Face recognition system using fringe projection and moiré: characterization with fractal parameters

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Summary
We show a new method for face recognition which combines the projection of structures with different characteristics (fringes, bars or grids, dots or speckle) over the face. These projections will then allow the creation of a computer-generated moiré pattern over which different kinds of fractal and complex geometry parameters are then measured. Such parameters will then be used as inputs for a neuro-symbolic hybrid system. Here, we analyze the incidence of some parameters on the efficience for the face recognition method.

Key words:
Face recognition, moiré structure, fractal geometry, complexity,, hybrid system..

1. Introduction

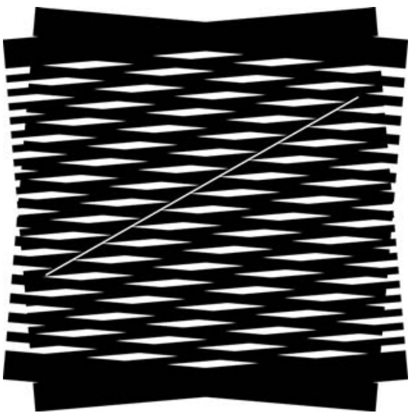
Moiré effect [1-3] and fringe projection [4,5] has been broadly studied by several authors, and we can also find in the literature numerous applications of these studies. Basically, the moiré effect is obtained as a pattern of clearly visible fringes when two or more structures (for example grids or diffraction gratings) with periodic geometry are superimposed. It has also been verified that the obtained fringes are a measure of the correlation between both structures [3]. Additionally, it has been shown that the moiré effect can be obtained when other types of structures are superimposed, such as random and quasi-periodic ones [6,7] or fractals [8-10]. Fringe projection entails projecting a fringe pattern or grating over an object and viewing it from a different direction. It is a convenient technique for contouring objects that are too coarse to be measured with standard interferometry. A simple approach for contouring is to project interference fringes or a grating onto an object and then view it from a different direction.
Both, moiré and fringe projection also have applications in biometric analysis [11-13], where the main objective is to achieve identification of a person, depending on their physiognomy or behavior [14]. In the same way the topography of a surface is studied, the moiré pattern can be obtained from the surface of a face by projecting structures (fringes, dots, speckle) over it. This will give us an idea of the face geometry.
Some of the tools used in face recognition are artificial neural networks [15-16] and fractal geometry [17-19], which have been used in applications related with finding specific areas of a face, or for changing its characteristics in terms of fractal dimension. Our interest in the present work is to develop a new approximation in face analysis, by using basically fractal analysis and moiré effect as inputs for an artificial neural network.
The advantage of the proposed method is that it can be combined with the measurements obtained with other known methods, but allowing this way, the use of fractal parameters.
Figs. 1(a) y 1(b) show different types of moiré obtained for the case of grids and dots respectively, both are distributed in a periodic way. This can also be applied for the case of random distributions.
As we pointed out, the main objective of the present work is the application of fractal parameters, combined with moiré and/or fringe projection. These fringes can even have fractal geometry, in which case, the variation in the fractal dimension with respect to the projection over a plane is shown. Moiré can be obtained from different structures, but we mainly show the result for the case of dots distribution. Also, generalized entropy will be considered for a complex analysis of the image of the face directly obtained with an imaging system.
Our intention is to take advantage of all the mentioned parameters in order to implement a hybrid neuro-symbolic system, where they will be used as inputs in order to make comparisons with images stored in a database. In this work, we will study the incidence of these complex parameters when using a simple neural network (perceptron multilayer).

Manuscript received July 5, 2009
Manuscript revised July 20, 2009

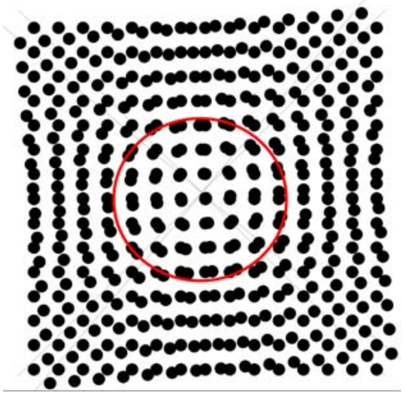
2. Acquisition and image processing

Here, we consider the capture of a 3D image of a face then, the application of some of the already known methods for face recognition [20,21] are applied, afterwards a clusterization is performed based on the use of generalized entropy (Renyi [22] and Tsallis [23]). Then, the proposed method is applied. Fig. 2 shows a block diagram representing the sequence of the procedures involved in the proposed face recognition system.

First, a structure than can form moiré patterns or that can be used in 3D image processing, is projected over a face. The examples considered in the present work are fringes which can be obtained with an interferometer, as well as distributed bars, grids or dots obtained by different methods (high resolution photography or holography), or even speckle generated from a laser beam or a random mask.



(a)



(b)

Figure 1 – Moire obtained for: (a) periodic grids, (b) dots with periodic distribution.

This way, a 3D image of the face is obtained, that can allow a parallel processing performed by the already known methods, as shown in Fig. 2. This means, that in both cases a system for the visualization of the image is available, for capturing the image from different angles, or by using a 3D scanner. With the support of image processing techniques, the image is filtered in order to obtain a deformed version of the projected dots distribution. Afterwards, a pattern is obtained by superimposing the original distribution with its deformed version, for the case of the different types of structures mentioned before. This is known as computer-generated moiré, which has already been applied for face recognition [24].

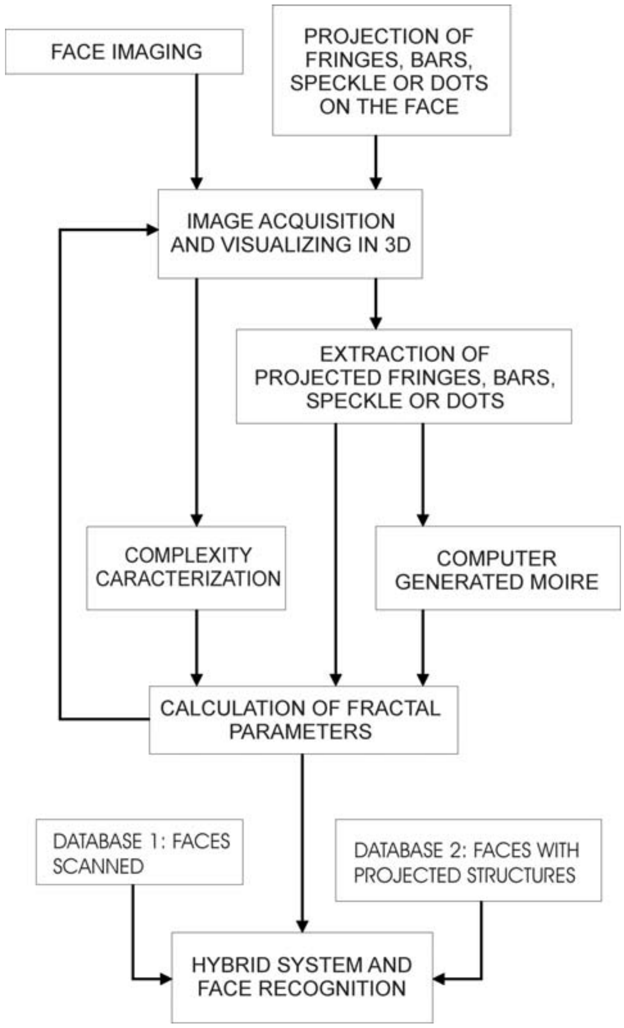


Figure 2– General system for the face recognition.

Different fractal parameters are calculated for the image of the face with and without the projected structures and for the image with a computer-generated moiré [25]. This means that fractal parameters can be calculated by three means. Over the image, with the projected structure, in which case, changes in such parameters with respect to the projection over the plane will be evaluated; another option is through the computer-generated moiré structure; and finally it can be calculated by using complexity considerations, that in our case will be calculating Renyi and Tsallis entropies in a way similar to the one used in a previous work [26]. In this case clusters are formed when particular portions of the face are taken, which can also be useful for making corrections in the image caused by lack of illumination or focus issues in the original image. As shown in Fig. 2, this will lead again to adjust the image acquisition system so that these parameters could be used for image correction or obtaining more details.

This information will be the input to the neurosymbolic hybrid system, which performs the classification.

Matching of the face of a certain person with its corresponding image is done by comparing images contained in two databases. One of them is the MIT-CBCL Face Recognition Database [27], the other one was generated for the present work (containing the projection of structures over the faces). These cases of fringe projection were obtained by a simulation over de faces in the database, for different angles and by using different characteristics for the projected structures. After obtaining the results from these projected fringes the corresponding calculations were performed, and also the moiré structures were obtained.

The difference between the proposed method, and the already existing ones, is that the projected structure or the parameters used over the obtained moiré have fractal characteristics. The following parameters can then be calculated for the pattern: generalized fractal dimension (box-counting, information and correlation included) [28], perimeter – area relation, lacunarity and succolarity [29], Tsallis [22] and Renyi [23] entropies.

We now include some definitions for the used parameters:

- Generalized dimension. If we define S_q^R as the Renyi entropy with order *q,* for a linear parameter *ε*, we have:

$$D_q = -\lim_{\varepsilon\to\infty}\frac{S_q^R(\varepsilon)}{\log(\varepsilon)} \tag{1}$$

and it can be demonstrated that D_0 is the box-counting dimension, D_1 is the information dimension and D_2 the correlation dimension. In general, D_q ($q>2$) is the correlation dimension of order *q*.

- Correlation dimension: This parameter estimates the average number of data points within a radius *r* of the data point *y(n)*. The quantity *C(r)* is defined by:

$$\boldsymbol{C(r)} = \frac{1}{\boldsymbol{N\,M}}\sum_{\boldsymbol{k}=1}^{\boldsymbol{M}}\sum_{\boldsymbol{n}=1}^{\boldsymbol{N}}\theta\left[\boldsymbol{r} - \left|\boldsymbol{y(k)} - \boldsymbol{y(n)}\right|\right] \tag{2}$$

where θ is the Heaviside function:

$$\theta[r] = \begin{cases} 0 & r<0 \\ 1 & r\ge 0 \end{cases} \tag{3}$$

where *N* and *M* are the elements for a matrix of pixels. The correlation dimension is defined as:

$$\boldsymbol{D_{corr}} = \lim_{\boldsymbol{r}\to 0}\frac{\log \boldsymbol{C(r)}}{\log \boldsymbol{r}} \tag{4}$$

- Perimeter – area relation:

$$A \approx P^{\frac{2}{D}} \tag{5}$$

where *A* is the area, *P* the perimeter of the fractal set and *D* is the perimeter/area dimension.

- Tsallis entropy. For an index *q* and a probability distribution P_i:

$$S_q^T = \frac{1}{q-1}\left[1-\sum_{i=1}^{N}P_i^q\right] \tag{6}$$

- Renyi entropy. For an index *q* and a probability distribution P_i:

$$S_q^R = \frac{1}{1-q}\log\left[\sum_{i=1}^{N}P_i^q\right] \tag{7}$$

3. Moire and fringe projection

In this type of techniques, a grid with dark and clear bars or an interferometric array is used. The topography of a surface can be studied from these methods and is a very well known technique. We now show the expression for the calculation of heights for the topography methods using moiré and fringe projection. [30,31].

The equations for describing the contours of projected fringes onto a surface are given by:

$$C = \frac{\lambda}{2\sin(\Delta\theta)\sin\alpha} \quad (8)$$

where λ is the wavelength, α is the angle where the fringes are viewed and $\Delta\theta$ the angle between the two interfering beams. In this work we present, for the first time, the projection of fringes with fractal geometry, as well as dots projection, which can be extended to speckle projection. In the first case, a variation of the fractal dimension, this can easily be deduced from the definition of generalized dimension. In the second case, a change in the correlation integral exists, and therefore, we can expect that the formed moiré superposition in such case will lead to a variation in the correlation dimension (*q=2*).

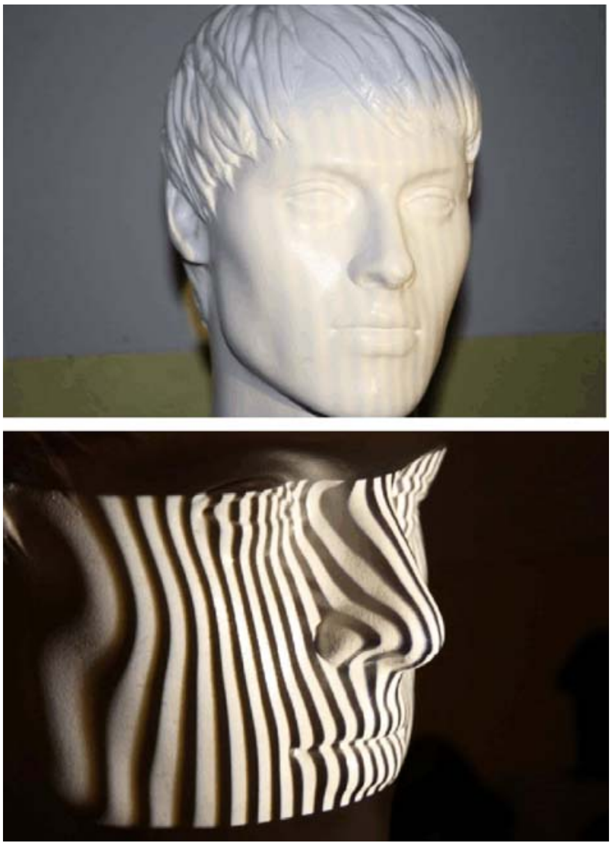


Figure 3 – Original face and fringes projection with periodic distribution.

4. Results obtained

As a first step, the methodology was tested with and experimental array by using a mannequin Fig. 3 shows an example over a face, as well as the distribution of periodic fringes projected in order to make different considerations and perform the moiré superposition. Fig. 4 shows the Cantor fringes projection, where the fractal dimension has changed from *1.683±0.008* (when projected over a plane) to *1.474±0.006* (when projected over a face). This shows the important variation that exists, and the importance of using this parameter as one of the inputs for a hybrid system.

Once tested, the methodology was implemented over the faces of the mentioned database by using computer simulation for generating and projecting the fringes in a similar way as was done with the mannequin as can be seen in Figs. 3 and 4. This way a second database was obtained containing the faces with fringe and dot projection in order to test the method.

The implementation of the method used a multilayer perceptron since it has proven its effectiveness in classification tasks. The neural network was trained with 60 examples of each class (person) and at least 10 different classes were used. Finally the neural network gives as an output the identified face.

In the case of dot projection, the distribution of the dots can be studied in terms of their size and density. The final system is then able to identify different people based on the fractal characteristics of each face, the projected structures and the generated moiré pattern

In the obtained results, the system has demonstrated being highly precise, since it uses a very robust method for the calculation of parameters and processing based on a neural network. For these developments we used the NeuroSolution (for structuring the neural network) and Benoit (for calculating the fractal dimension) software, as well as other software developed by us with Microsoft .net.

Basically two types of projected structures were used: fringes and dots. The efficiency of the method varies according to different characteristics that still need to be studied and it ranges from 70% to 80%, however once the system is implemented as shown in Fig. 2, we can expect to obtain a highly efficient system.

In Fig. 5 we show the variation of the correlation dimension (calculated over the surface of a face) with the angle for a window over the image, where the superposition of dots was considered for the same face with a different one. If the registered face by the image acquisition system corresponds with one in the database, a peak of correlation exists (black line), while this is not seen for the case of different faces (red line). In the same way, as mentioned before, there exists a change in the fractal dimension when fringes with fractal structure were projected over the faces. These parameters were then used as inputs for the neural network.

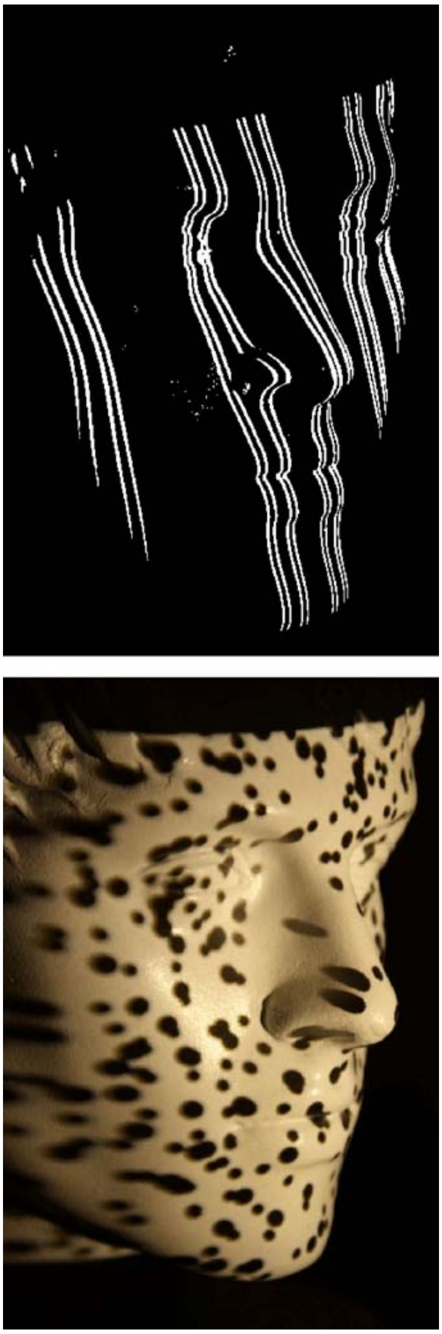


Figure 4 – Projection of Cantor fringes and random dots distribution.

Regarding face characterization by using complexity parameters (Renyi and Tsallis entropies) and fractal dimensions (box-counting and perimeter/area relation) [32-34], we have also arrive to good results by taking different portions of the images, and focalizing in a specific zone. When comparing with images already stored in a database the results mentioned before increases around 90%.

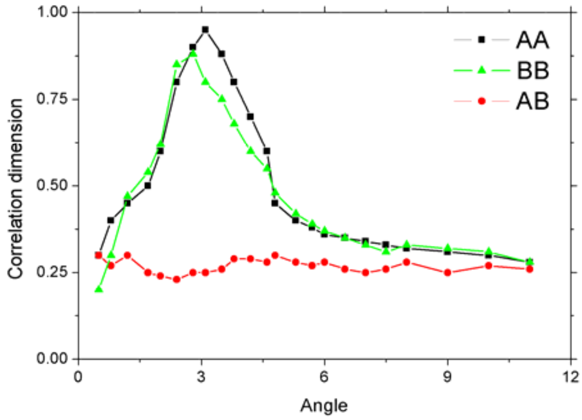


Figure 5 – Correlation dimension as a function of the angle rotation between both 3D distributions.

5 Conclusions and future developments

We have developed a robust system that uses image processing, fringes projection, fractal parameters, and computer-generated moiré, for sending several data as inputs for a hybrid neuro-symbolic system, which performs face recognition tasks. This method is new and we present it here for the first time. In its more general form, it combines the traditional methods for 3D characterization by using fractal geometry. It also, considers the use of some image processing techniques by using such parameters. Also, complexity parameters such as Renyi and Tsallis entropies allow the clusterization of a portion of the image which can be compared with a face database (MIT-CBCL).

In future works, we will introduce the study of generalized entropy and clustering, as well as the study of textures. We will also develop a database containing faces over which fringes, dots, and other structures have been projected and that can form moiré patterns. Also, several tests related to gestures and how they relate with changes in the fractal dimension on a still face will be performed.

Acknowledgments

This work was supported by Centro Multidisciplinario de Ingeniería y Tecnología, CEMINT A.C.

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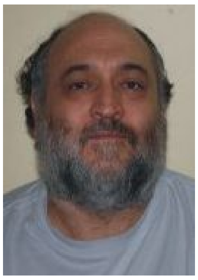

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