# Profile-Based 3D Face Registration and Recognition

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**Abstract.** With the rapid development of 3D imaging technology, face recognition using 3D range data has become another alternative in the field of biometrics. Unlike face recognition using 2D intensity images, which has been studied intensively by many researchers since the 1960's, 3D range data records the exact geometry of a person and it is invariant with respect to illumination changes of the environment and orientation changes of the person. This paper proposes a new algorithm to register and identify 3D range faces. Profiles and contours are extracted for the matching of a probe face with available gallery faces. Different combinations of profiles are tried for the purpose of face recognition using a set of 27 subjects. Our results show that the central vertical profile is one of the most powerful profiles to characterize individual faces and that the contour is also a potentially useful feature for face recognition.

**Keywords:** 2D, 3D, biometrics, contour, face, intensity, moment, profile, range, recognition, registration.

## 1 Introduction

Face recognition has been widely studied during the last two decades. It is a branch of biometrics, which studies the process of automatically associating an identity with an individual by means of some inherent personal characteristics [1]. Biometric characteristics include something that a person is or produces. Examples of the former are fingerprints, the iris, the face, the hand/finger geometry or the palm print, etc. The latter include voice, handwriting, signature, etc. [2]. Compared with other biometric characteristics, the face is considered to be the most immediate and transparent biometric modality for physical authentication applications. Despite its intrinsic complexity, face- based authentication still remains of particular interest because it is perceived psychologically and physically as noninvasive. Significant motivations for its use include the following [2]:

- Face recognition is a modality that humans largely depend on to authenticate other humans.

– Face recognition is a modality that requires no or only weak cooperation to be useful.
– Face authentication can be advantageously included in multimodal systems, not only for authentication purposes but also to confirm the aliveness of the signal source of fingerprints, voice, etc.

The definition of face recognition was formulated in [3] as: "Given an image of a scene, identify one or more persons in the scene using a stored database of faces." This is called the 'one to many' problem or identification problem in face recognition. Another kind of problem is 'one to one', i.e., the authentication problem. This kind of problem is to determine whether the input face of a person is really the person he or she claims to be or not. In this paper, we deal with face recognition in the first scenario. The potential field of the application of face recognition is very wide, mostly in areas such as authentication, security and access control, which include the physical access control and logical access control. Especially in recent years, anti-terrorism has been a big issue throughout the world. Face recognition will play a more and more important role in its efforts.

In the last ten years, most of the research work in the area of face recognition used two-dimensional images, that is, gray level images taken by a camera. Many new techniques emerged in this field and achieved good recognition rates. A number of these techniques are outlined in survey publications, such as [5]. However, most of the 2D face recognition systems are sensitive to the illumination changes or orientation changes of the subjects. All these problems result from the incomplete information contained in a 2D image about a face. On the other hand, a 3D scan of a subject's face has complete geometric information about the face, even including texture information, in the case of some scanners. It is believed that, on average, 3D face recognition methods will achieve higher recognition rates than their 2D counterparts. With the rapid development of 3D imaging technology, 3D face recognition will attract more and more attention.

In [6], Bowyer provides a survey of 3D face recognition technology. Some of the techniques are derived from 2D face recognition, such as Principal Component Analysis(PCA) used in [7, 8] to extract features from faces. Some of the techniques are unique to 3D face recognition, such as the geometry matching method in [9], the profile matching proposed in [10, 11] and the isometric transformation method presented in [4].

This paper outlines a new algorithm used to register 3D face images automatically. Specific profiles are defined in the registered faces and these are used for matching against the faces on a database including 27 subjects. The impact of using different types of profiles for matching is studied. Also the possibility of using the contour of a face as a feature for face recognition is explored.

The structure of the paper is as follows: Section 2 describes the database used for this research. Section 3 presents the registration algorithm and Section 4 outlines the matching procedure using different profiles and contours and gives the results of the experiments. Section 5 is the conclusion.

## 2 3D Face Database

Unlike 2D face recognition research, for which there are numerous databases available in the Internet, there are only a few 3D face databases available to researchers. Examples are the Biometrics Database from the University of Notre Dame [12] and the University of South Florida(USF) face database[13]. In our experiment, the USF database is used.

The USF database of human 3D face images is maintained by researchers in the department of Computer Science at the University of South Florida, and sponsored by the Defense Advanced Research Projects Agency (DARPA). The USF database has a total number of 111 subjects (74 male; 37 female). All subjects have a neutral facial expression. Some of the subjects were scanned multiple times. In our experiment, the 3D faces of the subjects who were scanned multiple times are considered, so that one scan can be used as a gallery image, i.e., one of the faces that are assumed to be prerecorded, and the remaining scans from the same subject can be used as probe images, i.e., faces to be identified. A subset of 27 subjects is used in this research, with 27 faces in the gallery and 27 scans to be identified (probe faces).

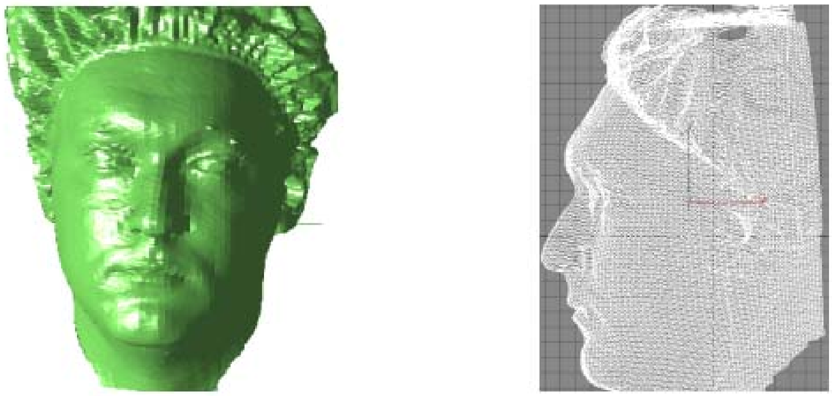

**Fig. 1.** Rendered 3D face image(Left) and triangulated mesh 3D face image(Right)

The 3D scans in the USF database were acquired using a Cyberware 3030 scanner. This scanner incorporates a rugged, self-contained optical range-finding system, whose dynamic range accommodates varying lighting conditions and surface properties [14] .

The faces in the database were converted into Stereolitography (STL) format. Each face has an average of 18,000 vertices and 36,000 triangles. Figure 1 shows a face from the database in its rendered and triangulated mesh forms.

## 3 Registration and Preprocessing

In 3D face recognition, registration is a key pre-processing step. Registering may be crucial to the efficiency of some matching methods. Earlier work used Principal Curvature and Gaussian Curvature to segment the face surface and register it, such as the methods in [9, 10, 15]. The disadvantage of using curvatures to register faces is that this process is very computationally intensive and requires very accurate range data [16].

Another method often used involves choosing several user-selected landmark locations on the face, such as the tip of the nose, the inner and outer corners of the eyes,etc., and then using the affine transformation to register the face to a standard position[7, 8, 11].

A third method performs registration by using moments. The matrix( Equation 1) constituted by the six second moments of the face surface: m200,m020, m002, m110,m101,m011,contains the rotational information of the face[17].

$$M = \begin{bmatrix} m200 \; m110 \; m101 \\ m110 \; m020 \; m011 \\ m101 \; m011 \; m002 \end{bmatrix} \tag{1}$$

$$U \Delta U' = SVD(M) \tag{2}$$

By applying the Singular Value Decomposition (Equation 2), the unitary matrix U represents the rotation and the diagonal matrix $\Delta$ represents the scale, for the three axes. U can be used as an affine transformation matrix on the original face surface. The problem with this method is that during repeated scans for the same subject, besides the changes in the face area, there are also some changes outside the face area, such as the different caps worn by the subjects during the scanning process (Fig. 1). These additional changes will also impact the registration of the face surface, causing the registration for different instances of the same subject not to be the same. This limitation constrains this approach to only the early stages of registration.

Figure 2 is an example of a scanned face rendered in a Cartesian coordinate system, with the X axis corresponding to the depth direction of the face, the Y axis corresponding to the length direction of the face and the Z axis corresponding to the width direction of the face. In the registration process, we assume that each subject kept his head upright during scanning, so that the face orientation around the X axis does not need to be corrected, but the orientation changes in the Y and Z axes need to be compensated for.

The registration algorithm proposed does not require user-defined landmark locations and can be done automatically.

First, the tip of the nose is found by looking for the point with the maximum value in the X direction. Then a ‘cutting plane’, parallel to the XZ plane is set to contain the tip of the nose (Fig. 3). The intersection of this cutting plane with the face defines the horizontal profile curve. In effect, the result is a discretized curve with a spacing of 1.8 mm between samples (Fig. 4).

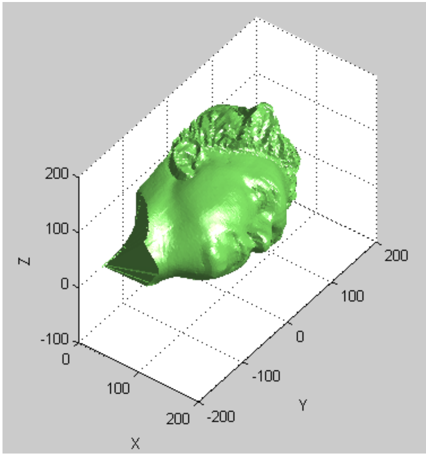


**Fig. 2.** Face surface in a Cartesian coordinate system( the units in the three axes are mm)

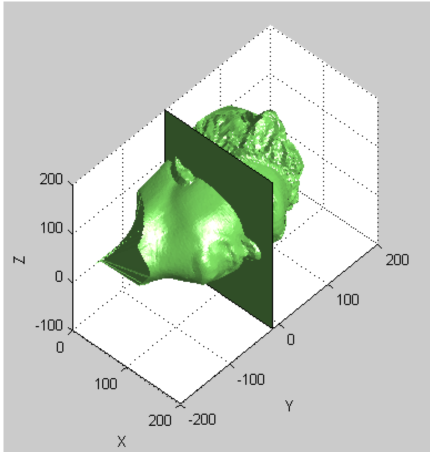


**Fig. 3.** Illustration of the extraction of the horizontal profile

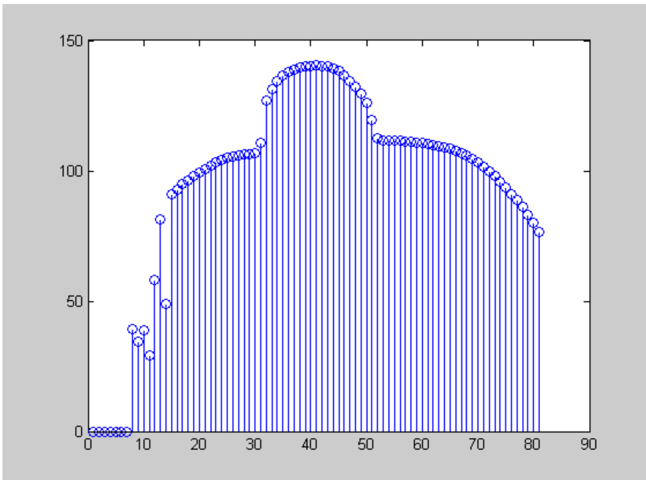


**Fig. 4.** Discrete horizontal profile before registration

A trilinear interpolation method is used to find the value of each point in this profile. (Fig 5). The point P is in the YZ plane. P' is the intersection between the triangle ABC and the straight line PP', which is normal to the YZ plane. The length of PP' is the profile value corresponding to point P.

Next, the following cost function is minimized with respect to $\alpha$, where I is the index of the maximum point of X.

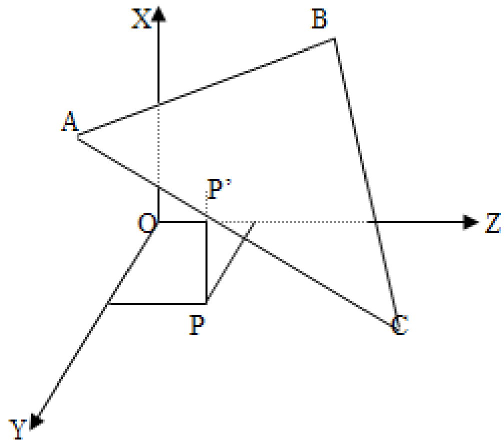


**Fig. 5.** Trilinear interpolation to get exact values of profile elevations

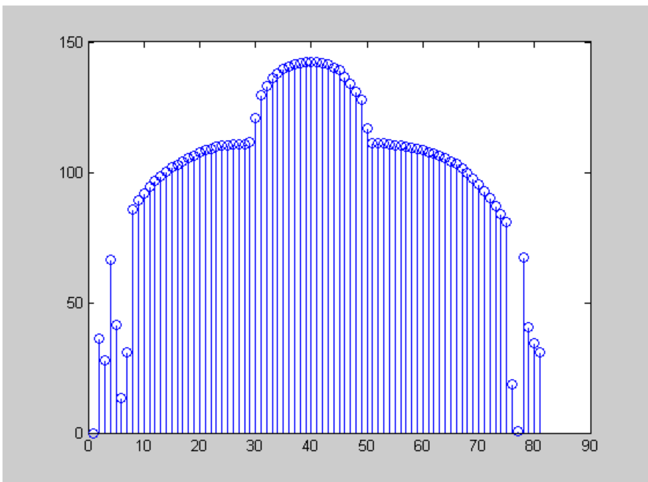


**Fig. 6.** Horizontal profile after registration around Y axis

$$E = \sum_{i=1}^{15} [(X(I+i) - X(I-i)]^2 \tag{3}$$

For every $\alpha$, the affine transformation is applied to the face surface using the following transformation matrix, and the horizontal profile is found, as illustrated before.

$$T = \begin{bmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{bmatrix} \tag{4}$$

$$\alpha = arg\{min[\sum_{i=1}^{15}[(X(I+i) - X(I-i)]^2]\} \quad (5)$$

The final value of $\alpha$ represents the orientation change around the Y axis required for the registration.

Figure 6 shows the horizontal profile seen in Figure 4, after the Y axis adjustment has been performed:

Typically, a rotational adjustment around the Z axis will also be required. Analogous to Figure 3, Figure 7 shows the intersection of the face surface with a cutting plane, which is parallel to the XY plane and passes through the tip of the nose. This intersection is the central vertical profile. Similar to Figure 4, Figure 8 shows the discretized central vertical profile, before adjustment.

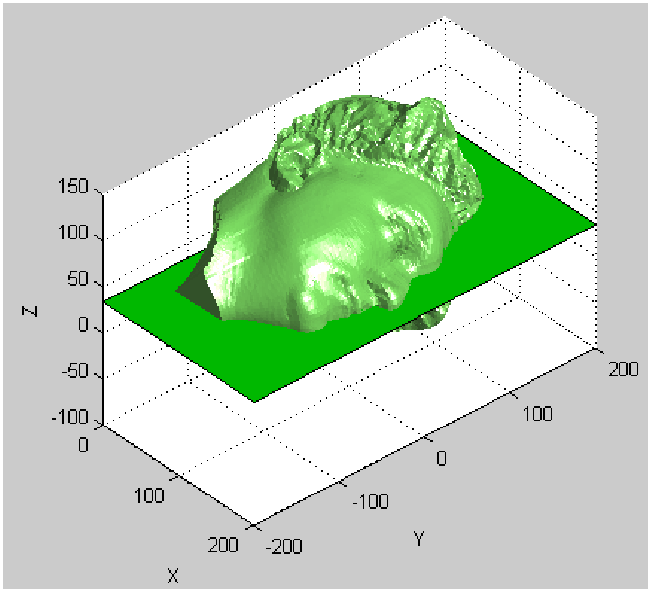


**Fig. 7.** Illustration of extraction of central vertical profile

The cost function to be minimized in this case is the following,

$$E = abs(X(I-50) - X(I+40)) \quad (6)$$

Minimization is with respect to $\alpha$. I is the index of profile point with the largest value of X.

$$\alpha = arg\{[min(abs(X(I-50) - X(I+40))]\} \quad (7)$$

For every $\alpha$, the affine transformation is applied, using the following transformation matrix.

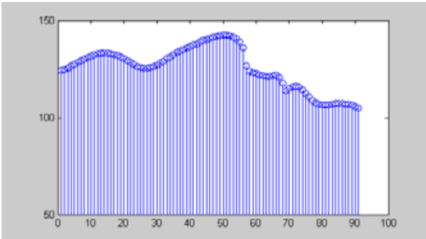


**Fig. 8.** Discretized central profile before registration

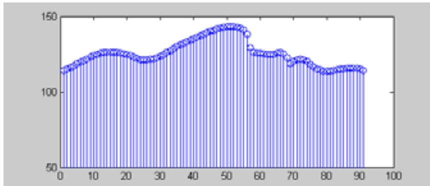


**Fig. 9.** Central vertical profile after registration

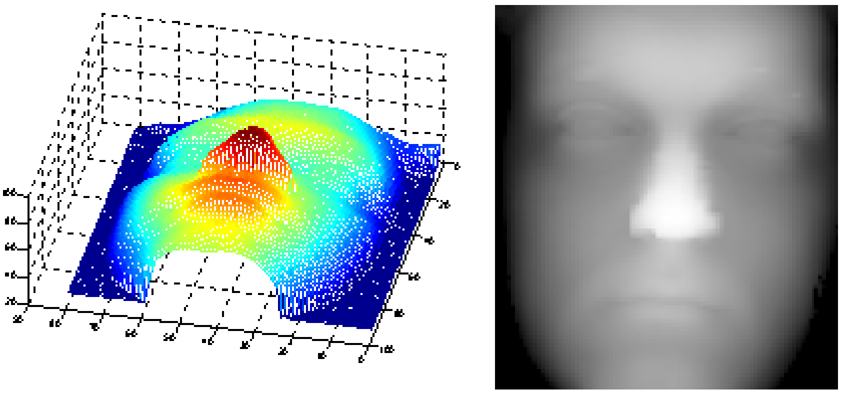

**Fig. 10.** Mesh plot of the range image(left) and gray level image plot of range data(right)

$$T = \begin{bmatrix} \sin\alpha \; 0 \; \cos\alpha \\ \cos\alpha \; 0 - \sin\alpha \\ 0 \quad\;\; 1 \quad\;\; 0 \end{bmatrix} \tag{8}$$

The aim is to equalize the X coordinates of two critical points contained in the central vertical profile: the end point on the forehead side and the end point on the chin side. Figure 9 is the central vertical profile after adjustment around the Z axis.

To complete the registration process, a grid of 91 by 81 points is prepared that corresponds to pairs of (y, z) coordinates. The point (51, 41) of the grid is made to coincide with the tip of the nose in the adjusted face surface. This grid assumes a spacing of 1.8 mm in both the Y and Z directions, with 91 points in the length direction and 81 points in the width direction. The value associated to each point in the grid is the distance between the point in the face surface and the corresponding location on the YZ plane, calculated by trilinear interpolation (Fig. 5). The values are offset so that the value corresponding to the tip of the nose is normalized to 100 mm. Values below 20 mm in the grid area are thresholded to 20 mm.

Figure 10 is a Matlab mesh plot of the resulting grid, and a gray level plot of the same range image.

## 4 Recognition Experiments and Results

For the experiments described here, a gallery database of 27 range images of 27 subjects (one for each subject) and a probe database of 27 different scans of the same 27 subject were used. The time interval between the acquisition of the gallery image and the corresponding probe image for a given subject ranges from several months to one year.

The use of profile matching as a means for face recognition is a very intuitive idea that has been proposed in the past. In [10, 11, 18, 19], different researchers explored the profile matching method in different ways. In our research, because the range image has already been obtained, profile extraction is simple. We have, in fact, tested the efficiency of several potential profile combinations used for identification. Besides profiles, the contour of a face was also tested for its potential applicability for face recognition. In our experiment, a frontal contour defined 30 mm behind the tip of the nose was extracted for each scan. Although in computing the distance or dissimilarity between profiles, some researchers [19] used the Hausdoff distance, we found that the Euclidean distance is suitable for the context of our experiment.

The following six different feature combinations and direct range image matching variations were tested with the experimental data described above:

(a) Central vertical profile alone.

(b) Central horizontal profile alone.

(c) Contour, which is 30 mm behind the tip of the nose.

(d) Central vertical profile and two horizontal profiles. The two horizontal profiles are defined at 18 mm and 36 mm above the tip of the nose. The distance between central profiles is given the weight of 0.7; the two horizontal profile distances are given the weight of 0.15 each, towards the overall matching score for identification.

(e) Central vertical profile and two more vertical profiles, one passing 18 mm to the left of the central profile, the other passing 18mm to the right of the central profile. The distance between central profiles is given the weight of 0.7; the other two vertical profile distances are given a weight of 0.15 each.

(f) Using the entire range image.

From the results in Figure 11, we can see that scheme (a), i.e., matching the central vertical profile alone, has the highest recognition rate. On the other hand, using the whole range image for matching yields the lowest recognition rate. Because the probe image was taken several months to one year after the gallery image was taken, we have sufficient reason to assume there were changes in the face for every subject. The high recognition rate using the central vertical profile suggests that this profile has the most distinctive properties between different subjects and is the most consistent through time for the same subject. These observations concur with a similar analysis, presented in [11]. Besides the central vertical profile, the contour of a face also shows its potential as a feature to be used in face recognition.

## 5 Conclusion

In this paper, a new registration algorithm for 3D face range data was proposed. This algorithm is valid under some constrains; i.e., only orientation changes along the width direction and length direction of the face need to be compensated. But this algorithm can also be extended to register arbitrarily oriented face surfaces in 3D space, combined with simple registration algorithms that use the six second moments of the face surface.

Also in this paper, face identification based on profile matching was explored. Different combinations of profiles for matching were compared. It was found that the central vertical profile is the feature that best represented the intrinsic characteristics of each face and had the highest identification value among all the profile combinations tested. The contour of a face also has the potential to be used as one of the features in face recognition.

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