2011 International Conference on Environment and BioScience
IPCBEE vol.21 (2011) © (2011) IACSIT Press, Singapore

Accurate Extraction of Iris and Eye Corners for Facial Biometrics

Ali Mollahosseini [+], António dos Anjos and Hamid R. Shahbazkia

DEEI, Faculty of Science and Technology, University of Algarve, Portugal

Abstract. An algorithm for accurate iris and eye corners extraction is proposed. This algorithm is suggested for facial symmetry analysis that, usually, requires a high ratio of accuracy. The method is based on estimating the iris according to the averaged gradient of the luminance component, and segmentation of the sclera by means of color segmentation. Using the sclera region, the extracted iris is refined and an ellipse is fitted. Finally, an adaptive dilation and erosion operation is used for extracting the caruncle. Experimental results show that the proposed approach can detect the iris of different colors accurately and also is very accurate in finding the eye corners.

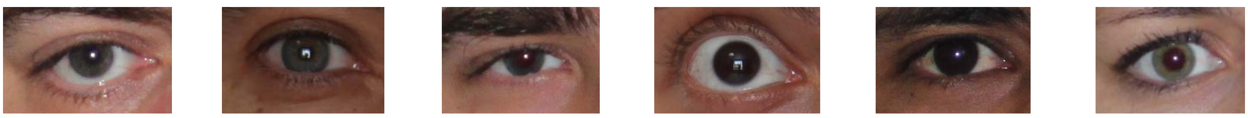
Keywords: feature extraction, eye corner, iris, sclera, biometrics

1. Introduction

Phenotypes are directly related to genotypes, therefore, some researchers believe that fluctuating asymmetry results from genetic variety, traumatic and immune disorders [1], and many studies have been made on the existence of a relation between facial asymmetries and personal instability [2], health signal [3], beauty [4] etc. However, these studies have usually been done by means of manually symmetric measurement and performed on symmetry distance of facial key points. Therefore, a complete application which models face and its elements, in high resolution images with precision, is highly demanded not only on symmetry research but also on other facial phenotype research.

Among other facial features, exact detection and extraction of eyes and their parts is extremely difficult. There are many methods for eye, iris and eye corner detection used in face detection, face recognition, biometric identification, eye modeling etc., which have their own accuracy, speed and characteristics. Fig. 1 shows some sample of eyes images. It is obvious that they have different: shape; iris color; red bloody spots on the sclera; similar grayscale intensity between the sclera and lower skin; similar color between the caruncle and skin; and different corner shape which is not always interpolative by contour edges with straight lines. These characteristics make any algorithm deal with many difficulties.

In this paper, we propose a new algorithm for the precise detection of iris and eye corners, which is part of an application for facial symmetry analysis. The rest of the paper is organized as follows: In Section 2 related work is briefly introduced and discussed. Our algorithm is described in Section 3, and results are discussed in Section 4.



(a) (b) (c) (d) (e) (f)

Fig. 1: Eye samples with different shapes, corners and irises colors.

2. Related Work

[+] Corresponding author. Tel.: +351-289800900 (Ext 7742).
E-mail address: ali.mollahosseini@gmail.com

Active Shape Models (ASM) [5] and Active Appearance Models (AAM) [6] are two of the most common methods for facial features detection. Original ASM tries to learn a model from training data and build a statistical model by selecting top eigenvalues. For fitting the model on test data, it uses the edge intensity in an iterative procedure. AAM is somehow like ASM, except it uses not only shape, but also texture information. Although ASM and AAM can be successful in fitting the model if starting from a proper initial position, they lack accuracy. Therefore, methods for facial features extraction usually perform locally on each part of the face if higher accuracy is needed.

In [7], eye detection methods have been categorized in four major approaches: shape-based approaches, feature-based methods, appearance-based methods, and hybrid models. Among these, shape-based and hybrid models are usually more accurate and able to extract the shape of the eye.

Shape based methods describe the open eye by a complex shape, which includes the iris and pupil contours and sometimes eyelids, and try to fit the model by minimizing an energy function. Yuille et al. [8] proposed a model of the eye which defines iris and eyelid borders by eleven parameters, and minimize five weighed energy functions of valley, peaks, edge and internal forces. Much more complex and accurate shape based methods have also been proposed by defining other energy functions or changing the definition of the template [9]. Problems inherent to model based methods are their sensitivity to the initial position, computational expense, and lack of robustness in the images having weak boundary between sclera and skin.

However, for exact eye biometric, definition of a template plays a more vital role. For example, in [8] two parabolic curves for the upper and lower eyelids have been defined as contour of the eye, that are horizontally symmetric but as it is clear from Fig. 1, most of the eyes have different shapes and curvature near the inner and outer corners (the eye inner corner is the corner which is near to the nose and the outer is the opposite). In [9], a template of the eye contour has been defined by inner and outer corners, and the corners formed by the occlusion of the iris and the upper eyelid, nevertheless, in some eyes the iris may not be occluded by the upper eyelid (Fig. 1-d). In addition, finding accurate inner and outer corners is also an extremely complex problem by itself. Furthermore, as final shape in both [8] and [9] don't contain the caruncle, these methods select the outer part of the sclera as inner and outer corners.

In [10] a variance projection function (VPF) has been used to locate the eye corner and iris of a model consisting of six landmarks (eye corner points and occlusion of the iris and both eyelids). In [11] a generalized projection function (GPF) has been proposed, of which VPF is a special case. These methods usually find eye location properly, but have an accuracy problem in the exact corner detection. In addition, iris is not always occluded by the eyelid (Fig. 1-a and 1-d) and, therefore, the shape will be incomplete.

In [12], approximate iris center is found from the red channel in the RGB color space. By means of a circular integral in the interval of $[-\pi/4, \pi/6] \cup [5\pi/6, 5\pi/4]$, changing the radius in the neighborhood of the approximated center, iris is found. For eye contour and corners, luminance "valley" points are selected and by the assumption that a corner is built from two straight lines, outliers are removed. However, that assumption is not accurate (Fig. 1-a, 1-b and 1-c) and, sometimes, the luminance valley in the lower eyelid is mistaken by eyelashes. For example, Fig. 1-a has high luminance in the lower narrow pink skin part, and a valley in the eyelashes.

In [13], the pupil is extracted from the H channel of the HSV color space, and the method proposed in [12] is used for iris detection. For the right and left corners, a Gabor filter bank is applied and an averaged filter is built from 80 images. This method is sensitive to training images, and has an accuracy problem in different caruncle shapes, especially in high resolution images.

3. Proposed Method

3.1. Iris Center Estimation

The proposed algorithm needs an approximated center of the iris. There are many methods for iris or pupil estimation, using intensity thresholding, Hough transform, color of the sclera [12], center value of the highlighted pupil [13], among others that find a proper center of the iris. In this article an approximated center of the iris, resulting from a simple Active Shape Model on face images, is used. The reasons for that are: firstly the face should be extracted from the image for every algorithm and secondly, one needs approximate regions of other elements of the face for the whole facial symmetry. As mentioned before the ASM method depends on its training dataset and lacks accuracy in estimating the center of the iris. However, the proposed algorithm is not sensitive to this issue.

3.2. Reflection Removal

After estimating the iris center, reflections caused by flash or direct natural light should be removed from the images. Regions with reflection are areas, or points, that have a sharp peak of light in the luminance components of the HSL color space. We simply select points with the intensity above a given threshold T, and empirically expand their region for 10%. Then, each reflected pixel is interpolated by four pixels as:

$$I(k) = \big(d_l I(r) + d_r I(l) + d_u I(d) + d_d I(u)\big)/(d_l + d_r + d_u + d_d) \quad (1)$$

Where $I(x_k)$ is the intensity value of pixel k, d_l, d_r, d_u and d_d denote the distance between point k and nearest left, right, upper and lower point outside the region, and $I(l), I(r), I(u), I(d)$ denotes their pixel magnitude respectively. Experiments show that, even if some non-reflected parts are selected, the result is small and does not affect the rest of the procedure.

3.3. First Estimation of the Iris

In this step the iris is estimated. The iris is a region having a darker area when compared to the sclera and, depending on the color of the iris, it can be darker or brighter than the skin. For finding the iris borders, n lines having an angle $\Theta_i = (i \times 2\pi)/n$, $i = 0,1,\ldots,(n-1)$ are extracted, starting from the estimated center with a maximum length of p pixels. In each line, the point having the maximum averaged absolute derivative is chosen. The absolute averaged derivative for the i^{th} pixel is calculated in following way:

$$g(x_i) = \left|\left(\sum_{j=1}^{m} L(x_{i-j}) - \sum_{j=1}^{m} L(x_{i+j})\right)/2m\right| \quad (2)$$

Where $L(x_i)$ denotes the luminance value of the i^{th} pixel, and m is the length of the support window used to calculate the average intensities involved in the gradient calculation. It is clear that the averaged absolute derivative is less sensitive to noise when compared to the normal derivative, and results in more precision than only applying a normal gradient to the pre-median filtered image. Experiments show that this estimation is robust to the color of the iris, but, because of occlusion with the eyelids, and huge differences between the pupil and iris, many of the detected points do not belong to the iris border. These outliers are removed in next steps.

3.4. Detection of the Sclera

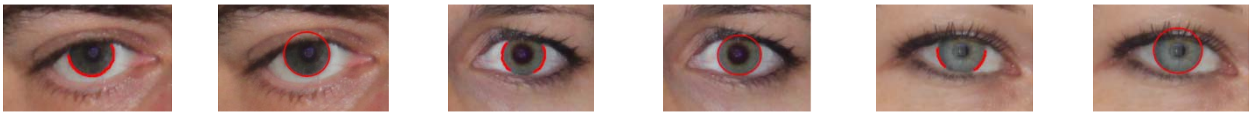
As sclera is the only white part in the eye, thresholding on pixel intensity or saturation level should suffice. However, defining the value for the threshold is a controversial issue. In addition, because of the existence of red bloody spots in the sclera, thresholding may fail. In this paper, a color segmentation method (JSEG), proposed in [14], is applied. The general idea behind JSEG is labeling each color after quantization, and clustering labels in a way that increases the ratio of 'between' and 'within' classes' distance. Then a region growing method is applied for obtaining the final segmentation. This segmentation is robust to texture variations, and the results are very promising when comparing with other tested methods. Fig. 2 shows typical results of JSEG. It is noticeable that it is able to extract the sclera's segment well. After segmentation, segments of the left and right sides of the sclera should be detected among the other segmented parts. Here we simply select the nearest segment to the estimated iris which has maximum average saturation level.

(a) (b) (c) (d) (e) (f)

Fig. 2: Some typical results of JSEG

3.5. Iris Extraction

Sclera segments are used for validation of the estimated iris points (Section 3.3), i.e. the point on lines that are not passing through the sclera parts are considered as outliers. For an accurate estimation of the iris, an ellipse is fitted to the non-outlier points by means of a non-iterative ellipse fitting method [15], which is fast and accurate. It should be mentioned that, despite the iris may be roughly approximated by a circle, it rarely appears as a true circle in the images [16]. Fig. 3-a, 3-c and 3-e show valid points on eyes with different irises' colors, and Fig. 3-b, 3-d and 3-f show ellipse fitted to them.



(a) (b) (c) (d) (e) (f)

Fig. 3: Valid irises points and fitted ellipses.

3.6. Inner Corner Enhancement

As samples in Fig. 2 show, it is expectable that the result of color segmentation does not cover the red caruncle in the sclera segment. Defining the exact region of this corner is not an easy task because its color is similar to the skin region's color. For finding the caruncle region, an adaptive local mean threshold with radius r is applied to the segmented sclera near the inner corner.

The resulting binary images contain the caruncle region inside the sclera part with a contour border around it. However, the border of the sclera (or black part) may not be connected, because the caruncle has a magnitude that is too similar to the skin, and therefore, the whole region of the caruncle may not be in the white regions of the binary image for being bigger than the local area radius. Therefore, we propose an adaptive erosion and dilation for refining the inner corner region, i.e. if the upper and lower black borders in the binary image is not connected, the image will be iteratively dilated by one pixel disk until it becomes connected, and the vice-versa with adaptive erosion if it is connected.

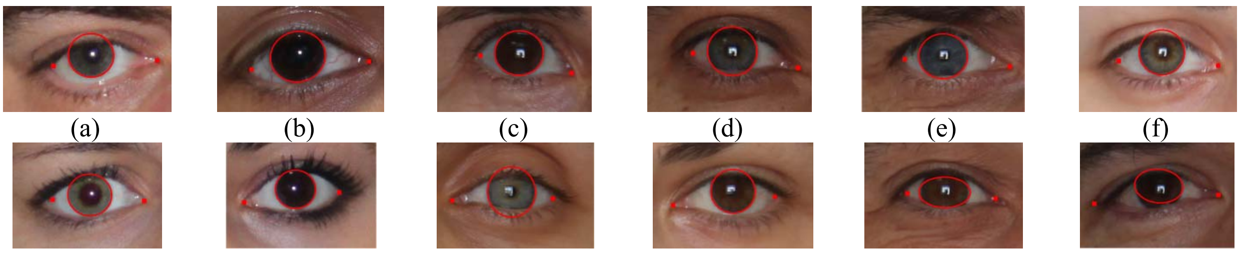
Fig. 4 shows sample iterations of the adaptive erosion. As shown in Fig. 4-a, color segmentation will not include the inner corner in the white part of the sclera. Fig. 4-b shows the result of the mean threshold with radius $r = 10$. Because the caruncle is brighter than its neighborhood, it should be considered as white. However, in this image it has a big area and, thus, a border will appear between the caruncle and the sclera. Fig. 4-c and 4-d show the iterative erosion until it loses connectivity (Fig. 4-e). At the end, the outer pixel of the white connected component which contains the sclera is considered as the inner corner (center of the circle in Fig. 4-f).

(a) (b) (c) (d) (e) (f)

Fig. 4: Iterations of the adaptive erosion and final inner corner extraction process.

4. Experimental Results

The proposed algorithm has been applied to images of approximately 75 individuals from different nationalities, taken in different days and conditions, and at the same focal distance, for the study of facial symmetry. The images are high resolution, and each pixel corresponds to less than 0.14 mm. Typical detection results of extracted iris and corners are shown in Fig. 5-a to 5-j.



(a) (b) (c) (d) (e) (f)

(g) (h) (i) (j) (k) (l)

Fig. 5: Results of applying the proposed method for eye corner extraction.

As it is shown, the proposed algorithm can find the iris, the outer and inner eye corners precisely. In rare poor results such as Fig. 5-k and 5-l, the sclera part found by color segmentation has problems and, consequently, affects the iris extraction procedure. This is usually because there is a really small difference between the lower pink skin and sclera, or huge bloody spot in the sclera. Manually evaluation of the iris extraction on our dataset indicates that 85.5% of irises have been extracted exactly without any error. For further research, the inner and outer corners of the eyes have been marked manually in all the images. The results of correct estimation, less than a given Euclidean distance, are presented in Table 1.

Table 1: Percentage of the correct estimation of inner and outer corners.

	3 px ≈ 0.4mm	**6 px ≈ 0.8mm**	**9 px ≈ 1.2mm**	**12 px ≈ 1.7mm**	**15 px ≈ 2.1 mm**	**21 px ≈ 2.9 mm**
inner corner	64.00%	80.33%	82.33%	86.00%	90.00%	94.33%
outer corner	22.66%	54.66%	73.33%	84.00%	89.33%	90.66%

5. Conclusion

In this paper a new algorithm for exact extraction of the eye corners and iris is proposed. As experimental results show, the algorithm extracts the iris independently from its color. Additionally more than 85% of the corners are detected with a very good precision.

This method is part of an application for facial symmetry analysis. It can be used for other facial feature analysis such as face and facial expression detection. Other algorithms for the other elements of the face such as lips, nose, and the face contour are also under research as we intend to produce a complete application for facial symmetry analysis.

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