Global, Semi-Global and Local Color Angular Features for Unsupervised Face Recognition

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***Abstract*—In face recognition applications, dealing with images under different conditions is a challenging task because they can affect dramatically the recognition performance. Among many image features, color is an useful feature which is generally used for image matching and retrieval purposes. Besides, to represent images through features, we generally need an extensive number of parameters forming a large feature set. Color angles need only three parameters to represent an image in a small feature set and are considered as pose and illuminant-invariant. Hence, in this work, we have made an attempt to study the use of color angles in face recognition approach with images obtained under different conditions. In addition to this, face image features are spatially extracted from different combination of sub-images similar to the edge histogram descriptor scheme denominated as Global, Semi-Global and Local features. Since we have proposed an unsupervised learning approach, no previous knowledge about images are required. Six types of images obtained under two different illumination conditions including with face expression and scale are used as query images in a base of images obtained under controlled condition. According to the experimental results, an expressive recognition rate can be obtained from face expression and scale. One of the main goal of this work is the use of Semi-Global features with Global and Local features. From this initial study, we can identify that the Local and Semi-Global features influence in the recognition performance than Global features.**

I. Introduction

During the 1980's, face recognition (FR) research remained stable and no prominent works were developed. Since the early 1990's, research interest in FR has grown very significantly as mentioned in the classical work [2]. FR received much attention by attracting researchers from different areas such as Image Processing, Pattern Recognition, Computer Vision, Artificial Intelligence, Computer Graphics and Evolutionary Computing [24], [25]. It has also received significant attention from both public and private research communities [22]. For the past 20 years, research has been focused on the construction of automatic FR methods by detecting a face in an image and extracting features such as eye, mouth, nose, eyebrows, lips etc. Factors like illumination variation, pose changes, occlusion, face expressions, imaging conditions and imaging orientations can change the overall appearance of faces and, consequently, can affect dramatically the recognition performance [24]. To date, a variety of approaches and solutions have been proposed to solve the FR problem. However, FR is still a challenging task.

Main actions of FR involve segmentation, detection, feature extraction from face regions, classification, retrieval and, finally, recognition [25]. The FR process normally solves the problem of identification in which a given unknown face image is compared to images from a database of known individuals to find out a correct match.

The success of FR methods depends on the extraction of stable features. One of the common methods is the geometric feature-based method which normally extracts information from local features such as eyes, nose and mouth. The common drawback of this method is that they may be easily affected by the feature extraction and measurement processes. In addition to this, Template matching methods are also used in FR tasks using the pixel information as global features. But, it is highly sensitive to environment, size and pose. Comparing the representations of two similar shapes may not guarantee a good measure if they have undergone some transformation like rotation or variation of lighting conditions [24]. Several works have been proposed to detect and recognize faces using global features such as skin, color, size and shape.

Color represents an useful feature for image matching and retrieval purposes. The skin color information can be useful to differentiate a face region from complex backgrounds which can probably reduce the computational effort spent in complex background regions [13]. Hsu et al. [11] proposed a face detection algorithm that is suitable for static color images using a lighting compensation technique and a nonlinear color transformation in the YCbCr color space. Liu and Liu [15] proposed a novel hybrid Color and Frequency Features (CEF) method for face recognition, which derives the complementary features in the frequency domain of the component images in the hybrid color space RIQ. This color space is the combination of the R component of RGB, and the chromatic component of I and Q of the YIQ2 color space. It is based on the criteria that the application of complementary features of color spaces may improve the face recognition performance and fusing features across color spaces can also enhance the discrimination power [15].

Images can be represented by one or more types of features extracted from colors, edges and textures and using a variety of methods which may based on spatial or frequency filters, for example. From these feature extraction methods, generally, a large quantity of features are extracted forming a huge feature vector which may have in the of order thousands of elements [19]. To cope with this issue, it is common in the FR literature, the dimension reduction of feature vector using PCA (Principal Component Analysis) followed by machine learning process, for example, SVM (Support Vector Machine) [5]. In this context, we established an objective to obtain a feature set with few parameters sothat it can be compact and representative of a face image.

More generally, color features are globally represented by histograms which summarize the color distribution in an image. Hence, histograms serve as tools for color image analysis and for many spatial domain processing techniques [5]. Although histograms are invariant to rotation and translation, they can not deal with illumination variations. Several works have been proposed to overcome the illumination variation problem. In this direction, an approach was proposed by Finlayson et al. [9], a color angular indexing scheme in which objects are represented using a color-distribution-based descriptor represented by three color angles which are invariant to pose and substantial change in illumination. Hence, our work is motivated by the fact that the color angles can be used as image descriptors in FR approaches.

The main objective of this work is to propose an unsupervised approach for FR using color angles and images obtained under different conditions which include face expression, different illumination conditions, lateral face illumination and scale. One of the main contributions of this work is to explore the use of color angles and its positive and negative implications in FR with our face images. Another contribution of our approach is the way the features are extracted (color angles) from the face image database as explained below.

More generally, from the early to most recent studies on recognition approaches, many attempts have been made using either global or local features of images [21]. Global features describe the image as a whole meanwhile local features represent a small part of the image. Likewise, global features have the potential of generalizing an entire image which may provide some guide lines for class discrimination purposes. On the other hand, local features obtain local information at multiple points or some interior parts of face images such as eyes, nose and mouth [8]. The image parts from which local features are extracted can be uniform and non-overlapping regions as in the case of EHD [8], [16] or non-uniform and overlapping points as in the case of SURF [3]. Hence we assume that local features can somehow improve the robustness of recognition systems. Since both global and local features are generally obtained in a distinct way, they can also provide different types of information [14]. Likewise, we believe that similar to global and local features, semi-global features can also provide us some different information about face images. Up to now, with the exception of the works based on EHD, we have not yet found any work using semi-global features in FR applications.

Based on the above mentioned considerations, in addition to color angles and inspired on the EHD method proposed in the MPEG-7 standards [16], we have made an attempt to extract the color angles from global, local and semi-global regions of face images. To understand the influence of these features on the performance of our FR approach, we have conducted experiments using all possible combinations of them. Furthermore, most of the FR applications are developed through supervised learning approaches, but, our proposal is strictly based on the image features and their combination based on color angles without any training scheme.

Many works have been published in recent years extracting color as local and global features. In [4] the authors studied the face verification using Template Matching based on cross-correlation and histograms. Both are dependent on the values of image pixels. Template Matching depends on local pixel information meanwhile histogram matching on global pixel information of the face images. According to the conclusions, global histograms capture and represent the image color distribution and are suitable for face recognition and related tasks. However, when dealing with image influenced by variations such as pose and illumination more investigation using local image information is needed. The work developed by Jeng et al. [12] is mainly based on the idea that the features of interest are present in some image blocks, which contains features with spatial relationship. Therefore, the facial image is treated as a set of blocks where facial features can be detected. Using global and local features, Amaral and Thomas [8] have proposed an FR approach comparing LBP (Linear Binary Pattern) and PCA (Principal Component Analysis) in order to understand the behavior of both methods when using pre-processed and previously spatially normalized face images. Similar to our study, but, using EHD was conducted by Rahman and colleagues [20]. This work indicates that the MPEG-7 edge histogram improves the FR performance significantly and local edge histograms are better than global and semi-global histogram descriptors. The use of local and global features for FR through a two-stage recognition was proposed by Singh [21] in 2012. In this paper, global features are extracted from Zernike moments and local features from the histogram-based Weber Law Descriptor. Both methods overcome the image variations.

The main task in this work is to query a face image obtained under different conditions into a database of face images obtained under controlled condition. Similarity between two images will be obtained using the three color angles which are obtained from different sets of image partitions.

This paper is organized as follows: in Section II we explain about the fundamentals of color angles and how they can be extracted from single face images. Our FR approach is described in Section III. In Section IV we describe our experimental setup and the results obtained using different types of query images. Final conclusions and future work directions are drawn in Section V.

II. Color Angles

The color angles approach is initially proposed by Finalyson and colleagues [9]. Their main goal was to develop a color based image descriptor that is concise, expressive and illumination variant. In addition to this, they aimed to construct a descriptor with very few parameters so that it can be useful for computationally intensive algorithms.

In images, illumination variation can be treated as a linear transform of image colors [9]. With the presence of noise, the representation of this transform may not be stable and expressive. However, a scene viewed under two different illuminants can be connected by 3 simple scale factors. In this case, each pixel in the first image (R_i, G_i, B_i) becomes $(s_1 R_i, s_2 G_i, s_3 B_i)$ where s_1, s_2 and s_3 are scalars. These scalars represents the illuminant-variant information between two images seen under same view. Hence, the images that differs only in terms of the scene illuminant can be related by a simple 3-parameter diagonal matrix [9]. If an image band is represented as a vector in a high-dimensional space, when the illumination changes, then the vector becomes longer or shorter but its orientation remains unchanged. Hence, under a diagonal model of illuminant change, the 3 angles between the different bands of an image can define the illuminant invariant relation.

The investigation of colors under a changing illuminant indicates that likely illuminant changes can be defined as a restricted subset of linear transforms. From this observation, we can extract useful illuminant-invariant statistics from color distributions. Hence the color distributions represented by color angles encode important low-order statistical information [9]. One way of describing the color distributions using a statistical measure is by a mean image color which is defined as follows:

$$\mu(I) = \frac{1}{M} \sum_{i=0}^{M-1} (R_i, G_i, B_i) \tag{1}$$

where M represents the number of pixels and R_i, G_i and B_i are red, green, and blue pixels values of an image respectively.

According to the work proposed in [23] which uses a simplified form of [9], the relation between three channels R, G and B is represented by three color angles ϕ_{rg}, ϕ_{gb} and ϕ_{rb}. The first step to compute the color angles is the calculation of zero-mean color vectors r_0, g_0 and b_0 as defined by the following equations:

$$\mathbf{r}_0 = \mathbf{r} - \overline{r} \tag{2}$$
$$\mathbf{g}_0 = \mathbf{g} - \overline{g} \tag{3}$$
$$\mathbf{b}_0 = \mathbf{b} - \overline{b} \tag{4}$$

where $\overline{r}$, $\overline{g}$ and $\overline{b}$ are the average pixel values of the color channels R, G and B, respectively (Equation 1). In the following step, the zero-mean color vectors are normalized and they are represented by $\mathbf{r}_N$, $\mathbf{g}_N$ and $\mathbf{b}_N$:

$$\mathbf{r}_N = \frac{\mathbf{r}_0}{\|\mathbf{r}_0\|} \tag{5}$$
$$\mathbf{g}_N = \frac{\mathbf{g}_0}{\|\mathbf{g}_0\|} \tag{6}$$
$$\mathbf{b}_N = \frac{\mathbf{b}_0}{\|\mathbf{b}_0\|} \tag{7}$$

To calculate the color angle between two color channels, for example, R and G, based on the a geometrical assumption, we calculate the inverse cosine of dot products of the normalized vectors of two color channels:

$$\phi_{rg} = \arccos(\langle \mathbf{r}_N, \mathbf{g}_N \rangle) \tag{8}$$
$$\phi_{br} = \arccos(\langle \mathbf{b}_N, \mathbf{r}_N \rangle) \tag{9}$$
$$\phi_{gb} = \arccos(\langle \mathbf{g}_N, \mathbf{b}_N \rangle) \tag{10}$$

In our study, the three color angles are calculated based on the approach proposed in [9] and [23]. In the following sections, we explain how our FR approach was developed.

III. METHODOLOGY

The general view of FR systems is shown in Figure 1 which initially consists of image acquisition and normalization and then, feature extraction and recognition. In this section, we briefly discuss about these tasks of FR process.

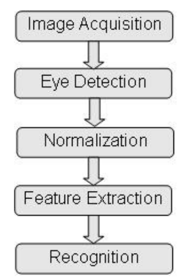

Fig. 1. General view of face recognition system

According to the classical work in FR [2], the images used in the recognition process must be derived from operational situations similar to those in which the recognition system is expected to work . The experimental image database was created based on the context of standardization rules provided by the International Committee for Information Technology Standards (INCITS) and Data Interchange formats [10], [18], for example, images without face expressions, without eyeglasses, etc.

Normalization is a critical issue in FR systems. Typically, the face images must be normalized before being used in face recognition system. Facial features that are usually normalized include size, orientation and illumination. Through eyes detection, our database of face images are normalized for size and orientation except for illumination [6].

In general, the major part of all content-based retrieval systems involves extraction of visual features and search in the visual feature space for similar images. Hence, in any FR system as shown in Figure 1, though there are tasks such as image capture and normalization, the first main task concerns the extraction of facial features. In this stage, extracted face features should confirm the similarity between base images and query images with a minimum error. When a query image is presented, to find out a similar one, an appropriate feature representation and a similarity measure to rank the images should be necessary [7]. Image acquisition and normalization stages are not part of our work. Instead the main tasks in our approach are feature extraction and recognition.

The main objective of the feature extraction stage is to construct a database of features. Hence, in this work, all features are extracted following the EHD method illustrated in

Figure 2. Using this database, FR tasks can be accomplished when a query face image is presented to the system.

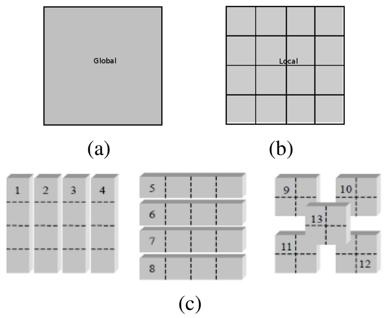

Fig. 2. Image partition scheme for feature extraction (a) Global (b) Local (c) Semi-Global

Finlayson and coworkers [9] have defined the color angles as global image descriptors and their analysis is structured with global features. In this FR work, we have made an attempt using color angles by combining global, local and semi-global features. Hence these features are spatially extracted from the different combination of partitioned images (sub-images) in a similar way as EHD. Finally, these three types of features are used to construct the feature set of database. The schematic diagram of the proposed face recognition approach is shown in Figure 3. All the features extracted from the face images will be represented through feature sets of numerical formats that can be easily used for matching.

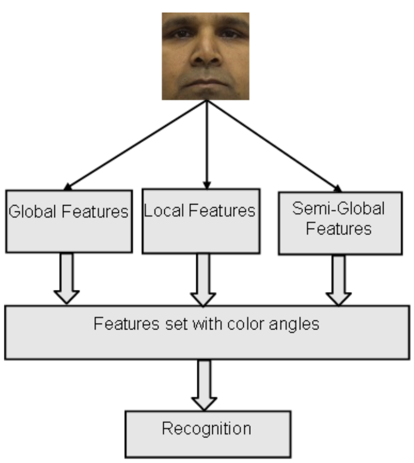

Fig. 3. Schematic diagram of proposed face recognition approach

For feature extraction, the single face images are first partitioned and grouped into three main categories of sub-images: Global, Semi-Global (SG) and Local (L) (Figure 2. The features of face images are extracted under seven different categories which is basically a combination of all G, SG and L regions. Based on the EHD method, the feature set using color angles consists of 3 global (G) angles, 48 (16 x 3) local (L) angles and 39 (13 x 3) semi-global (SG) angles for each image. Thus the size of the feature vector will consist of 90 elements.

The classification process in this approach is based on K-NN (k-nearest neighbor algorithm) in which k=1. During the querying process, the feature set of the query face image will be compared with the feature set of each face image in the database (1 to n). In other words, the face recognition will be done by matching the feature set of a query face image to all feature sets available in the database. The matching procedure is based on Euclidean distance measure. During the matching, the retrieved feature vector that presents a minimum distance among all comparisons will be considered as a correct match.

IV. Experiments and Results

A. Image preparation and Experiment details

The single face images that are used in our experiments were obtained from our own database. Our database consists of 138 different individuals each providing seven different images. They were obtained under two main categories based on illumination condition: controlled (CIL) and uncontrolled (UCIL) [6]. Under CIL, one set of images were acquired using a specific lighting system following the recommendations established by NIST [17]. Likewise, another set of frontal images were captured using just the illumination conditions provided by the fluorescent lamps of the room. Therefore this condition is denominated as uncontrolled condition (UCIL). For both categories, CIL and UCIL, we have obtained seven images, four from CIL and 3 from UCIL. They are classified as follows: CIL- Frontal, Face expression, Scale, Lateral illumination and UCIL-Frontal, Face Expression, Scale. In the same order, some sample set of images are displayed in the Figure 4. In both conditions, face expression images were obtained with smiling faces. Under CIL-Lateral illumination condition, the images are partially illuminated only on left side of the face. To capture the scale image, the camera was fixed at 1.75 meters distance from the face.

Similarly to the FR works found in the literature, our single face images are cropped into the the size of 550 x 550 pixels. In fact, before we crop the face images, they are normalized using the central coordinates of eyes as discussed in [6]. In all experiments, the faces from the first category, CIL-Frontal, are maintained as the base images for query purposes and images from other six categories are used as query images. We have run our experiments on a desktop computer with Intel Pentium IV 2.8MHz processor and 4GB memory under the Linux operating system.

Fig. 4. Sample single face images

B. Experiments

As we mentioned in Section I, our proposal is an unsupervised learning FR approach which is strictly based on image features. For query purposes, in all experiments, only CIL-frontal image features are kept as base features. Experiments are grouped into two categories: images under controlled and uncontrolled conditions. The first experiment is conducted with query images obtained under controlled condition as shown in Table I.

TABLE I. RECOGNITION RATE USING QUERY IMAGES UNDER CONTROLLED ILLUMINATION CONDITION

Features Combination	Expression (%)	Scale (%)	Lateral Illum. (%)
G+SG+L	65.22	76.09	10.14
G	25.36	23.91	1.45
SG	65.22	73.91	2.90
L	42.03	65.94	6.52
G+SG	66.67	73.19	4.35
G+L	46.38	70.29	6.52
SG+L	61.59	75.36	10.14

It can be observed from Table I that for images with facial expression, the maximum recognition rate is obtained from G+SG features combination. Although this combination highlights among others, the recognition rate of G+SG+L and SG combinations are also close to it. Similarly, with scaled images, the highest recognition rate is obtained from G+SG+L combination. The next best rate, 75.36%, is achieved using SG+L features. However the difference between both combinations is relatively small. From these results, we can roughly conclude that the high rate of recognition can be achieved only with the presence of features obtained from Semi-global region and in some times, with local or global. Finally, in the third image condition, with lateral face illumination, the recognition rates are relatively low in comparison with the previous two conditions. It points out the drawback of the proposed approach regarding illumination variation in the face. This conclusion confirms the affirmation of Belhumeur [1] that image variations due to illumination and viewing direction influence the recognition performance much more than the variations due to the change in face identity.

TABLE II. RECOGNITION RATE USING QUERY IMAGES UNDER UNCONTROLLED ILLUMINATION CONDITION

Features Combination	Expression (%)	Scale (%)	Lateral Illum. (%)
G+SG+L	21.01	15.22	17.39
G	3.62	2.90	2.17
SG	15.22	8.70	13.04
L	23.19	13.77	15.94
G+SG	11.59	9.42	13.77
G+L	25.36	15.22	21.01
SG+L	24.64	15.22	18.84

The next experiment was done to evaluate our approach with images acquired under uncontrolled condition. This condition reflects the real-world situation, because, in the security area, most of the single face images are normally captured from public places without the knowledge of individuals. In this experiment, base image features are matched with UCIL-Frontal, Expression and Scale images. The experimental result data is presented in Table II. More generally, the maximum recognition rate is obtained for all conditions using G+L features. Besides, the recognition rates are low in comparison with the previous experiment conditions expression and scale. Therefore, under uncontrolled conditions, color angles can not provide discriminative features sufficient enough for recognition of all images.

One more graphical analysis is illustrated in Figure 5 by selecting the best recognition rates obtained from aforementioned experiments with CIL and UCIL. From the plotted graph, we can finally conclude that the proposed method is suitable for just two conditions: CIL-Expression and Scale. It implies that a reasonable rate can be obtained only when there is a variation in face images under same illumination condition of base images.

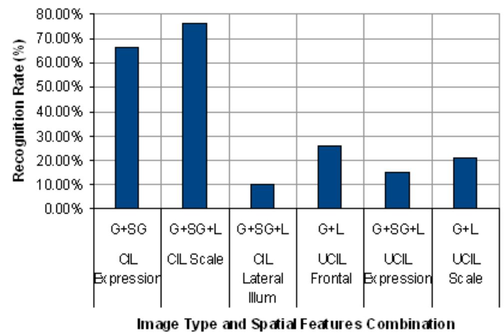

Fig. 5. Best recognition rates obtained

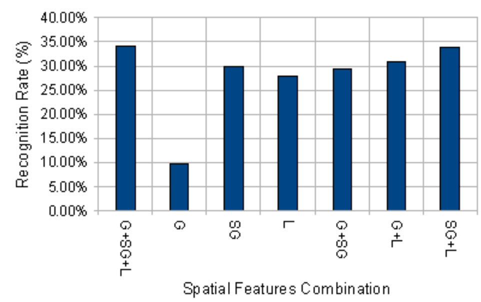

Fig. 6. Recognition rate using all single face images from both CIL and UCIL

We have done another experiment to check the invariant capacity of the proposed approach regarding scale using CIL-Expression and CIL-Scale face images. In this experiment, we have maintained the same base features obtained from the images of size 550 x 550 pixels and resized the query images to 275 x 275 pixels. According to the results shown in Table III, the difference in best recognition rates are -0.72% for CIL-Expression with G+SG and +3.62% for CIL-Scale images with G+SG+L.

The final experiment was conducted to check furthermore the performance of our proposal under complex condition. In this experiment, query images are constituted from six categories of face images totalizing 828 (6 x 138) images. The results are depicted in Figure 6. We can observe from the plotted graph that our approach can yield up to 34.18% with G+SG+L and SG+L features. In addition to this, only with G features, the recognition rate stays below 10%. Therefore, we can conclude that the global features alone do not have enough power to recognize the face images. We can note from

TABLE III. RECOGNITION RATES USING SCALED IMAGES (275 X 275 PIXELS)

Features Combination	Expression (%)	Scale (%)
G+SG+L	60.87	72,46
G	23.19	26,81
SG	66,67	71,01
L	39,13	60,87
G+SG	67,39	70,29
G+L	44,20	64,49
SG+L	59,42	71,01

the graph that some significant results can be obtained only in combination with other types of features, more specifically with SG and L features.

V. CONCLUSION

As an initial study, this work presents an unsupervised FR method using color angles with very few parameters and feature extraction scheme based on EHD. The entire experimental analysis was done on different combination of Global, Semi-Global and Local features. As stated before, the main objective of our work is to study the performance of color angles in FR application. From the experimental analysis using our database, we can conclude that the color angles approach is suitable for images captured under controlled condition with expression and scale. In addition to this, the influence of Semi-Global and Local features in the recognition rate is evident. More generally, we can affirm that best recognition rate can be produced only with the combination of minimum two types of features. It is important to emphasize that the results are obtained from an unsupervised learning approach which strictly depends on the extracted features. Another important point that should be reinforced in this work is that an image can be represented by only three color angles which produce a compact and representative feature set. The above experiments demonstrates that the proposed method can be applied to any kind of images and also with Semi-Global features. Based on the above considerations, we believe that this method still deserves a deep investigation. Our future works may include attempts to increase the recognition rate by applying some pre-processing or illumination compensation techniques or by combining other feature extraction methods. Furthermore, we plan to validate our approach with additional experimental analysis using other base images and FR methods.

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