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Iris Segmentation: a survey

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Abstract: *The use of biometric systems has been increasingly encouraged by both government and private entities in order to replace or improve traditional security systems. Iris recognition biometric systems have proved to be efficient at personal recognition with highest recognition accuracy. This paper presents an up-to-date survey of iris segmentation algorithms that had been developed in literatures. It discusses the centrality of segmentation stage to effectiveness of iris recognition system. It identifies the methods used in the segmentation algorithms, database(s) on which the algorithms were used, the accuracy of the method and some noticed limitation(s) of the reviewed algorithms. Through this, it is able to identify the gaps for further researches in the field of application of iris recognition system in computer security. It was discovered that much work has not been done on black iris segmentation.Researchers are hereby encouraged to develop iris segmentation algorithm that can effectively localise black iris.*

Key words: *computer security, iris, iris database, iris recognition, iris segmentation, noise.*

I. Introduction

With increase in emphasis on security nowadays, biometric technologies are becoming much more important than ever [1]. In particular, iris recognition in recent years receives growing interests. Iris pattern recognition is unique to each subject,remain stable throughout life and offers several distinct advantages[2; 3; 1]. Especially, it is protected by the body's own mechanisms and impossible to be modified without risk. Thus, iris is reputed to be the most accurate and reliable for person's identification [5] and has received extensive attentions over the last decades.The degree of freedom of iris textures is extremely high, the probability of finding two identical irises is close to zero therefore, iris recognition systems are very reliable and could be used in most secure places.

Iris segmentation is to locate the valid part of the iris for iris biometrics [7], including finding the pupillary and limbic boundaries of the iris, localizing its upper and lower eyelids if they occlude and detecting and excluding any superimposed occlusions of eyelashes, shadows or reflections. The centrality of segmentation to effectiveness of any iris recognition system cannot be overemphasized[4]. It determines effectiveness of the system [8].Two well-known iris segmentation approaches are attributed to Daugman and Wildes. Daugman developed integro-differential operator to find circular pupil and limbus boundaries. It can be interpreted as a circular edge detector, which searches, in a smoothed image by Gaussian filter, the parameters of a circular boundary along which the integra derivative is maximal [2]. Wildes proposed a two-stage iris segmentation method: a gradient based intensity image, and next the inner and outer boundaries are detected using Hough transform [9]. It is reported that most failures to match in iris recognition system result from inaccurate segmentation [10].

The contents of this paper are thus arranged: section 2 elucidates on available iris segmentation techniques. Section 3 identifies some available public iris databases that can be used for iris system validation. Section 4 gives an exhaustive literature review of iris segmentation methods discussed in literatures/researches while 5 and 6 discuss some limitations and areas of future researches respectively.

II. Existing iris segmentation techniques.

The review of iris segmentation in literatures reveals two major approaches: Daugman'sintegro-differential operator and Hough's transform-based. Nearly all existing methodologies use one of these two or their variants for segmentation.

2.1 Daugman's method

Daugman presented the first approach to computational iris recognition, including iris localization [2]. An integro-differential operator is proposed for locating the inner and outer boundaries of an iris. The operator assumes that pupil and limbus are circular contours and performs as a circular edge detector. Detecting the upper and lower eyelids is also performed using the Integro-differential operator by adjusting the contour search from circular to a designed accurate [2]. Integro-differential operator is defined as:

$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi r} \, ds \right| \qquad (1)$$

where$I(x,y)$is an image containing an eye. The integro-differential operator searches over the image domain (x,y) for the maximum in the blurred partial 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 center co-ordinate (x_0,y_0). The symbol $*$ denotes convolution and $G_\sigma(r)$ is a smoothing function such as a Gaussian of scale (σ) and is defined as:

$$G_\sigma(r) = \frac{1}{\sqrt{2\pi r}} e^{-\frac{(r-r_0)^2}{2\sigma^2}} \qquad (2)$$

The integro-differential operator behaves as a circular edge detector. It searches for the gradient maxima over a 3D parameter space, so there are no threshold parameters required as in the Canny edge detector. Daugman simply excludes the upper and lower most portions of the image where eyelid occlusion is expected to occur.

2.2 Wilde's method

Wildes had proposed an iris recognition system in which iris localization is completed by detecting edges in iris images followed by use of a circular Hough transform to localize iris boundaries [9]. In a circular Hough transform, images are analyzed to estimate the three parameters of one circle (x, y, r) using the equations:

$$H(x_0, y_0, r) = \sum_i h(x_i, y_i, x_0, y_0, r) \quad (3)$$

where(x_i, y_i) is an edge pixel and *i* is the index of the edge pixel

$$h(x_i, y_i, x_0, y_0, r) = \begin{cases} 1 & if\ g(x_i, y_i, x_0, y_0, r) = 0 \\ 0 & otherwise \end{cases}$$

where

$$g(x_i, y_i, x_0, y_0, r) = (x_i - x_0)^2 + (y_i - y_0)^2 - r^2 \quad (4)$$

The location (x_0, y_0, r) with the maximum value of $H(x_0, y_0, r)$ is chosen as the parameter vector for the strongest circular boundary. Wildes' system models the eyelids as parabolic arcs. The upper and lower eyelids are detected by using a Hough transform based approach. The only difference is that it votes for parabolic arcs instead of circles. One weak point of the edge detection and Hough transform approach is the use of thresholds in edge detection. Different settings of threshold values may result in different edges that in turn affect the Hough transform result significantly.

2.3 Camus and Wildes' method

Camus and Wildes (2004) described an algorithm for finding a subject's iris in a closed-up image. In a way similar to Daugman's methodology, their algorithm searches in anspace for the three circumference parameters (center(x, y), radius (r)) by maximizing the function

$$C = \sum_{\theta=1}^{n} \left((n-1)\|g_{\theta,r}\| - \sum_{\emptyset=\theta+1}^{n} \|g_{\theta,r} - g_{\theta,r}\| - \frac{I_{\theta,r}}{n} \right) \quad (5)$$

The method is very accurate on images where the pupil and iris regions' intensities are clearly separated from the sclera ones and on images that contain no reflections or other noise factors. When dealing with noisy data, the algorithm's accuracy deteriorates significantly [11].

2.4 Martin-Roche methods

This methodology, proposed by Martin in a way similar to Daugman's. it receives a grey-scale image, applies the histogram stretch and tries to maximise the average intensity differences of the five consecutive circumferences, defined as

$$D = \sum_m \left(\sum_{K=1}^{5} (I_{n,m} - I_{n-k,m}) \right) \quad (6)$$

where$I_{i,j} = I(x_0 + i\Delta_r \cos(j\Delta_\theta), y_0 + I\Delta_r \sin(j\Delta_\theta))$. Δ_r and$\Delta_\theta$are the increments of radius and angle, respectively, and is the image intensity[12]. In practical sense, this method find three N^3circumference parameters (center(x, y), radius (r)), where the intensity difference between five successive circumferences is maximal.

III. Various Public Iris Databases and their limitations

There are many various public databases available for verification of performance of iris recognition systems. It include: *CASIA:* this is the most widely used iris image database, having different distinct versions (up to version 4.) the first version has one major advantage: the authors pre-processed the images such that the pupil region is identified and filled with black pixels. The database is not captured under varied light intensity. *BATH:*images from this database are quite similar to the one contained in MMU they have very similar characteristics and few noise factors, almost exclusively related with small eyelid or eyelashes obstructions.*MMU:* images from this database present few noise factors and their characteristics are also very homogenous. A fixed image-capture process must have been followed, clearly simulating a cooperative environment.*ICE:UPOL:WVU:UBRIS:Lions institute:* this is the most heterogeneous iris database images: thus it is useful for heterogeneous iris recognition system. All images were captured with optometric framework resulting in optimal images with extremely similar characteristics (Dobes and Machala,).

IV. Literature review on iris segmentation

Daugman proposed an integro-differential operator for localizing iris regions along with removing the possible eyelids noises [2]. From the publication, we cannot judge whether pupil and eyelash noises are considered in his method.
Kong developed a noise detection model for iris segmentation. Whereas pupil noises have not been considered in the model, secondly noise regions were directly segmented from original iris an image, which is time-consuming, and thirdly, it has not been tested based on the prevailing recognition algorithm on a large iris dataset [13].

Daugman proposed an Integro-differential operator for locating the inner and outer boundaries of iris, as well as the upper and lower eyelids. The operator computes the partial derivative of the average intensity of circle points, with respect to increasing radius, *r*. After convolving the operator with Gaussian kernel, the maximum difference between inner and outer circle will define the centre and radius of the iris boundaries. For upper and lower eyelids detection, the path of contour integration is modified from circular to parabolic curve [2;3].

Wildes used edge detection and Hough transform to localize the iris. Edge detector is applied to a grey scale iris image to generate the edge map. Gaussian filter is applied to smooth the image to select the proper scale of edge analysis. The voting procedure is realized using Hough transform in order to search for the desired contour from the edge map. The center coordinate co-ordinate and radius of the circle with maximum number of edge points is defined as the contour of interest. For eyelids detection, the contour is defined using parabolic curve parameter instead of the circle parameter [9].

Kong *et al.*,proposed Gabor filter and variance of intensity approaches for eyelash detection. The eyelashes were categorized into separable eyelashes and multiple eyelashes. Separable eyelashes are detected using 1D Gabor filters and multiple eyelashes were detected using variance of intensity. Connective criterion was used in their model. A low output value was obtained from the convolution of the separable eyelashes with the Gabor filter. For multiple eyelashes, the variance of intensity in a window is smaller is smaller than a threshold, the center of the window was considered as the eyelashes [13].

Boles and Boashah, Lim and his associates, and Noh mainly focused on the iris image representing and feature matching, and did not introduce the information about segmentation [14;15;16].

In 2002, Tisse*et al.* proposed a segmentation method based on integro-differential operators with a Hough Transform. This reduced the computation time and excluded potential centers outside of the eye image. Eyelash and pupil noises were also not considered in his method [17].

Ma, in their algorithm processed iris segmentation by simple filtering, edge detection and Hough Transform. This made the overall method very efficient and reliable. There was no method proposed for processing eyelash and pupil noises. Their algorithm was able to detect noise due to pupils and eyelashes [18].

Cui *et al.*,(2004)decomposed the iris image using Haar wavelet before pupil localization. Modified Hough's algorithm was used to obtain the centre and radius of pupil. Iris outer boundary was localized using an integral differential operator. Texture segmentation was adopted to detect upper and lower eyelids. The energy of high spectrum at each region is computed to segment the eyelashes. The region with high frequency is considered as the eyelashes area. The upper eyelashes are fit with parabolic arc. The parabolic arc shows the position of the upper eyelid. For lower eyelid detection, the histogram of the original image is used. The lower eyelid area is segmented to compute the edge point of the lower eyelid and the lower eyelid is fit with edge points [19]. The same year, Huang *et al.*, published an iris segmentation method which fussed edge and region information for noise detection. Edge information was obtained based on phase congruency by a bank of Log-Gabor filers whose kernels are suitable for noise detection [20]. Threshold method was used to exclude noise due to pupil and eyelashes because they both have high intensity values.

Black hole search method was proposed by Teo and Ewe to compute the center and area of a pupil. Since the pupil is the darkest region in the image, this approach applies threshold segmentation method to find the dark areas in the iris image. The dark areas are called "black holes" [21]. The center of mass of these black holes is computed from the global image. The area of the pupil is the total number of those black holes within the region. The radius of the pupil can be calculated from the formula of a circle, (2005).

Proenca and Alexandreproposed an iris segmentation method which aimed at detecting noise due to eyelashes and pupils. Their algorithm aims at proper segmentation of iris captured under non-cooperating condition from the subject. The method proposed a pre-processing method which applies the fuzzy-k-means clustering algorithm on the position and intensity feature vector of the iris image followed by Hough transform.Tuceryan textural method (Tuceryan, 1994) was employed on UBIRIS database and then modified it to appropriately segment iris images. Representing the images as 3D ((x,y),z) (pixel position + intensity), information about the spatial relations in the image as well as about the individual properties of each pixel were preserved [22]. The moments f_{20} andf_{02}proved to identify the iris border but also produced considerable noise regarding the eyelid region.

Richard *et al.*, developed an iris segmentation approach which was able compensate all four types of noises in order to achieve higher accuracy rate [23]. It consists of four parts: firstly, the pupil is localized using threshold and Circular Hough Transform methods. Secondly, two search regions including the outer iris boundaries are defined to locate the outer iris. Next, two search regions are selected based on pupil position to detect the upper and lower eyelids and finally, threshold is implemented to remove eyelashes, reflection and pupil noises. The method's performance on CASIA iris database was found to perform as high as 98.62% accuracy.

Peihua and Xiaomin presented an incremental method for accurate iris segmentation. The algorithm works in two stages: first roughly locate a square region that contain pupil, followed by Canny edge detection plus Hough transform for accurate pupillary boundary localization; secondly roughly localizing two annulus sectors in which limbic boundary is finely positioned. The proposed method is not without limitations. Some limitations of the approach include: closure (complete or almost) of the eye; poor quality of the images due to variation of illumination, bad focus or noise; finally, inaccurate rough localization of pupillary boundary [1]. Nakissa and Mohammed developed a stepwise level set approach for iris segmentation of an iris recognition system [8]. Though it has many advantages on all existing methods, the lack of point correspondence is one of its important drawbacks.Yahyah and Nordin proposed iris segmentation by direct least squares fitting of ellipses [24].

Donida and his research group developed agent-based pupil localization (MAPL) and multiple views iris boundaries iris refining (MVBR) method for iris localization [25]. The present method was advancementon their previous work [26] method which employed an ANN method to locate pupil area. Donida and Scotti identified the iris boundaries by searching the peculiar pattern transitions in the radial gradient image around an observation point.In the present work, they used a set of *N* observation points and properly fused the extracted information in order to better interpolate the inner and outer iris boundaries. The algorithm was applied on two major public iris databases (CASIA and UBIRIS version 2). The segmentation algorithm error rate was 2.9% and it did not have eyelash location and reflection removal algorithm.

Kheirolahy*et al.,* (2009) used optimized color mapping to make pupil region clear and easy to segment and they achieved 98% recognition accuracy by applying optimized color mapping [27]. The algorithm worked well in most of the eye models.

Abdulsamad and Nordin employed Chan-Vese active contour method to extract the iris from the surrounding structures [28]. The proposed algorithm is such that the image is loaded, reflections are identified using inpainting technique, adaptive boosting (AdaBoost)-Cascade Detector is adopted to detect iris region and finally Chan-Vese active contour method is applied to find the boundaries of the iris.When employed on UBIRIS iris database against some other iris segmentation methods [3; 9], it was discovered that it performed better with error rejection rate (ERR) of 5.5068. (Daugma [16.8635];Wildes [33.8226]).

Puhan and Kaushalramdeveloped an efficient segmentation algorithm using Fourier spectral density [29]. The Fourier spectral density computed for a pixel indicates the energy level in its neighbourhood. In an iris image, the energy level at pixels in sclera region is higher than the iris pixels due to the white sclera region. Thus making it possible to discriminate the sclera region from the iris. The specular reflections were removed by performing connected component labelling and threshold on the image.

Mahmoud and Ali proposed an iris segmentation algorithm which was able to localise an iris image in an unconstrained environment [30]. After pre-processing stage, circular Hough's transform was utilised for localizing circular area of iris inner and outer boundaries. Linear Hough transform was used to localise the boundaries between upper and lower eyelids occluding the iris. The algorithm was applied on CASIA iris database and gave an accuracy of 97.5%. Efficiency of the algorithm is not too good with varied illumination as we have in BATH database.

Sastr and Durga, developed an enhanced iris segmentation method that allows real-time iris recognition system [31]. This reduced iris segmentation time further allows high resolution iris images to be used thereby enhancing recognition accuracy of the system. His main target was to reduce the segmentation time.All occlusion were removed using Sobel filter both in vertical and horizontal directions. The inner and the outer boundaries were assumed to be a circle. Its recognition accuracy was found to be 99%.

V. Limitations of identified algorithms

Daugman, identified the following facts about human iris which must be bore in mind while developing iris recognition system [7]. The inner and outer boundaries are not perfect circle, active contour can be used for appropriate boundary determination. Secondly much greater demands are coming as nations are thinking of biometric based security system. The presence of outlier members of the populate who for various reasons may have non-standard eye appearance (e.g., non-round iris, coloboma, oddly shaped pupil, drooping eyelids, or much eyelash occlusion) or who simply have difficulty presenting to the camera (e.g., nystagmus or deviated gaze).

From all the aforementioned works, several interesting points can be concluded as follows:

- All these methods including Kong's detected all possible noise regions directly from original iris images. It would be more time-consuming if one want to accurately detect all possible noises;
- Although Kong's model has introduced how to accurately detect eyelash and reflection noises, it has not been tested based on the prevailing recognition algorithm on a large iris database;
- No method considered how to accurately segment the iris regions and the pupil regions when the shape of the pupil boundary cannot be approximated as circles;
- No method has been proposed to detect all four kinds of noises, namely eyelashes, eyelids, reflections and pupil in a single algorithm;
- Inner and outer boundaries, eyelashes and eyelid are detected in different steps, causing a considerable increase in processing time of the system;
- Usually, the inner and outer boundaries are detected by circle fitting techniques. This is a source of error, since the iris boundaries are not exactly circles.
- The results of the circle fitting method are sensitive to the image rotation, particularly if the angular rotation of the input image is more than 10^0.
- In noisy situations, the outer boundary of iris does not have sharp edges.
- After detecting iris boundaries, the resulted iris area is mapped into a size independent rectangular shape area. The rectangular normalization is having its disadvantages (Mahboubeh and Abdolreza, 2011).
- Critical examination of African iris reveals an improperly differentiated boundaries which will require a modification of some of the existing segmentation algorithm(s) for their proper recognition.

VI. Conclusion

Advancement of iris segmentation algorithm for black iris is needed urgently as world globalization and inter/intra boarder movement increases in this century. Development of public black iris database will also be of great importance to enhance development in iris biometric researches.

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