A New Method for Iris Pupil Contour Delimitation and Its Application in Iris Texture Parameter Estimation

José Luis Gil Rodríguez [1] and Yaniel Díaz Rubio [2]

[1] Advanced Technologies Application Center, MIMBAS,
7a #21812 e/ 218 y 222, Rpto. Siboney, Playa. C.P. 12200,
Ciudad de la Habana, Cuba,
Office Phone Number: (+)537.271.4787, Fax number (+)537.273.0045
[2] Havana University, MES,
San Lázaro y Universidad, Vedado, Ciudad de La Habana, Cuba
jlgil@cenatav.co.cu, verol@ghost.matcom.uh.cu

Abstract. The location of the texture limits in an iris image is a previous step in the person's recognition processes. The iris localization plays a very important role because the speed and performance of an iris recognition system is limited by the results of iris localization to a great extent. It includes finding the iris boundaries (inner and outer). We present a new method for iris pupil contours delimitation and its practical application to iris texture features estimation and isolation. Two different strategies for estimating the inner and outer iris contours are used. The results obtained in the determination of internal contour is used efficiently in the search of the external contour parameters employing a differential integral operator. The proposed algorithm takes advantage of the pupil's circular form using well-known elements of analytic geometry, in particular, the determination of the bounded circumference to a triangle. The algorithm validation experiments were developed in images taken with near infrared illumination, without the presence of specular light in their interior. Satisfactory time results were obtained (minimum 0.0310 s, middle 0.0866 s, maximum 0.1410 s) with 98% of accuracy. We will continue working in the algorithm modification for using with images taken under not controlled conditions.

1 Introduction

Person's recognition using the iris texture has been an active investigation area in last time, because it is considered the most unique phenotypic visible feature in human face that determines their identity and offer biometric feature acquisition without invasion. Person's recognition with iris constitutes one of the main applications of the biometrics at the moment. In this process, the first step to do is the automatic texture iris localization which is characterized by a circular or quasi circular form limited by two borders (iris inner border and outer). The two limits with near circularity form are shown in Fig. 1. The iris inner border coincides with the contour of the eye's pupil and the iris outer border establishes the contact iris-sclera. The iris localization means isolate the iris texture information and play a very important role in the speed and

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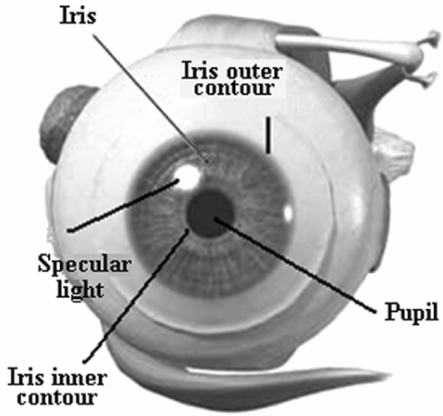

Fig. 1. Circular form of the Iris and pupil. See the iris inner and iris outer boundaries.

performance of an iris recognition system. With the iris texture area delimited we can begin to construct the iris code which is the base of an iris recognition system.

In this paper we present a new method to obtain both, the iris inner and outer border parameters in order to isolate the iris texture information. The proposed method uses different strategies for the parameters estimation of each one of the interest borders, and it uses the results obtained in the determination of the internal contour, in the most efficient search of the external contour parameters.

In order to compute the parameters of the iris inner contour we use the so called "Three Points Method" [1]. It uses well-known elements of analytic geometry and trigonometry, in particular, the determination of the parameters of the circumference bounded to a triangle. To obtain the parameters that define the external contour was used the Daugman's algorithm [2, 3]. This second algorithm receives the output from the first one and after that, search the abrupt gradient changes of a contour integral to find the iris – sclera border.

Portions of the research in this paper use the CASIA iris image database (version 1.0) collected by Institute of Automation, Chinese Academy of Sciences [4]. Our experiments show that the sequential combination of these two algorithms (Three Point Method + Daugman algorithm) during the texture isolation is precise, fast and efficient. The IrisCode formed with the iris texture obtained with our method offer good results during the eye matching applying a test of statistical independence on two coded patterns originated from the same or different eyes.

2 Parameters of the Iris Inner Contour

The iris inner contour coincides with the pupil's external frontier. Since it is assumed that the pupil possesses circular form, the parameters that should be obtained are, the pupil's center coordinates and its radio. To solve this task the algorithm of the three points was designed.

Three points algorithm
The algorithm receives a 256 grey tones image as input (Fig. 2a) and also a precision level P to define the accuracy for finding a point on the pupil contour. P is a threshold used to compare the variation of a texture feature between two points. Particularly, if these two points are located in different regions characterized with different textures, the value P will help us to know the texture change from one region to another.

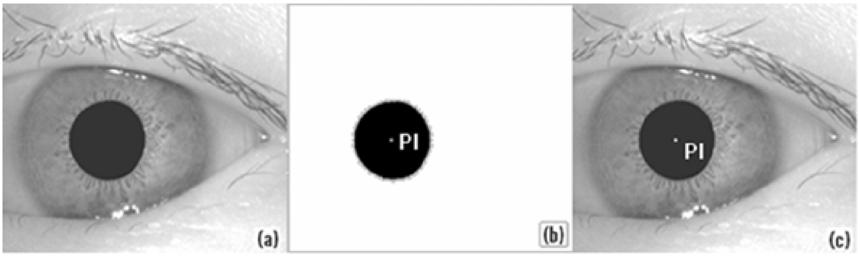

Fig. 2. Process in order to obtain the "interior point" PI using the T*hree points Method*. a) 256 grey tones image as input to the algorithm [3], b) binarized image showing the interior point PI, and c) original image showing the interior point PI already associated.

The general idea is very simple, beginning with an interior point of pupil, we will find three points on the circular contour of the pupil, named P1, P2 and P3 (Fig. 3). With these three points we have a triangle and also a bounded circumference to it. Finally, the bounded circumference parameters are calculated. The mentioned circumference is exactly the pupil's contour. The algorithm steps are as follows:

Step 1: Find the initial point PI located inside the pupil

The original image (Fig. 2a) [3] is binarized to isolate the pupil object from the rest of image. Working with the binarized image we determined which is the row F and the column C with bigger quantity of dark points continuously. A dark point is that whose grey level belongs to the lowest values of the scale [0 .. 255] and it will usually be smaller than 70. The intersection point of the row F and the column C will always be located inside the pupil and we take it as PI (Fig.2b). Taking PI as initial point, the algorithm will begin the search of the points P1, P2 and P3.

This approach is based on the fact that in the eye images, the pupil's grey levels are characterized to have a homogeneous or quasi homogeneous black color, and therefore, its binarization generates a new image with a black stain that represents the pupil on a white background and a grateful method of finding a point inside this stain is the one described above.

Step 2: Find the three points P1, P2 and P3 located on the circumference that defines the iris inner border

The search of these three points begins from the point PI found in the step 1. It is known that there is a very marked texture contrast between the pupil's regions and the iris. For this reason is appropriated to use a quantitative texture feature, as the standard deviation, to detect the frontier between the pupil and the iris. The standard deviation feature is calculated in a point considering a vicinity of 3x3 pixels size which is an habitual procedure in digital image analysis. The standard deviation varies very little inside the pupil, however it will suffer an instantaneous abrupt increasing once the vicinity 3x3 begin to take pixels belonging to the iris region.

The strategy to find the three points P1, P2 and P3 consists on following three trajectories with different addresses whose angles will be 0º, 120º and 240º. On each point of the trajectory we compute the difference between the standard deviation of initial point PI (DSPI) and the points of the trajectory (DSPC). A point whose difference is bigger than threshold P (DSPC - DSPI> P), it will be selected as point belonging to the pupil's contour. The trajectories are taking with these addresses in order to obtain the biggest quantity of information about the contour (Fig. 3).

Step 3: Find the circumference parameters of the iris inner contour

The circumference parameters are the radius and the coordinates of its center. Inside of this circumference the eye pupil is located.

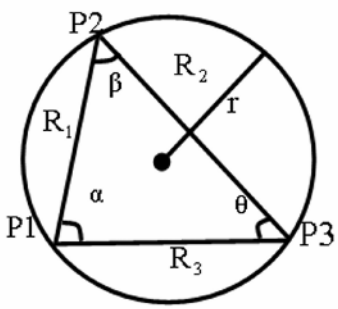

Fig. 3. Circumference bounded to the triangle P1-P2-P3 whose sides are R1, R2 and R3

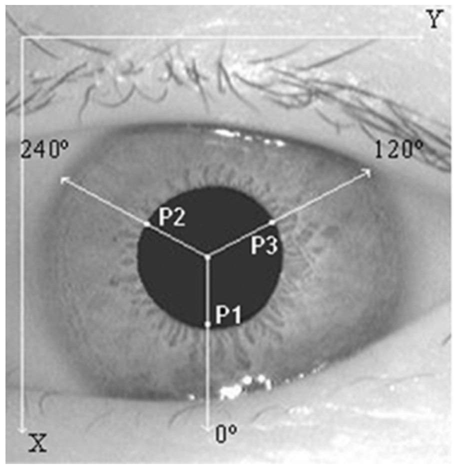

Fig. 4. Image from Fig. 2 (a) showing the points P1, P2 and P3 on the pupil's contour at orientation 0°, 120°, 240°

The points P1, P2 and P3 obtained in the step 2 are not aligned since they belong to the internal contour of the iris which is surrounded by the texture quasi - circular of the iris, that in general possesses irregular form. These three points allow to build a triangle of sides R1, R2 and R3 (Fig. 4) and on that triangle it is possible to define a bounded circumference of radio r that defines the eye's pupil and therefore it determines the extension of iris inner contour that we want to know.

Knowing P1, P2 and P3 the radius r is calculated using the equality settled by the sine law [4] that is enunciated in (1):

$$\frac{\overline{P_1 P_2}}{\text{Sen}\,\theta} = \frac{\overline{P_2 P_3}}{\text{Sen}\,\alpha} = \frac{\overline{P_3 P_1}}{\text{Sen}\,\beta} = 2r \tag{1}$$

Where,

$\overline{P_1 P_2}$: Segment from point P_1 to point P_2 (see Fig. 4).

θ, α and β : angles between the sides of triangle R2,R3; R1,R3 and R1,R2 respectively.

Therefore,

$$r = \frac{\overline{P_1 P_2}}{2 * \text{Sen}\,\theta} \tag{2}$$

If $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ are the positions coordinates of P_1 y P_2 then the longitude of segment $\overline{P_1 P_2}$ is obtained from (3):

$$\overline{P_1 P_2} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{3}$$

Calculation of angle θ:

The angle θ is comprehend between the segment R2 and segment R3 whose slopes are respectively m_2 and m_3, it can be calculated using the expression (4):

$$\theta = \left| \arctan\left(\frac{(m_2 - m_3)}{(1 + m_2 * m_3)} \right) \right| \tag{4}$$

The slopes m_2 and m_3 are obtained using the well-known formula (5):

$$m = \frac{y_2 - y_1}{x_2 - x_1} \tag{5}$$

When all the necessary data have been calculated, then applying the formula (2), the circumference's radius is obtained. That circumference defines the iris inner contour.

As the circumference is bounded to the triangle P1-P2-P3 (Fig. 4), then its center coincides with the median line intersection point of this triangle. The Fig. 5 shows the circuncenter point. The median line point of the segment $\overline{S}$ is the perpendicular straight line to it, and also crosses by its half point.

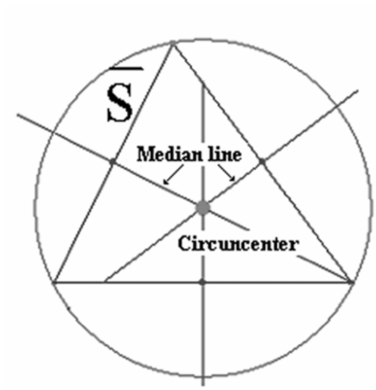

Fig. 5. The circumcenter point is the intersection point of two median line that are sides of a inscribed triangle in a circumference

The points P1, P2 and P3 define the segments $\overline{P1P2}$ $\overline{P2P3}$ $\overline{P3P1}$. We use two of these segments in order to find the median line M1 and M2 and their interception represents the circumference center.

To define the median lines we must find a point that belongs to each one and also their slopes. A point that belongs to the median line is the half point of segment which cuts it. The half point of a segment $\overline{XY}$ is possible calculate it as,

$$Pm = \left(\frac{x_2 - x_1}{2}, \frac{y_2 - y_1}{2} \right) \quad (6)$$

The slope of a median line is equal to the inverse of the opposed of the slope of the straight line that contains the segment of which is median line. As the straight lines slopes that contain the segment we already found, it is only necessary to calculate the inverse of its opposed one. We need obtain the intersection of two of the three possible median lines, and in that point it is located the circumference center which has the property of being bounded to the shown triangle. This point constitutes the center of the iris inner contour.

3 Parameters of the Iris Outer Contour

In order to obtain the iris external contour parameters we use the values of the iris inner contour parameters already computed above - radius and the circumference center coordinates - which offer an advantageous starting point for the Daugman algorithm expressed in (7).

$$\max_{(r, x_0, y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} \partial s \right| \quad (7)$$

The above inequation presents the Daugman' integrodifferential operator for determining the coordinates and radius of the pupil; where I(x, y) is an image such as Fig. 2a containing an eye. The operator searches over the image domain (x, y) for the maximum in the blurred spatial derivative with respect to increasing radius r, of the normalized contour integral of I(x, y) along a circular arc ds of radius r and coordinates (x_0, y_0). The symbol * denotes convolution and $G_\sigma(r)$ is a smoothing function such as a Gaussian of scale σ. The complete operator behaves as a circular edge detector, blurred at a scale set by σ, searching iteratively for the maximal contour integral derivative at successively finer scale of analysis through the three parameter space of center coordinates and radius (x_0, y_0, r) defining a path of contour integration [2].

$$\max_{(r, x_0, y_0)} \left| \frac{1}{\Delta r} \sum_k \left(G_\sigma(r-k) - G_\sigma(r-k-1) \right) \sum_{m=\theta_0}^{\theta_1} I\left[\left(r\cos(m) + x_0 \right), \left(r\sin(m) + y_0 \right) \right] \right| \quad (8)$$

The final discreet expression (8) describes the process that is used practically in the iris-esclera contact detection with the human eye image.

4 Work of the Integrodifferential Operator

Since the operator behaves as an edge detector, the form of the edge depends on the contour integral used in its expression. In our case an integral of a circular edge detector is used, because the objective is to detect the iris external contour. The operator solves a problem of optimization on three variables: radius r, and the coordinates of the circumference center (x_0, y_0) on the image domain. The operator looks for the maximum of the a partial derived function respect the radius r, a function represented by a circular integral of edge on an arc ds that depends on the radius, the coordinates of the circumference and the angles that limit the arc, and that it is convolved with a Gaussian function which parameter is sigma (scale).

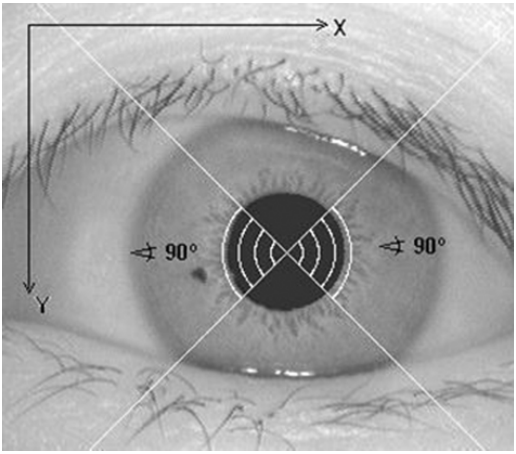

Fig. 6. Iris image showing the contour's integrals. The arches ds are of 90º centred in the axis X with address to positive infinite and negative infinite.

The contour's integral on an arch ds, defines the sector of the contour where it is wanted to find the value of the integral one. In our case, the arches ds are of 90º centred in the axis X with address to positive infinite and negative infinite. The objective of the angles in this address is to avoid the eyelid interference. The Fig. 6 shows the location of the coordinated system, as well as the successive arches that are explored, modifying the radius from inside toward outside, in order to detect the iris's limits.

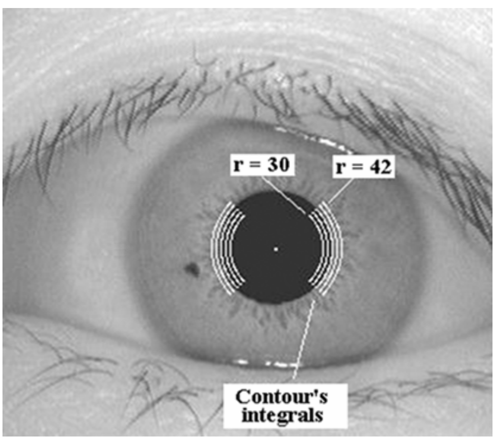

Fig. 7. Iris image showing the contour's integrals computed with r = 30, 33, 36, 39 y 42

The normalization of the contour's integral is applied to have an idea about the intensities half value at the points located on the contour.

The differential of the normalized contour's integral estimates the speed with which it changes their half value, being of interest their maximum values, because they indicate an abrupt change in the averaged intensities of the points among contours of different radios and therefore the sure detection of a border in the radial direction. (See Fig. 7 and Table 1).

The convolution operation with a Gaussian function, whose scale parameter is sigma, has the objective of pondering the obtained values during the differential function evaluation, giving higher importance to the values near to the radius with which the operator is evaluated.

Table 1. Daugman operator values computed from the pupils' center up to the iris border. The abrupt change of the texture properties between the pupil–iris contact and the iris-sclera contact guarantees the iris limits detection.

Radius r	30	33	36	39	42	45
Operator	0	0	20.14	60.41	6.84	6.45

5 The Optimization Problem

The solution to the maximization problem, begins selecting a point inside the pupil that is a center in relation to the iris outer boundary. This initial point is assumed as the pupil's center, previously obtained. Once the initial point is defined, a radius optimization begins. The processes continue changing by approximation, the outer boundary center point, until the max value is obtained.

The radius optimization is implemented increasing the radius in a certain step according to the precision needed to define the outer boundary. The used value is 2 pixels. The strategy for the displacement of the center coordinates is to move it with a certain step, following the vertical and horizontal addresses, 0º, 90º, 180º and 270º. This strategy appears in Fig. 8. The stop condition in the center optimization is the occurrence of three successive iterations without reaching a maximum value of the maximization expression, while in the optimization of the radius the integrals are calculated for all possible radius and selecting the best result.

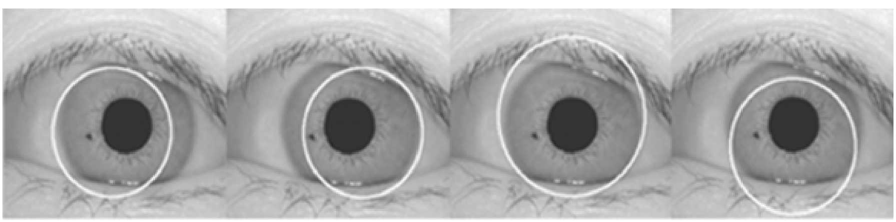

Fig. 8. Iris images belonging to optimization process of the external contour applying Daugman operator. Displayed images show different stages of the not concluded optimization processes.

6 Experimental Results

In order to compare the results of our method with another already published, the CASIA Iris Image Database was adopted. It includes 108 classes and each class has 7 iris images captured in two sessions with a time interval about a month. So there are totally 756 iris images with a resolution of 320x280 pixels. As it is know, in the CASIA iris images some irises are occluded by eyelids and some eyelids are out of the image window. In another way, some eyelash is inside the irises. The experiments are performed in Matlab (version 7) on a PC with P4 2.6 GHz processor and 512Mb RAM.

The Fig. 9 shows an iris images sequence where the inner and outer borders, delimiting the iris's texture, were detected using the Three Point Method combined with the Daugman operator.

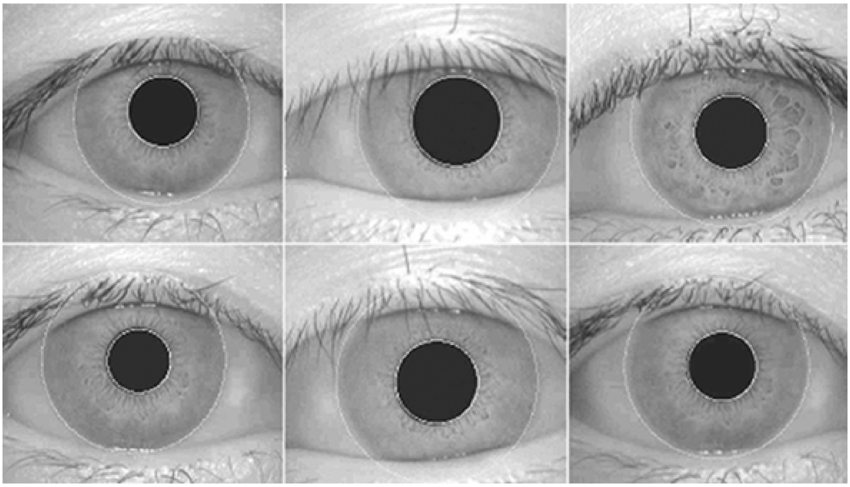

Fig. 9. Results of the proposed method for pupil's circle detection and its combination with the Daugman operator for iris-sclera circle detection

We studied the whole CASIA Iris Image Database in order to obtain the following statistics. In Table 2, the accuracy is the result of eye observations, because we have not developed a method to evaluate quantitatively the boundaries localization results.

Table 2. The localization results of inner and outer iris boundary

Boundary	Accuracy	Mean time	Min. time	Max. time
Inner boundary localization	100%	0.0198 s	0.0150 s	0.0320 s
Inner and outer boundary localization	98%	0.0576 s	0.0160 s	0.3260 s

Observing the accuracy from Table 2, we can see: a) 100% iris inner boundary localization results, this means all the 756 images precisely detected; b) some false localization results that mean several pixel displacement from de true position of contact iris – sclera.

Because there are some special tricks unknown in Daugman, Wildes and Cui' methods, we do not compare with them, but compare the localization results of inner and outer iris boundary published in [5] and the results are listed in Table 3. We also include our results.

Table 3. Comparion with other algorithms

Method	Accuracy	Mean time	Min. time	Max. time
Daugman	98.6%	6.56 s	6.23 s	6.99 s
Wildes 1 [6]	99.9%	8.28 s	6.34 s	12.54 s
Wildes 2 [7]	99.5%	1.98 s	1.05 s	2.36 s
Cui et al. [5]	99.54%	0.2426 s	0.1870 s	0.3290 s
Proposed	98.0%	0.0576 s	0.0160 s	0.3260 s

Note that the accuracy is 98% with the proposed method, lower than the others. However it is the faster, with a 4 times higher speed than the best.

The theoretical reasons of the high speed and robustness of the proposed method are the follows:

1. Pupil detection uses circle fitting, which use the solution of the "Three Point Method". The method makes full use of the local texture variation and doesn't use any optimization procedure. For this reason it can reduce the computational cost greatly.
2. The outer boundary localization combine the output of the "Three Point Method" as input to the integrodifferential operator taking advantage in order to search the abrupt gradient changes of a contour integral to find the iris – sclera border.

Our method combines two different strategies, texture variation (pupil – iris) and edge detection (iris – sclera) to localize the iris zone.

7 Conclusions

Iris localization serves not only computing the position of the iris, but also detecting the important iris texture area, useful to develop the IrisCode information. In this paper we propose an algorithm to localize iris based on pupil and iris texture segmentation. The pupil local texture has a great contrast with the iris texture, this fact is very important for iris localization and at the same time, it is useful to save computational time with our "Three Point Method". The pupil detection using it, provide the initial parameters set (radius, $x_{0,}$ y_0 of the pupil circle) to the Daugman operator, which takes advantage using these values in order to detect the iris – sclera boundary. The experimental results show the promising performance and robustness of the method. It is fast and we hope a good behaviour in a real time iris recognition system. In the near future, we will continue working to improve the accuracy of the inner and outer boundary localization. We also must do experiments with images taken under not controlled condition, different of CASIA Iris images Database.

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