Automatic Face Recognition

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Abstract

This paper describes the activities of the RMA/SIC department in the field of Automatic Face Recognition, involving a frontal, a profile and a surface approach. After outlining the difficulties encountered while looking for robust lighting- and pose-invariant features in the frontal face analysis, a prototype for automatic profile identification is presented. This prototype benefits from the simplicity and quickness of contour analysis and allows to demonstrate real-time identification. This geometrical approach is further investigated by considering the capture and comparison of 3D facial surfaces. A cheap and fast 3D acquisition system has been developed and a recognition approach has been designed based on the extraction of planar profiles. From the presentation of the three approaches we conclude that a face recognition system should integrate 3D capabilities in order to benefit from the complementarity of the geometrical and gray-level information. Furthermore, the 3D analysis brings robust features and can help normalise a gray-level approach that would otherwise largely depend on illumination and point of view.

1. Introduction

Automatic face recognition has gained a large interest [Chellappa95,Samal92] this last decade for several reasons.
First, the ever increasing mobility of people raised the issue of improving security. Typical applications concern the access to buildings, networks or secured data.
Secondly, the computational power offered by nowadays computer makes possible to implement methods which were poorly tractable before.
Thirdly, although several biometrics solutions have been developed and commercialized, the face recognition advantage lies in the user acceptance. Unfortunately, its practical implementation is constrained by a wide variety of "real life" influences (pose, lighting, facial expression) so that the obtained performances are insufficient for most applications. Nowadays solutions are based on several modalities (image, speech, password or card) to cope with the current face recognition limitation.

2. Framework

We address the problem of face recognition in the context of access control. This leads to three simplifications.
The first one concerns the relatively high level of control during system installation. The camera can be positioned close enough to offer a good resolution of the acquired face, possibly with a simple background. Lighting conditions can be adapted to achieve good quality images.
The second simplification comes from the user cooperation. The user knows that he is checked and accepts the rules to be able to enter the building or to obtain the service. For example, he will adopt a correct attitude and pose and he will take care that disturbing artefacts like hat and scarf do not interfere.
Finally, the reference database used to check people identity is under control. This means that facial updates like beard, glasses or hair color can be handled easily thanks to the user cooperation.

3. Scenario

The typical scenario for a face recognition system consists of two steps.
The first one is the creation of a database of reference images or characteristics. This is done during the enrollment of each person to be recognized and with the supervision of a human operator.
The second step concerns the use of the system. An image of the person is taken and is compared with entries of the database, either in the form of images or subimages or thanks to the extraction of

characteristics like the nose length, the distance between the eyes or the hair color. Based on the degree of resemblance, the person can be accepted, rejected or asked to supply further information in case of doubt.

Two different comparison approaches exist. In the first case, called verification, the person first declines his identity so that he can be compared with his own reference data in the database. The comparison issues a similarity measure which is compared with a threshold to decide for acceptance or rejection. In the second case, called identification, the comparison is made with the whole database in order to find the best match which is supposed to be related to the searched person if this match is good enough. Identification requires more comparison effort, especially for large database.

4. System Evaluation

Recognition systems can be evaluated according to several criteria [Jain99]. Let us mention the facility to extract information, the permanence of the extracted features, the user acceptability against the system and the recognition performances. The choice of a solution depends on the application and has to take into account the irritability of a person wrongly rejected and the penalty of accepting an imposter.
Scientific organizations often focus on the recognition performance. We decided to guide the research to achieve the best recognition performance, but keeping into account the time response, the hardware needs and the code simplicity.

The recognition performance is evaluated in terms of false acceptance (FA: the person is accepted although he should be rejected) and false rejection (FR: the person is not accepted, although he should be). Related to the number of tests and expressed as a percentage, we talk about False Acceptance Rate (FAR) and False Rejection Rate (FRR). Figure 1 depicts a typical 'ROC' curve, showing the operational points (FAR/FRR couples) for different values of the acceptance/rejection threshold. The curve expresses the natural compromise between a low FAR and a low FRR. Depending on the application and thanks to the threshold, one can choose to favour lower FAR, to reduce the risk of imposter accesses, or lower FRR, such as in forensic applications where we want to maximize the chance to identify a criminal. The Equal Error Rate (EER) is often given as an overall performance number. It corresponds to the operational point for which FAR equals FRR.

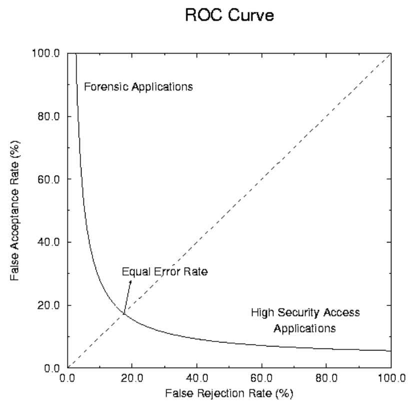

Figure 1: Typical ROC Curve showing the compromise FAR/FRR.

5. Historic

The activities of the Signal and Image Centre in face recognition started in 1990 rather naturally with the study of frontal images. Although offering a fair success for a few persons, the frontal face analysis appeared to be much too dependent on head pose, lighting conditions and face changes (hairstyle or expression). Also, most of partial solutions to these problems implied high computational needs.
We thus started in 1992 a profile based study in order to develop a fast identification system, relying on the external contour of the profile, and little dependent on pose and illumination. The success of this

geometrical analysis of the face made us consider in 1994 the facial surface as a 3D object, in order to get more geometrical information, independent from pose and illumination.
From 1995 till 1998, we participated to a European project of the ACTS programme (M2VTS: *Multi-Modal Verification for Teleservices and Security Applications* [Richard99]) which aimed at developing a multi-modal (speech and image) person verification system for teleservices and security applications. In this project, we realized a prototype for real-time profile identification [Beumier97] and we worked on the facial surface acquisition and analysis. We also studied the combination (fusion) of the different modalities.
Today, the activities in fusion are pursued with a study of the best combination of speaker and face recognition experts ([Verlinde00]).

6. Automatic Frontal Face Recognition

6.1 Motivations

Tackling the problem of face recognition from frontal images seems quite logical, as the frontal view is the normal presentation and offers many facial features. Cooperation from the user is natural. Two kinds of information can be exploited. On the one hand, each facial feature (eye, mouth, nose, hair, chin, …) can be analyzed independently to look for discrepancies between test and reference images using criteria like length, area, shape or color. On the other hand, the spatial configuration of the different facial features leads to other personal characteristics.

6.2 Approaches

There are basically two different approaches to compare objects and in particular faces.

The first one, called global or 'holistic' considers the face image as a whole without trying to analyse its content. The utilized techniques encompass pixel correlation, artificial neural network with images as input pattern (see [Kohonen89,Stonham86]), or image transform such as the principal component analysis [Turk90], to name a few. The same techniques are advantageously applied to facial parts, usually rectangular areas around the nose, the eyes and the mouth ([Brunelli93,Beymer94]).

The second approach, called 'featural', looks for facial characteristics such as distance, area, shape or color measures. It typically analyses parts of the face such as the eyes, the nose, the mouth, the chin, and the hair. The comparison of the face is then translated into the comparison of the feature vector and classical classification techniques can be used to verify similarity (by techniques such as nearest neighbor, neural network or least mean squares).

The global approach has the advantage to process the whole image without a priori analysing its content. However, image computation is often heavy and important facial details relating to small areas collapse in front of large but non informative regions. The featural approach benefits from a more controlled strategy of analysis, although requiring more work from the developer and leading to application dependent solutions. Feature extraction also allows for information compression as a few features are expected to code most of the facial information. To be complete, let us mention the model-based approach [Mundy91, Yuille89, Wiskott96] which shares the advantages of the global and featural techniques. Global characteristics are present in the generic model. This model is adapted to a given image thanks to extracted features.

6.3 Difficulties

Several major difficulties complicate the frontal approach. First, the image quality largely suffers from the lighting conditions and the distance between the subject and the camera. Secondly, the 2-D image projection on the camera sensor of the 3-dimensional face depends on the relative orientation between the camera and the head ('point of view'). Thirdly, the person does not always adopt a neutral attitude (no emotion, with eyes opened and mouth closed). Finally, glasses, a hat and a scarf are likely to hide partial information and are not always easily handled. The last three difficulties can however be reduced thanks to the cooperation of the user.

6.4 Results

In our first experiments with Artificial Neural Network in 1990, a Kohonen map [Kohonen89, Perneel90] was tested with face images as input patterns. Although the recognition ability of the

network was shown, this global approach revealed its limitations in dealing with illumination, rotation, scale and translation changes.
We then considered a featural approach about the configuration of facial components, where reference points were obtained from the vertical gray-level profile, horizontally centered around the nose region (see Figure 1). Although successful even with low resolution images, this implementation suffered from the limited number of available features.

Figure 1: Vertical gray-level profile and vertical and horizontal references.

6.5 Conclusions
The problem of automatic frontal face matching is not easy to address, due to extrinsic (light, point of view) and intrinsic (emotion, changes, accessories) conditions. While basic features can be easily obtained (distances between facial parts, hair color, beard presence), their combination is not trivial as many features may be improperly measured or may vary significantly.

7. Automatic Profile Identification

7.1 Motivations
If a frontal image of a face can undergo large variations, a profile, on the contrary, remains rather stable in normal situations. The term profile used hereunder relates to the external contour of the head from side view and is composed of the forehead, the nose, the lips, the chin and the neck, most of which are rather rigid parts.
From the user point of view, the cooperation is easy. The user looks in a given direction, perpendicular to the camera, and preferably with his mouth closed.
Practically, the profile capture doesn't require illumination conditions which are difficult to satisfy and processing relates to a 1-Dimensional curve allowing for quick computation.

Figure2: a) Profile image
b) contour extraction, nose and eye localization, feature extraction

7.2 Approach
The first step of profile recognition consists in extracting the external contour of the head profile. To simplify processing, we implemented a method based on a white background.
The second step is the extraction of characteristics. The contour is analyzed in terms of curvature and protrusion to localize the nose which is used as first reference point. The second reference point is the

eye, obtained as the first concavity above the nose. These two reference points define a scale unit and a rotation reference. From the nose reference point, and at regular interval based on the reference scale, angle and curvature values are measured along the profile. Angles are given relatively to the direction nose-eye. The curvature values are derived from three neighbor points along the profile.
The third step is the profile comparison with reference profiles to identify the most similar person. We based our distance measure on the difference of angle and the difference of curvature values of corresponding points along the profiles. Using the very precise nose localization no translation adaptation has to be made.

The three steps have been designed and implemented to be very fast. On a Pentium 200 MHz, the acquisition, feature extraction and comparison with a database of more than 270 contour references take less than 250 msec. In continuous identification, the system delivers 4 identifications each second. For a natural pose of a few seconds, this allows to analyze more than ten system answers to reduce false rejections and false acceptances.

7.3 Results
A profile identification prototype has been developed with a PC, a camera, an acquisition board and a white wall as background. A database of 41 people with 5 to 10 shots per person has been acquired in a span ranging from a few days to a few months, depending on the availability of people. Considering half the entries as references and the other half for test, we reached a recognition rate of about 80 % (Equal Error Rate = 10 %). The same recognition rate was achieved with another database of 120 people containing one session used as reference and one as test, these sessions being acquired two months apart from each other.

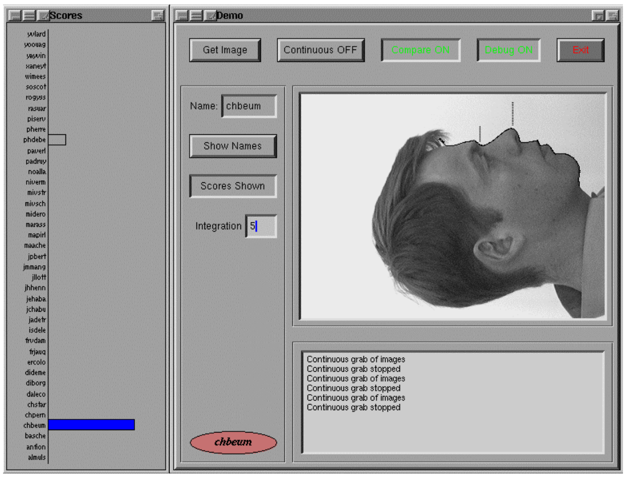

Figure 3: Graphical user interface for the profile system

As a second test, the available persons were asked to test the system in real time, considering all the entries of the database as references. For this a few seconds of presentation were necessary to obtain between 10 and 20 person identifications. If half or more of the identifications concerned the same person, this person was assumed to be identified (maybe wrongly). This temporal fusion reduced by far the false acceptance level (false acceptance occurs less often than right acceptance) and also false rejections because up to half of the identifications can be missed. After testing more than half of the persons present in the database and a few imposters, the EER achieved less than 4.0 %.

7.4 Conclusions
The developed profile prototype offers an easy and quick solution to the problem of automatic person identification. The user constraints are rather soft: looking in a general direction and taking glasses out, if any. The response latency amounts to a few seconds. The white background can be replaced by a static background if profile extraction is based on image difference.
One important conclusion to be drawn from the profile analysis is that geometric information is well suited to automatic face recognition. It weakly depends on illumination and is rather stable for a given individual although major differences exist between people.

8. Automatic 3D Head Verification

8.1 Motivations

The success of the profile approach motivated a facial surface analysis. This brings more information than the sole profile. The 3-D description allows for translation, rotation and scale normalization. As the volume information is looked for, the dependence on illumination can be kept small.

3-D acquisition has been traditionally reserved to expensive solutions with rather slow scanning devices. There has recently been an increase of developments of low cost 3D acquisition systems based on structured light illumination [Jarvis93, Proesmans97, Turing], and capturing the 3D scene in one or a few images. At video speeds, this results in quick solutions for which the subject is no more asked to stay still for a while.

Although 3D facial analysis is active in the field of image coding and synthesis [Saulnier94, Aizawa95], reported 3D facial recognition experiments are still rare [Lapreste88, Lee90, Gordon91, Achermann97].

8.2 Approach

The method is described in terms of its two components: 3D acquisition and 3D comparison.

The 3D acquisition (see [Beumier99a]) of the facial surface is made by triangulation, thanks to a camera and a projector sending a specific pattern of light. The structured light consists in our case of parallel lines (‘stripes’) of two different thicknesses, arranged as a barcode in order to allow for the identification of each stripe when the thickness of a few neighbors are known.

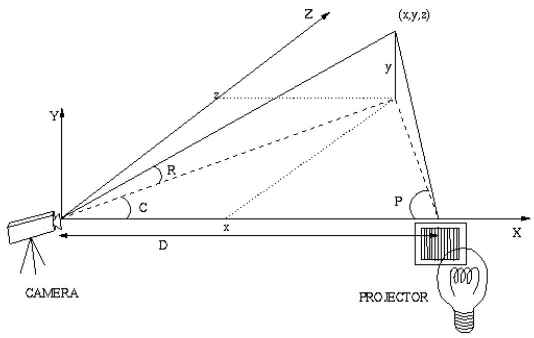

Figure 5: Structured light system

The system is cheap, involving a normal camera and a normal projector. The slide is made of glass to avoid thermal effects with the lamp heat. To work with lenses with small optical distortion, but to stay at reasonable distances, we chose a distance of work of 1.5 m. The corresponding volume of acquisition is 40x30 cm with a depth of focus of about 40 cm. It fulfils the needs of head capture for a sitting and cooperative person.

Figure 4: Images with and without stripes

The system is fast. A single image with projected stripes contains full 3-D information. At the speed of video cameras, no normal human motion impairs the integrity of the volume captured.

The striped image (see Figure 4) is first processed to detect vertical lines corresponding to the stripes. Line detection problems in dark areas appearing around the eyes, the eyebrows, the mouth and the nostrils have been reduced by turning the system so that the face is diagonally striped.
Each stripe is then classified as thick or thin based on the relative amount of dark and bright gray-levels present in the horizontal gray-level profile around the stripe. Based on a few neighbor thicknesses, each stripe is labeled by its number. The position in the image of points along each stripe and the stripe label allows to derive the xyz coordinates of these points. The intrinsic (CCD, acquisition board, lenses) and extrinsic parameters (camera/projector relative position) of this transformation are obtained during a calibration phase based on the capture of the corners of a reference planar square (Figure 6).
Perspective reconstructions are shown in Figure 7. The time spent to get the 3D coordinates from the image is about half a second on a Pentium 200 MHz.

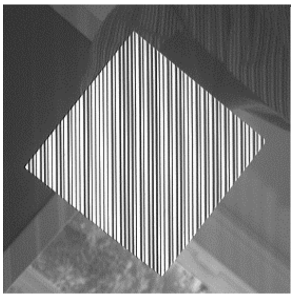

Figure 6: Calibration square

Figure 7: 3-D reconstruction

The 3D comparison method adopted in our project considers planar cuts in the volume by parallel planes separated by 1 cm. Each planar cut delivers a 2D profile which is compared to its homologue of another facial volume (see Figure 8). This profile comparison outputs a distance equal to the area contained between the two profiles. The 3D comparison process minimizes the total distance of the plane cuts for the possible 3 translations and 3 rotations, no scale factor being considered as the system measures the true scale. This 6-dimensional minimization was successfully carried out by a ‘iterative conditional mode’ procedure where each parameter is recursively optimized on its own. Good approximation of initial values helped avoiding local minima and speeded up the process. A comparison between two facial surfaces on a Pentium 200 takes typically 1.0 second.

In order to further speed up processing, we also considered the comparison of the vertical profile passing through the nose augmented with the average of the two lateral vertical profiles at 3 cm from the nose (Figure 9). This choice was motivated by the fact that those vertical profiles can be extracted automatically from each volume independently, thanks to the horizontal symmetry of the head. The verification of a test surface requires the extraction of the 2D vertical profiles of that test surface (about 0.5 second) and their matching with the vertical profiles of the reference surfaces, extracted offline. This matching only involves 3 parameters and lasts less than 0.1 second on a Pentium 200.

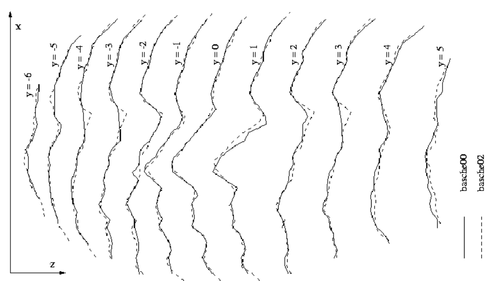

Figure 8: 3D comparison by parallel planar cuts.

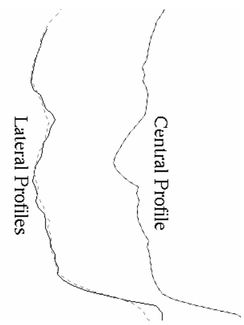

Figure 9: Central and Lateral profiles.

Finally, because the 3-D analysis allows to solve one of the main problems of frontal face analysis, the point of view, we considered the gray-level analysis normalized by the 3D information. First, the point of view can be obtained from the 3D information. Secondly, illumination influences can be compensated thanks to a model of the light projected and the captured facial volume. The ultimate goal is to combine gray and volume information which look to complement each other very well. On the one hand, gray-level features are localized in the mouth, eyes, hair and nose, precisely where a structured light system encounters acquisition problems. On the other hand, the forehead, cheeks and chin are poor in gray information although they are well captured by a 3-D system.

8.3 Results

A database has been acquired [Beumier99b] to test our 3D acquisition system and the face verification performances of the proposed methods. It consists of 120 people chosen for their probable availability in our premises. Three sessions have been organized in late 1997, early 1998 and mid 1999.
The automatic 3D acquisition program worked properly, especially regarding that no tuning was performed during the database collection. Common problems concerned the beard, moustache and spectacles while minor problems were found in the eyebrows, the nose and mouth.
The two methods presented in 8.2 offered similar results. [Beumier98, Beumier00b] give a precise description of the results. With fully automatic processing (acquisition and comparison, rejecting a few very bad acquisitions) the EER is about 10%. When manually refining the acquisition and the matching procedures, the EER falls at about 4%. Combining 3D and gray-level features on the same database led to a recognition rate higher than 95 %, as described in [Beumier00a].
Results could still be improved thanks to a better acquisition system, a better representativity of people, and a better matching procedure.

8.4 Conclusions

The whole chain of 3D processing, from acquisition to matching, offers a good performance relatively to the numerous disturbing factors mentioned above. An EER of 10 % has been obtained by two different comparison techniques, including normal acquisition errors, a lack of representativity and possible matching troubles. Manual intervention showed that the discrimative power of the 3D approach is higher, having reached 4% of EER when acquisition and matching were supervised.
A special care has been taken to keep the processing time below three seconds, from acquisition to decision. The integration is quick enough to verify the identity of one person in a few seconds on a Pentium 200.

At least four ways of improvement can be considered.
The first one concerns a better acquisition system, solving facial inconsistencies (thanks to a model) or cleaning regions which revealed to be too noisy. Secondly, the matching procedure could be accelerated and avoid local minima, possibly using gray-level features. A third improvement would take benefit of the acquisition speed to consider a better representation of people (more references) and to base the decision on a few captured surfaces. Finally, a gray-level analysis would complement the 3D processing. Gray-level clues can help the acquisition to deal with critical zones such as the beard, eyebrows or eyes. They can help in leading the matching procedure. They provide for complementary information, as shown in experiments [beumier00b], mainly in the eye, hair, nose and mouth, precisely where 3D capture is difficult.

9. Conclusions

The activities of the SIC in face recognition were presented. They were all conducted to meet practical constraints such as the time response, user cooperation and hardware cost.

Frontal face analysis appeared to be the most difficult to get good performances, considering the large influence of pose and lighting conditions.
The profile view offered a simple and quick automatic solution, based on the external contour consisting of rather rigid parts. The development of a prototype showed adequate system behaviour in realistic conditions, taking advantage of the overall speed to perform time fusion.
The 3D approach contained two challenges. The first one showed that 3D capture can fulfil system requirements about speed, cost and precision. The second challenge proved that facial surface analysis contains discriminative information, adequate for person verification.

An important and interesting future work lies in the further exploitation of gray information within the 3D approach. A system combining gray and volume information at all level of processing (capture, comparison and classification) appears to be a perfect example of fusion.

In order to increase the robustness of person identification, the activities of the SIC in expert fusion will be continued. They will lead to the development of a prototype implementing the fusion between speaker and face modalities.

10. Acknowledgements

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Biography

Charles Beumier was born in Mons, Belgium, in September 1964. He got the degree in electrical engineering from the Université Libre de Bruxelles (ULB) in July 1987. Since 1988, he has been working at the Signal and Image Centre (SIC) of the Electrical department of the Royal Military Academy of Belgium. He was first concerned with image acquisition and graphical user interfaces. Then he focused on Pattern recognition. From 1990, he was deeply involved in automatic face recognition, considering frontal, profile and volumetric approaches. Since 1999, he has been active in the field of humanitarian mine detection.