3D Face Recognition

Charles Beumier
SIC Dpt, Royal Military Academy, Brussels Belgium
beumier@elec.rma.ac.be

***Abstract*- This paper describes the developments of the RMA/SIC department in 3D Face Recognition and situates them in the research activities in this field. 3D Face Recognition appears as a promising approach for biometric person identification, bringing robust and specific features, with easy face detection from depth and quite difficult faking possibilities. The successful development of a prototype for real-time automatic profile identification by the SIC led us to the more complete geometrical analysis of facial surfaces. Several versions of cost effective and fast 3D acquisition systems have been realized to capture facial surfaces. Two databases were created and used to make recognition experiments by matching facial surfaces through planar profile comparison. Our developments and other works confirm that a face recognition system should integrate 3D capabilities to exploit the complementarity of robust geometrical features and normalized grey-level cues.**

I. INTRODUCTION

The increasing mobility of people and data is calling for more and more security. Automatic solutions are appealing for their commodity and receive the support of the evolving digital technology. In this context, **Face Recognition** has been gaining much attention for more than ten years as confirmed by the organization of specific conferences (*Audio- and Video-based Biometric Person Authentication AVBPA, Automatic Face and Gesture Recognition AFGR*), the publication of surveys [1, 2, 3], and the setup of empirical evaluation (FERET [4]).

From the large number of commercialized **biometric solutions,** Face Recognition has the advantages of being less intrusive and well accepted by users. Unfortunately, the sensitivity to the viewpoint, illumination and subject attitude impairs performances in practical implementations. Therefore nowadays solutions typically combine several modalities like images, speech, password or cards.

The **3D approach** has been considered since the 90's to reduce the difficulties due to pose and lighting variation. Before, the price and quality of 3D capture, the visualization and processing of acquired data limited 3D developments. It appears today to be the best approach when dealing with large variation in pose.

In what follows, section II presents the framework of our development in face recognition. Section III motivates 3D Face Recognition. 3D Face Acquisition and available 3D Face Databases are the subject of the next two sections. Section VI presents our 3D Face Comparison approaches and results. Section VII concludes the paper.

II. FRAMEWORK

The **scenario** for face recognition begins with the enrolment of clients in a database of references. Then, the system can be presented people for recognition. Based on the similarity with references, people are accepted or rejected.

Our developments address the problem of face recognition for **cooperative access control**. In this situation, capture conditions can be optimized, the reference database is under control and subjects cooperate (attitude, pose), all contributing to better performances.

Recognition systems can be evaluated according to **several criteria** [5] like the facility to extract information, the permanence of features, the recognition performances and the user acceptability. We tried to achieve the best **recognition performances** taking into account the time response, hardware needs and code simplicity. Recognition figures were evaluated with the rates of false acceptance of impostors (FAR) and false rejection of clients (FRR). The Equal Error Rate (EER), corresponding to equal FAR and FRR, is given as an overall performance number.

III. MOTIVATIONS FOR 3D FACE RECOGNITION

The study of frontal images at the SIC in 1990 led to the conclusion that head pose and illumination variations were difficult to handle. We thus considered the external contour of the **head profile** and built a real-time prototype [6] able to continuously identify people among a database of 40 persons with an EER of 4 %.

The success of profile identification motivated a **facial surface** analysis to get more geometrical information. In the early 90's, the few 3D face recognition works used differential geometry applied to high quality 3D surfaces captured by expensive and slow LASER scanners. The possibility for fast and low cost 3D acquisition systems motivated our own development.

As an answer to the **evaluation criteria** given in section II, face recognition seems well accepted by the users and low cost 3D capture is more and more available. Extracted 3D facial features are rather stable and enhance performances of face recognition.

Practically, the 3D Face Analysis can integrate most facial information (geometry and texture), simplify face detection thanks to depth and complicate forgery.

IV. 3D FACE ACQUISITION

A. 3D Acquisition

There exist several possibilities for 3D capture. The website *http://www.simple3D.com* lists approaches and products. We present here systems commonly used for 3D face capture.

LASER scanners were the first commercial products for 3D facial capture. They offer high precision and registered texture from a colour camera but remain very expensive and rather slow (e. g. Cyberware, Minolta VIVID).

Triangulation for depth estimation was ideally implemented thanks to pattern projection called **structured light**. A single image of the scene illuminated by the pattern allows for 3D and texture capture. This low cost and very fast solution has improved in quality since 1995, thanks to the increasing performances of digital cameras (e.g. Eyetronics, A4vision).

A less common approach to 3D face capture consists in applying triangulation from a **stereo** pair of images. In a first development (C3D), the Turing Institute proposed to project a pattern on the face to solve the correspondence problem. They showed recently that the skin texture suffices to find correspondences with very high resolution camera.

B. SIC Prototypes

Structured light appeared to be the most attractive approach for 3D face capture. We successively developed three prototypes, improving hardware and image processing [7]. These can capture a volume of minimum 40x30 cm with 40 cm in depth, at a distance of 1m50, with a resolution of at least 50x40 points on the face.

The projected patterns consist of parallel lines ('stripes') what provides for easy detection and precise localization. Depending on the prototypes, stripe labels were coded in the stripe thickness, color or in the position of dots on the stripes.

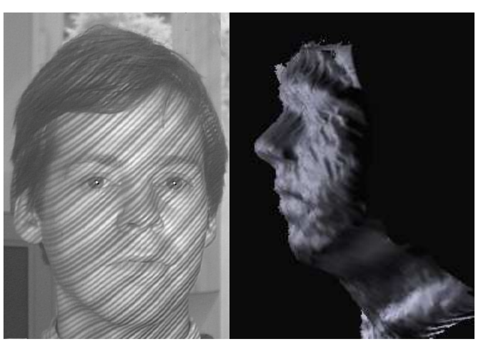

Figure 1: Striped image and reconstruction for prototype A

Figure 2: Striped image and reconstruction for prototype B

To measure 3D coordinates, projected lines (stripes) are first localized in the image. Their label is then estimated based on thickness for Prototype A [8] or color for prototype B [9]. Considering the label of a few neighbors, each stripe is assigned its index in the projected pattern sequence. Points along the stripes are then converted into X,Y,Z coordinates thanks to their image position and stripe label. The parameters of this conversion are estimated during a calibration procedure based on the capture of points of a reference planar object ([8] for ProtoA, [10] for ProtoB).

The comparison of reconstructed faces of Figure 1 and 2 shows the superiority of prototype B, thanks to the better camera quality (digital) and the improved calibration procedure. A third prototype with better results was developed but not finished.

C. Conclusions

Among appropriate technologies for face capture like LASER scanners, structured light and the promising passive stereo, structured light offers better solutions relatively to cost and speed.

V. 3D DATABASES

When we addressed 3D Face recognition in 1994, no 3D facial database was available. We had to build up our own, once our first 3D capture prototype became available.

The **3D_RMA database** captured with Prototype A (http://www.sic.rma.ac.be/~beumier/DB/3d_rma.html) has two sessions of 3D facial data [11] captured two months apart. Each session consists of 120 persons with three slightly different poses and one texture shot (projector switched off). Reconstructed surfaces are of medium quality limited by the analog camera, with major problems for facial hair and eyes (glasses). Some individuals were badly captured so that session1 has 98 subjects and session2 108. This free database is requested about once every month.

Prototype B [12] was used in BIOMET [13] as many other modalities (speech, fingerprint, palm, signature, face). Only the third session contained 3D capture, with 81 subjects. Although not as accurate as expected from the improvements relative to Prototype A, the facial surfaces are of better quality. 5 or 6 shots were captured with different orientations. Qualitatively, 15 persons (19%) were poorly captured mainly due to beard and limited contrast (out of focus).

A Minolta VIVID700 was used to create the **Gavab database** (http://gavab.escet.urjc.es/articulos/GavabDB.pdf) containing shape and texture of 61 persons for 9 poses with varied expression and orientation.

BJUT-3D-R1 Db (http://www.bjpu.edu.cn/sci/multimedia/mul-lab/3dface/pdf/MISKL-TR-05-FMFR-001.pdf) was captured with Cyberware 3030 (shape and texture) and is claimed to be the first 3D collection of Chinese people (500 subjects).

The **York University** populated a database of 350 subjects (http://www-users.cs.york.ac.uk/%7Etomh/3DFaceDatabase.html) according to FERET tests (15 different expressions and poses).

XM2VTS (http://www.ee.surrey.ac.uk/Research/VSSP/xm2vtsdb/) has one session provided with one 3D model acquired by the C3D system (293 subjects).

The **University of Notre Dame** has been creating a database containing more than 4000 3D shots from 277 people (http://www.nd.edu/%7Ecvrl/UNDBiometricsDatabase.html).

As presented, several databases with high quality are available today. They offer variable population, expression and pose. Most databases referred above are available for free.

VI. 3D Face Comparison

A. Introduction

Early 3D face recognition works were reported in the late 80's [14, 15, 16]. They analyze the face **geometry** thanks to curvature for normalisation or localisation and hence require high quality data obtained from a laser scanner. Since then a variety of geometrical approaches have considered profile distances [17], surface matching by Hausdorff distance [18], ICP (Iterative Closest Point, [19]) or Point Signature [20].

Many publications have adapted **PCA** (Principal Component Analysis) so popular for 2D to compare 3D data [21] or 3D and 2D [22].

Other works make use of a **3D face model**. In [23] for instance, shape and texture parameters, later used for recognition, are adapted in order to fit a 3D facial morphable model to captured 2D images.

This summary gives main research directions and lists few references. Several works have considered the combination of shape and texture. See [24] for a recent review.

We adopted a geometrical approach, based on planar profile comparison, which allowed for the qualitative estimation of acquired 3D faces and the visual control of matching developments.

B. Central and Lateral Profiles

Our first development in 3D face recognition consisted in the analysis of the central profile. To extract the central profile independently of the viewpoint, we search the plane of **facial symmetry** by considering the planar cuts (profiles) for 3 planes separated by 3 cm. Two parameters for plane orientations and one for plane translation are adapted to maximize the protrusion of the central profile and achieve the greatest similarity of lateral profiles. This normalization procedure (Figure 3a) is very fast and stable thanks to a clear optimum, except when 3D data are noisy. Rough initial values of the three parameters based on the nose, cheeks and forehead speed up the optimization and avoid many local minima. The optimal solution delivers two normalized profiles: the central one and the lateral one, average of both lateral profiles.

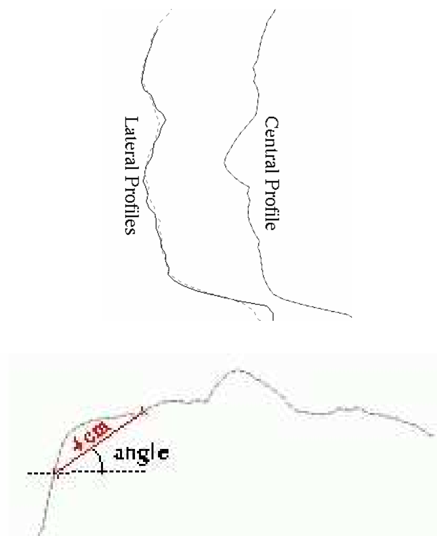

Figure 3 a) Central and Lateral Profiles

b) Slope measure along the profile

To bring two facial surfaces into correspondence, 3 rotation and 3 translation parameters have to be tuned. Three of those 6 parameters are obtained by the symmetry criterion applied for each face independently, possibly offline for the reference faces. The derived normalized central and lateral profiles can be matched through the adaptation of the remaining three parameters. A more efficient way consists in comparing the **slope** along the profiles (Figure 3b), only depending on a shift parameter if the standard variation is used as measure to suppress the effect of global rotation. The nose tip gives an accurate estimate of the shift. On a Pentium 200MHz, normalization takes about 0.5 s and profile comparison takes less than 0.01 s.

C. Grey Comparison

A texture (grey-level) analysis complements the geometric comparison, as they provide different information. Moreover, structured light acquisition systems often miss range capture where texture is strong. We designed a grey comparison approach that was easily integrated with the 3D comparison based on profiles [25].

In a first experiment, grey values were measured on the grey shot (prototype A: viewpoint of striped shot 1 with projector off), with 1.5 cm average on each side of the profiles (Figure 4a) to reduce noise and localization errors. To get grey values independent from illumination, we used local grey value differences along the profiles, as shown in Figure 4b for two persons and two sessions. Curves are indexed by the (signed) distance to the nose, thanks to the 3D knowledge of the corresponding profile. Normalized grey profiles were directly compared, allowing for a small shift to account for nose imprecision.

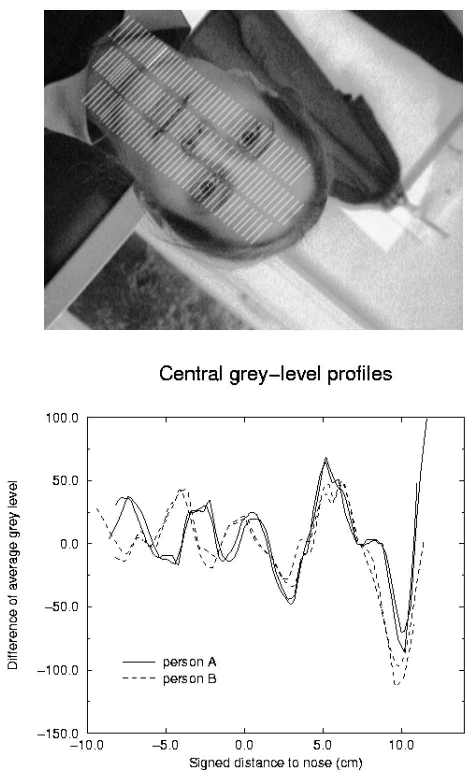

Figure 4: a) Extents of grey-level average

b) Central grey-level profile for two sessions

The top row of Table 1 presents the results of this experiment ('Shot 1 (grey)'). The worse performances of grey profiles come from the little information in lateral grey profiles and from their dependence on profile extraction. The fusion (linear combination with coefficients obtained with a learning set) of the geometrical and grey profiles shows a clear improvement in recognition.

Table 1: EER from 3D and Grey analysis for the central and lateral profiles, and fusion

EER (%)	3D Ctr	3D Lat	Grey Ctr	Grey Lat	Fusion
Shot 1 (grey)	12	8	9.5	16.5	1.2
Shot 1 (striped)	12	8	12	17.5	2.8
3 shots	14	12	16	20.5	7.2
3 shots (fusion)	10	9	15	17	4.1
Temporal fusion	8	7	9	16.5	1.4

In subsequent experiments, grey levels were measured in the striped images, allowing for more test data. Thanks to the average operation which partly washes the stripes influence, the reduction in performance is small ('Shot 1 (striped)'), especially when considering the practical advantage of using the same image for 3D and grey analysis. The performance penalty is higher when including shots 2 and 3 ('3 shots') which are not frontal: the overlap between shots is reduced and the directional light affects grey levels differently on the face. These performance reductions are compensated when summing the scores of the three references of each person ('3 shots (fusion)'), and when summing the scores of the three test images ('Temporal fusion').

D. Surface Matching with Profiles

To exploit more 3D information and to reduce the importance of the nose, the whole facial surface was considered. Up to 15 parallel planar cuts deliver as many profiles to be compared with homologue profiles of a reference 3D face. Each pair of corresponding profiles issues a distance measure, obtained from the area between the profiles divided by their length. The distance between facial surfaces (the average distance between all corresponding profile pairs) is minimized by adapting the three rotation and three translation parameters. First an Iterative Conditional Mode approach was adopted, tuning each parameter one at a time. Later, to speed up processing and reduce local minima, we matched faces by a normalization based on face symmetry followed by profile comparison in the slope space as described in B.

Applied to the BIOMET database, all persons included (except wrong acquisitions, 14 %), an EER of 3.6 % was reached when frontal shots (1 and 6) were compared. This rate drops to 14 % when shots 1,2,3 (Frontal1, Left, Right) were compared to 4,5,6 (Up, Down, Frontal2). Frontal shots are indeed more balanced for symmetry normalization and a difference in the viewpoint reduces the overlap of surfaces. This explains why a third prototype was designed to better cover the face with one capture. No texture analysis has been performed with Prototype B.

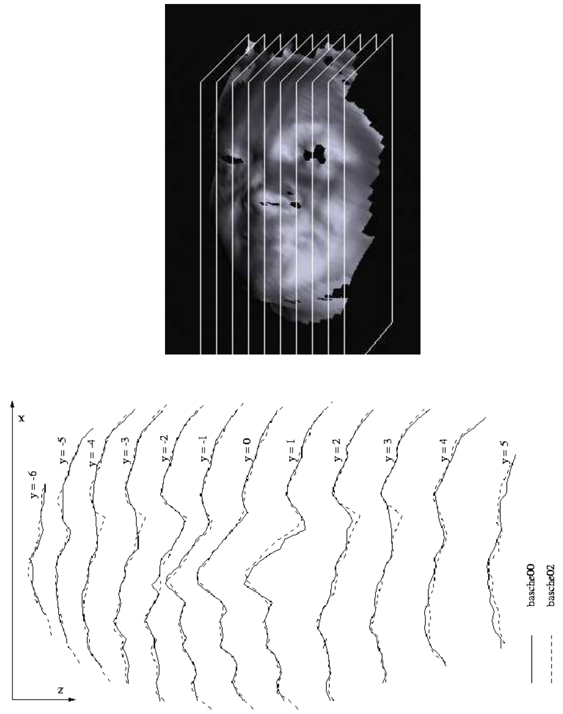

Figure 5: a) Parallel planar cuts b) Profile matching

E. *Conclusions*

We demonstrated the validity of 3D face recognition and the advantage of combining texture data. The system is low cost and fast. Results can be largely improved with better 3D acquisition (less noise, fewer holes and larger coverage). This would reduce local minima impairing comparison. A better representation of people in the database would favor the statistical validity of tests and of expectable performances of the 3D approach.
Other works with high quality databases, exhibit very good recognition performances, even for large orientation changes.

VII. Conclusions

The 3D Face Recognition approach contains two main challenges. The first one showed that 3D **capture** can fulfill system requirements about speed, cost, coverage and precision. The second challenge proved that facial **surface analysis** contains discriminative information, adequate for person verification.

Many 3D acquisition systems are commercialized. We expect most **3D databases** to collect shape and texture since they are available with most 3D sensors. Several databases have been presented.

Although SIC results suffer from low quality databases, the presented prototype has demonstrated the **validity of the 3D approach**, especially when **shape and texture** cues are used. The existence of commercial solutions (a4vision, FaceEnforce) confirms the 3D potential for security.

Acknowledgment

This work has been mainly supported by the Belgian MoD and partially by the European Programme ACTS and l'Ecole Nationale Supérieure des Télécommunications, Paris XIII.

References

[1] A. Samal and P. Iyengar, AUTOMATIC RECOGNITION AND ANALYSIS OF HUMAN FACES AND FACIAL EXPRESSIONS: A SURVEY, In *Pattern Recognition,* Vol. 25, No. 1, pp 65-77, 1992.
[2] R. Chellappa, C.L. Wilson and S. Sirohey, Human and Machine Recognition of Faces, In *Proceedings of the IEEE,* Vol. 83, No. 5, May 1995, pp 705-740.
[3] W. Zhao, Robust Image-based 3D Face Recognition, PhD thesis, University of Maryland, 1999.
[4] P. J. Phillips, H. Moon, P. J. Rauss, and S. Rizvi, The FERET evaluation methodology for face recognition algorithms, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No. 10, Oct 2000.
[5] In BIOMETRICS Personal Identification in Networked Society, *A. Jain, R. Bolle, S. Pankanti editors, Kluwer Academic Publishers, 1999.*
[6] C. Beumier, M.P. Acheroy, Automatic Profile Identification, In *FIRST INT. CONF. ON AUDIO AND VIDEO BASED BIOMETRIC PERSON AUTHENTICATION (AVBPA)*, Crans-Montana, Switzerland, March 12-14 1997, pp 145-152.
[7] C. Beumier, DESIGN OF CODED STRUCTURED LIGHT PATTERN FOR 3D FACIAL SURFACE CAPTURE, *EUSIPCO-2004*, Vienna, Austria, Sept 6-10, 2004, pp 2291-2294.
[8] C. Beumier, M. Acheroy, 3D Facial Surface Acquisition by Structured Light, In *International Workshop on Synthetic-Natural Hybrid Coding and Three Dimensional Imaging*, Santorini, Greece, 15-17 Sep, 1999, pp 103-106.
[9] C. Beumier, Facial Surface Acquisition with Colour Striping, *ICANN/ICONIP 2003,* Istanbul, Turkey, June 2003, pp 548-551.
[10] C. Beumier, Calibration of a structured light system for 3D acquisition, In *IEEE BENELUX Signal Processing Symposium,* Hilvarenbeek, The Netherlands, Apr 2004.
[11] C. Beumier, M. Acheroy, SIC_DB: Multi-Modal Database for Person Authentication, In *Proceedings of the 10th International Conference on Image Analysis and Processing*, Venice, Italy, 27-29 Sep, 1999, pp 704-708.
[12] C. Beumier, 3D Face Recognition, CIHSPS2004, *IEEE Int. Conf. on Computational Intelligence for Homeland Security and Personal Safety*, Venice, Italy, 21-22 July 2004.
[13] BIOMET Incentive research project of GET (RD123, RE408), France.
[14] J.Y. Cartoux, J.T. Lapresté, M. Richetin, Face Authentication or Recognition by Profile Extraction from Range Images, *IEEE Computer Society Workshop on Interpretation of 3D scenes,* 1989, pp 194-199.
[15] J.C. Lee and E. Milios, Matching Range Images of Human Faces, *3rd Int Conf on Computer Vision,* 1990, pp 722-726.
[16] G. Gordon, Face recognition based on depth maps and surface curvature, In *SPIE Geo-metric methods in Computer Vision,* Vol 1570, San Diego, 1991.
[17] C. Beumier, M. Acheroy, Automatic Face Verification from 3D and Grey Level Clues, In *11th Portuguese Conference on Pattern Recognition (RECPAD 2000),* Porto, Portugal, May 11th - 12th, 2000.
[18] B. Achermann, H. Bunke, Classifying Range Images of Human Faces with Hausdorff Distance, *Int. Conf. on Pattern Recognition 2000,* Barcelona, Spain, Sep 2000, pp 813-817.
[19] N. Uchida, T. Shibahara, T Aoki, 3D Face Recognition Using Passive Stereo Vision, *Int. Conf. on Image Processing 2005* (ICIP 2005), Genova, Italy, Vol II pp 950-953, Sep 2005.
[20] C-S. Chua, F. Han, Y-K. Ho, 3D Human Face Recognition Using Point Signature, *Int. Conf. on Automatic Face and Gesture Recognition 2000*, Grenoble, France, pp 233-238, March 2000.
[21] K. Chang, K. Bowyer, P. Flynn, Multi-Modal 2D and 3D Biometrics for Face Recognition, Int. *Workshop on Analysis and Modelling of Faces and Gestures 2003*, Nice, France, pp 187-194, Oct 2003.
[22] A. Colombo, C. Cusano, R. Schettini, 3D Face Recognition system using Curvature-based detection and holistic multimodal classification, In *Pattern Recognition*, Vol 39, pp 444-455, Mar 2006.

[23] S. Romdhani, V. Blanz, T. Vetter, Face Identification by Fitting a 3D Morphable Model using Linear Shape and Texture Error Functions, *European Conference on Computer Vision 2002*, Copenhagen, Denmark, pp 3-19, May 2002.
[24] K Bowyer, K. Chang, P. Flynn, A survey of Approaches to Three-Dimensional Face Recognition, *17th Int. Conf. on Pattern Recognition*, ICPR 2004, Vol 1, 2004, pp 358-361.
[25] C. Beumier, Automatic 3D Face Authentication, In *Image and Vision Computing,* Vol. 18, No. 4, pp 315-321.