^{N} C(i) \tag{1}$$

where $C(i)$ is the center of ellipse of i^{th} cross section.

ii) The Semimajor Axis Vectors $V_a(i)$ of i^{th} Cross Section: There are two directions along the semimajor axis of ellipse in each cross section, pointing from the center $C(i)$. The semimajor axis vector in each cross section which points to the facial surface was selected [10]. These vectors will be used for computing the face vector in the subsection 3.2.

iii) Average Ellipse Fitting Error $E_{Ae}(i)$ of i^{th} Cross Section: The ellipse fitting error at a point $X_p(i)= (x_p,z_p)$ in i^{th} cross section is defined as $E(i,p)$ as shown in Fig. 1(c). $E(i,p)$ is the orthogonal distance between a point $X_p(i)$ and ellipse. The $E_{Ae}(i)$ is computed from $E(i,p)$ in Eq. (2).

$$E_{Ae}(i) = \frac{1}{M}\sum_{p=1}^{M} E(i,p) \tag{2}$$

where M is the total number of the points on the i^{th} cross section.

3.2. Projected Face Vector Correction Algorithm

Based on the definition of nose region in ref. [10], there exist about fifteen cross sections in nose region counting from the cross section passing the nose tip. The nose ridge will be detected from the cross sections in nose region.

As mentioned in 3.1, there are many semimajor axis vectors pointing to the facial surface. Based on the experiments of all viewpoints, each cross section shows the different average ellipse fitting error. According to this property, the semimajor axis vector under the condition that the average ellipse fitting error of its cross section is less than 1 mm. tends to point to the surface near the nose. By averaging the semimajor axis vectors, the face vector can be calculated, and then the face vector is projected onto each cross section in nose region. We call it the projected face vector.

For each cross section in nose region, the points set on facial surface are projected on the projected face vector. Generally, the projected point from the nose ridge is farthest from the average center C_{Ae}, the projected face vector will be corrected to the farthest point. The process is done for the 15 cross sections in nose region. The 15 nose ridge points are localized. The vector pointing from the average center C_{Ae} to the center of 15 nose ridge points will be used in the section 4 as nose vector.

4. 3D Face Reconstruction

In this section, the mirror face construction and symmetry plane correction algorithm will be explained. According to these two algorithms, the 3D virtual face will be reconstructed.

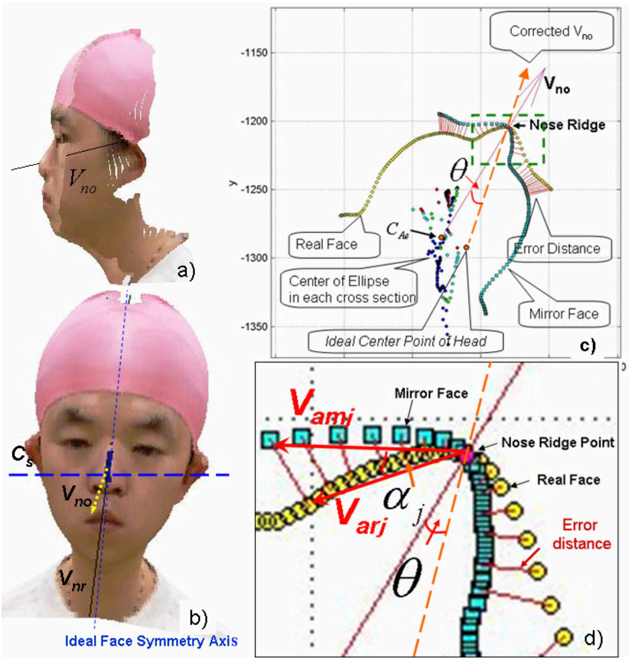

Figure. 2. a.) Illustrate the side viewpoint of real face, the nose vector *(V_{no})* point from the average center of head to the average center of nose ridge points. b.) The nose ridge vector *(V_{nr})* passes the nose ridge points (point on the nose). The 3D face shows wrong face shape. c) The direction of the nose vector is corrected. The vector with dash line is the corrected nose vector. θ is the rotation angle of the nose vector. C_{Ae} is the average center of ellipse. The distance between the corresponding points is the error distance. The detail in box with dash line is shown in Fig.2(d). d) Illustrate the rotation angle, where V_{am} and V_{ar} are the vector pointing from the nose ridge point to the corresponding points on the mirror face and the real face, respectively. α_j is the angle between the V_{amj} and V_{arj}. θ is the rotation angle.

4.1. Mirror Face Construction

The mirror face is computed using the symmetry plane and the real face captured. The 3D virtual face is reconstructed from the real face and its mirror face.

The symmetry plane is the vertical plane along the center line of the face passing the nose tip and ridge. The symmetry plane is defined by two vectors; nose ridge vector and nose vector.

In subsection 3.2., the 15 nose ridge points were detected. The nose ridge vector can be calculated from these points by using PCA (Principle Component Analysis) (See Fig. 2(a)).

The nose vector is the vector pointing from the average center C_{Ae} to the center of 15 nose ridge points (See Fig. 2(b)).

The symmetry plane is described in Eq. 3 and 4.

$$V_n = V_{nr} \times V_{no} \tag{3}$$

$$V_n \bullet X = 0 \tag{4}$$

where V_{nr} is the nose ridge vector, V_{no} is the nose vector, V_n is the normal vector of symmetry plane and X is a point on the symmetry plane, where the origin is C_{Ae} and $\times$ and $\bullet$ represent outer product and inner product respectively. By reflecting the real face in the symmetry plane, the mirror face can be computed, and then the 3D face can be reconstructed.

4.2. Symmetry Plane Correction

Although the 3D virtual face was constructed as mentioned in 4.1, the 3D virtual face shows the wrong shape and this method sometimes creates too fat or too thin face. These problems are occurred from the inclination of the symmetry plane related to the incorrect direction of the nose vector and the inclination of the nose ridge vector. In this subsection, a correction algorithm for the symmetry plane will be described.

4.2.1. Nose Vector Direction Correction. As the nose vector pointing from the average center C_{Ae} was defined in subsection 2.4, the nose vector has the significance to the symmetry plane. The correct nose vector should pass the ideal center point of the head.

The nose vector is rotated around the nose ridge by the average angle computed from the angle between two vectors V_{am} and V_{ar} as shown in Fig. 2(a), where V_{am} and V_{ar} are the vector pointing from the nose ridge point to the corresponding points on the mirror face and the real face, respectively. The corresponding points are the closest points on the real face and the mirror face.

$$\alpha_j = \arccos(V_{amj} \bullet V_{arj}) \tag{5}$$

$$\theta = \frac{1}{2N}\sum_{j=1}^{N} \alpha_j \tag{6}$$

$$V'_{no} = R(\theta)V_{no} \tag{7}$$

where V_{amj} and V_{arj} are the vectors of the corresponding point j, respectively. α_j is the angle between the V_{amj} and V_{arj}. θ is the rotation angle. V_{no} is the nose vector. $R(\theta)$ is the rotation matrix.

The nose vector V_{no} is rotated by rotation angle θ centering at the nose ridge point (See Fig. 2(c)). This algorithm is repeated while the average error distance is smaller than the next iteration. The direction of nose vector is corrected finally.

4.2.2. Extended Nose Ridge Vector Computation. According to the inclination problem of the nose ridge vector, the extended nose ridge vector is proposed for solving the inclination problem of the symmetry plane which is the consequence of the nose ridge vector.

1) **Region of Interest.** The region of interest (ROI) is defined as the cross section between the average center cross section and the chin neck cross section. The chin neck cross section is the cross section passing the chin neck junction.
2) **Farthest Point Detection.** The points set on facial surface in ROI are projected on the nose vector. Generally, the farthest point from the average center C_{Ae} is on the center line of the face. The algorithm in 3.2 is used to detect the farthest point.

The process is done for the whole cross sections in ROI. The farthest points are detected finally. The outlier farthest point will be removed and then the extended nose ridge vector is computed from the remained farthest points by means of the PCA.

After the correction algorithm is done, the symmetry plane is computed from the extended nose ridge vector and the nose vector, and then the mirror face is also computed by reflecting the real face in the symmetry plane as mentioned in 4.1. Finally, the virtual face is reconstructed.

5. Experimental Results

To test the performance of the proposed method, the difference viewpoints of face were tested. All the experiments were executed by Pentium M 1.73 GHz processor, 512 MB RAM and Matlab 7. The hair was covered with a cap. The five viewpoints from -45 degree to +45 degree around Y axis with step 22.5 degree of each people are tested because our algorithm uses both sides of facial data for the symmetry plane.

The similarity between the virtual face and its frontal real face is evaluated by matching the virtual face with the frontal real faces of 27 persons, and then comparing the average error distance between the corresponding point on the virtual face and the frontal real face of each person. The nose tips of the virtual face and the real face are identified manually. Then the nose tip of virtual face is fixed at the nose tip of the real face. The virtual face is rotated around the Y and X axis as the origin point at the nose tip to minimize the average error distance. The correct matching is when the average error distance is the smallest. The matching accuracy is the percentage of the correct samples to the total samples.

From the 135 samples in the different five viewpoints of the 27 people, the accuracy for matching the virtual face with the frontal real face was 97% as shown in Table I. The virtual face reconstruction result is illustrated in Fig. 3.

As shown in Table I, the bigger angle data tends to be worse result. This is because it becomes difficult to estimate the error between the mirror face and the real face correctly from comparing the small overlapped area.

TABLE I.
THE EXPERIMENTAL RESULT OF THE 3D FACE RECONSTRUCTION

Viewpoint around the Y axis (Degree)	Total Number of Sample	Number of Failed Samples	Matching Accuracy
-45	27	4	85.2%
-22.5	27	0	100.0%
0	27	0	100.0%
22.5	27	0	100.0%
45	27	0	100.0%
Total	135	4	97.0%

6. Conclusion

In this paper, we proposed the novel approach for reconstructing the 3D face by ellipse fitting technique. The only one 2.5D image captured from -45 degree to 45 degree was used. The distinctive performance of our proposed 3D face reconstruction method are 1) the only one 2.5D face image captured from a viewpoint between -/+ 45 degree is used. 2) The generic face model is not requested in our method. The 135 3D virtual face samples were reconstructed in the experiment. The results showed the feasibility of the proposed method. For future work, our method will be applied for the facial expression recognition research.

7. References

[1] H. Yuankui, Zh. Ying, and W. Zengfu, "Reconstruction of 3D Face from a Single 2D Image for Face Recognition", *Proc. 2nd Joint IEEE International Workshop on VS-PETS*, Beijing, October 15-16, 2005.

[2] G. Pujitha, Sh. Hisanari and S. Yukio, "3-D Face Modeling with Multiple Range Image", *15th Int. Conf. on Pattern Recognition (ICPR'00)*, Vol. 4, p. 4599, 2000.

[3] L. Yuan and L. G. Marina, "3D Facial Model Synthesis using Voronoi Approach", *3rd Int. Symposium on Voronoi Diagrams in Science and Engineering (ISVD'06)*, pp: 132-137, July, 2006.

[4] V. Blanz and T. Vetter, "A Morphable model for the Synthesis of 3D Faces", *SIGGRAPH*, pp: 187-194, 1999.

[5] V. Blanz, S. romdhani, and T. Vetter, "Face Identification across Different Poses and Illuminations with a 3D Morphable Model", *In AFGR 2002*, pp. 192-197, 2002.

[6] R. Zhang, P. Tsai, J. Cryer and M. Shah, "Shape from Shading: a Survey", *IEEE Trans. PAMI*, 21(8): 690-706, 2002.

[7] Yi Liao and Rongchum Zhao, "Analysis and Evaluation of Several Typical SFS algorithms", *Journal of Image and Graphics*, 6(10), pp. 953-961, 2001. 8.

[8] P. Tsai and M. Shah, "Shape from Shading using linear approximation", *Journal of Image and Vision Computing*, 12(8), pp. 487-498, 1994.

[9] Benz, M., Laboureux, X., Maier, T., Nkenke, E., Seeger, S., Neukam, F. and Häusler, G, "The symmetry of faces", *Proc. of Vision, Modeling and Visualization*, pp. 43–50 (2002).

[10] Th. Charoenpong, H. Hiroyoshi and T. Shogo, "Robust Nose Localization by Using Fitting of Ellipse", *Int. Conf. TENCON2006,* Hong Kong, Nov 14-17, 2006.

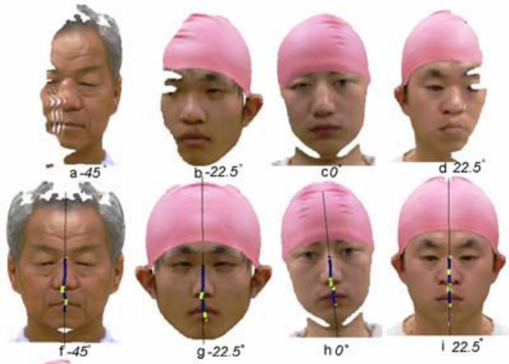

Figure 3. Illustrate the 3D face reconstruction results from the different view point. The first and the third row are the front view of real data which are captured from the different viewpoint starting from -45 degree on (a). to 45 degree on (e) with step 22.5 degree. The second and the fourth row is the reconstructed 3D face of the first row starting from (f) to (j). The right side faces for -45, -22.5 and 0 degree are mirror faces, left side faces for 22.5 and 45 degree are mirror faces. The blue points are the farthest point on the ROI. The yellow point is the outlier.