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State-of-the art iris segmentation methods: A Survey

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Abstract— In today's world scenario where security and privacy are the primary concern, the systems that are developed must employ accurate techniques to achieve this. The biometric recognition provides automated verification of individuals based on unique characteristics processed by an individual. The commercial biometric systems are popular and are used extensively, but not restricted to, in the fields of banking services, access secured database, airport surveillance, access control in the boarders etc. Biometric systems are developed based on the physical or behavioural unique characteristics of the individuals. Iris recognition system is the most reliable and accurate, which is grabbing the attention of the researchers now a day. The iris epigenetic patterns are unique, stable and accurate when compared with the other biometric traits. The iris recognition system is a very good research topic in the areas digital image processing, computer vision & pattern recognition. The segmentation or localization is a very crucial stage, because the system's accuracy highly relies on segmentation. In this paper, detailed state-of-the-art segmentation techniques have been presented.

***Keywords*—**Iris segmentation, Biometrics, Recognition system, Computer vision

I. INTRODUCTION

The automated methods used for recognizing/identifying individuals based on human physiological or behavioural characteristics are biometrics. Physiological characteristics are related to the shape of the body. Whereas, behavioral characteristics are connected to the patterns of behaviour of a person. The traditional methods include passwords, a card key or PINs are not reliable than biometric identifiers based on physiological or behavioural characteristics[1]. The earliest form of biometrics in the 19th century developed by Alphonse Bertillon, which is known as Bertillonage, for identifying criminals, is based on human anatomy which involves recording shapes of the body including scars, birthmarks, etc. the Bertillonage is later replaced when the idea of fingerprints as a means of individual identification has emerged on the scene. The idea of fingerprints as a biometric trait is first published by Dr Henry Faulds in the year 1880[2]. The first physiological characteristics based fingerprint identification system was first developed and implemented by Edward Henry in the year 1897. This new system of biometric-based on fingerprints was accepted more reliable than Bertillonage.

Table 1 The comparison of biometric traits

Biometric (trait)	Universality	Uniqueness	Permanence	Collectability	Performance	Acceptability	Circumvention
Iris (iris patterns)	H	H	H	M	H	L	H
Fingerprint (ridges & valleys)	M	H	H	M	H	M	H
Retina (blood vessels)	H	H	M	L	H	L	H
Signature (writing style)	L	L	L	H	L	H	L
Voice (tone or timbre)	M	L	L	M	L	H	L
Hand geometry (shape)	M	M	M	H	M	M	M
Face (facial features)	H	L	M	H	L	H	L

* H – High, M – Medium, L – Low

J. H. Doggort and F. H. Adler in the year 1949 and 1953 respectively, had stated that just like fingerprints, iris of an eye also exhibit distinct variations in every sample examined[3]. Later in the 1980s, L. Flom and Aran Safir patented the conjecture of Adler's & Doggart's that the iris could serve as a biometric trait[4]. Then in 1994 Daugman's algorithms depending on the failure of a test of statistical independence for pattern recognition was patented[5]. He also developed the first iris recognition system and gave the first live demonstration.

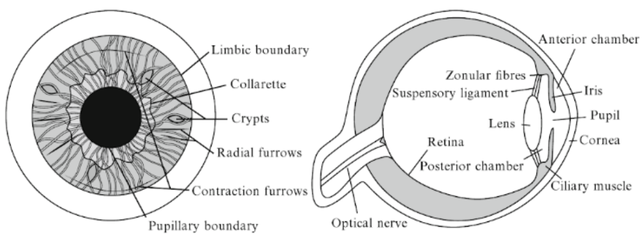

Figure 1 The anatomical structure of an eye

The selection of particular biometric for individual identification for a specific application is based on a weighting of several factors such as universality, uniqueness, permanence, measurability, performance, acceptability and circumvention. No single biometric system is available that fits all the factors mentioned above. Table 1.1 illustrates the comparison of biometric technologies. Among the biometric technologies available, the iris biometric technology is the most accurate modality, because iris complex random patterns are unique and stable they do not change throughout a person's lifetime[6]. The iris patterns are so distinctive and exhibit variations in every person examined. Hence, the Iris recognition is based on the fact that the human iris contains unique features and even genetically identical individuals have completely independent iris textures. The anatomical structure of an eye is shown in Figure 1.1, it includes unique complex patterns like thick radial furrows, crypts, and collarette.

II. IRIS RECOGNITION FRAMEWORK

The present methodology of the Iris recognition system has modules specifically segmentation/ localisation of iris out of iris image, normalisation, feature extraction, and iris code template matching (see Figure 2).

Segmentation: is the process of detecting the boundaries of objects in an image. In an iris recognition framework, the segmentation plays a vital role in discovering the inner and outer edges of an iris and isolating it from the other parts of an image, which are of no relevance.

Normalization: segmentation followed by normalization is the process of un-wrapping the segmented iris, i.e., converting the iris into a polar image (a rectangular block of fixed size) for subsequent processing.

Feature extraction: individuals are recognized based on the discriminating information present in the iris patterns. Phase information of the patterns is encoded to create a feature vector.

Iris code matching: the iris template made in feature extraction step is then compared with the templates stored in the database utilising matching metrics. Depending on the matching score that the individual's identity is determined.

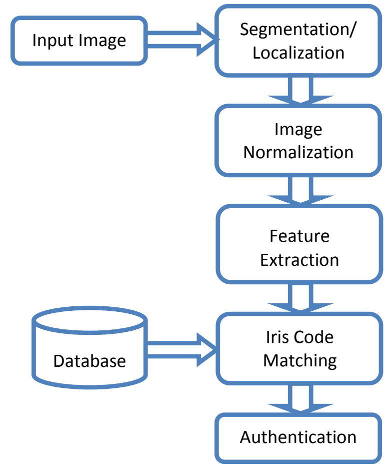

Figure 2 The block diagram of the iris recognition system

Among the modules of the iris recognition system discussed above segmentation is a crucial step because the actual information we are looking will be present within the iris patterns. Thus, it is logical that the first step in implementing an iris recognition system is isolating the iris region from the other parts of the eye image, which are of no relevance. The rest of the paper is organised as follows: section II describes the recognition framework. Section III presents the state-of-the-art segmentation methods. Finally, section IV concludes the paper.

III. STATE-OF-THE-ART SEGMENTATION METHODS

Substantial iris segmentation algorithms have been introduced by several authors in the literature. Most of the segmentation algorithms are based on the assumption that the iris boundaries are circular. The presence of noise artefacts such as specular reflections, eyelid/eyelash occlusions, off-axis gaze, motion blur and intensity inhomogeneities will corrupt the complex iris textures resulting in inferior segmentation accuracy, which in turn affects the overall recognition performance. Detailed state-of-the-art segmentation methods which are available in the literature has been presented in this chapter [7]–[15]. A multitude of segmentation techniques is available in the literature that will address the said noise artefacts. Based on the attributes of iris images, the segmentation techniques can be classified into four

- Edge based techniques
- Histogram and thresholding techniques

Table 1 State-of-the-art edge based segmentation methods

S.No	Author	Segmentation method	Remarks
1	Wildes[16]	Circular Hough transform	Computationally fast compared with IDO
2	Daugman[6] (1993,2003)	Integro differential operator	Provides faster recognition for ideal iris images
3	Boles&Boashah[17]	Edge based techniques	Low recognition rate, faster matching process
4	Li Ma *et al.*[18]	Edge detection & CHT	Feature extraction process is relatively slow
5	Li Ma *et al.*[19]	Edge detection & CHT	Characterizing key local variations
6	Masek *et al.*[20]	Canny edge detection and CHT	Eyelids localization by a simple thresholding
7	Dorairaj *et al.*[22]	Integro differential operator	Used global ICA encoding techniques
8	Schuckers *et al.*[21]	IDO and geometrical transforms	Effective segmentation of off-angle images
9	Monro *et al.*[23]	Circular Hough transform	1d DCT for feature extraction, low EER
10	Miyazawa et al.,[24]	Gravity based method, 2d fourier based method	Faster feature extraction
11	Zhaofeng He *et al.*[25]	Adaboost-cascaded iris detector, pulling & pushing elastic models	Fast and accurate segmentation of non-ideal images
12	Pundlik *et al.*[26]	Graph cuts	Efficient segmentation for out-of-plane rotation images
13	Jeong *et al.*[27]	Two circular edge detectors, Adaboost eye detection	Reports a FPR of 1.2% for non-ideal database
14	Radman *et al.*[30]	Adaptive IDO	Faster segmentation process
15	Frucci *et al.*[28], [29]	Watershed transforms	Improved performance on degraded images
16	Chen *et al.*[39]	Horizontal edge detection & Fast CHT	Fast & robust segmentation

- Clustering techniques
- Contour evolution methods

A. Edge based techniques

The segmentation techniques proposed by many authors based on the edge details of an image are presented in this section (see Table 1).

The initially patented iris model and adopted by almost all international companies is because of Daugman[6], introduced the idea of integro-differential operator to localize the iris. It is an accurate and efficient method for detection of ideal iris images. Another classical method suggested by Wildes[16], used a circular Hough transform (CHT) to get iris localization, which can be applied on a gradient based edge detected image. This system is computationally expensive. Authors in[17], also proposed a method for feature extraction, which used wavelet transform zero crossing, after detection of the iris. Li Ma *et al*.,[18] describes edge detection based circular Hough transform to segment the iris image. A multitude of symmetric filters (different frequencies for different regions) to extract the characteristics of the iris. Eyelid detection continues to be addressed in this paper. In his, another approach Li Ma *et al.*,[19] explained an algorithm based on characterizing key regional variants for iris authentication.

Masek & Kovesi[20], suggested a CHT based on canny edge detection for the discovery of inner and outer iris boundaries. Simple thresholding approaches are utilized to detect eyelashes and eyelids. Schuckers *et al.*,[21] proposed a methodology for off-angle image segmentation. Geometrical transformations to estimate the off-angle gaze and convert the image into a frontal view for further processing. Another method towards off-angle gaze estimation is due to Dorairaj *et al.*,[22] employs Daugman's IDO and hamming distance (HD) and a novel way for feature extraction by using Principal component analysis (PCA) based global independent component analysis (ICA). Authors in [23], proposed a new method for efficient iris code generation using 1-d DCT.

The authors in[24], suggested a 2D Fourier Phase Code (FPC) for symbolizing iris image. Gravity-based segmentation process is proposed. Fast feature extraction is the novelty in this method. Another way that deals with the computational time is by Zhaofeng He *et al*.,[25] used an Adaboost-cascade iris sensor and pulling & pushing elastic models for precise detection of the iris. A smoothing spline-based boarder matching technique and curve fitting to find the non-circular iris borders and localize eyelids, respectively.

Table 2 State-of-the-art thresholding based methods

S.No	Author	Segmentation method	Remarks
1	Dey and Samanta[51], [52]	Edge detection and thresholding	Fast & accurate matching
2	Ng *et al.*[54]	Thresholding and CHT	High recognition rate up to 98.62%
3	Min & Park[53]	Otsu's thresholding & parabolic Hough model	Efficient eyelid & eyelash detection
4	Ibrahim *et al.*[57]	Local histogram and standard deviation based adaptive thresholding	Automatic pupil segmentation
5	Hanfei and Jiang[56]	Otsu's thresholding and LOG	Real time prison management system
6	Bouaziz *et al.*[55]	Kapur's multilevel thresholding, ABC metaheuristic	Accurate non-ideal iris images segmentation
7	Soliman *et al.*[58]	Adaptive thresholding & morphological operations	Robust for occlusions and intensity variations

Pundlik *et al*.,[26] proposed a process to address out-of-plane rotation using graph cuts that use geometric details of the eye picture. The authors in[27], Proposed a non-ideal iris image segmentation using a combination of AdaBoost eye detection and Circular edge detection operations. Frucci *et al*.,[28] & Ferone *et al*.,[29] in their works proposed a new approach for iris segmentation using watershed transformation and Taubin circle fitting algorithm. Authors in[30],[31], suggested a quick and effective method by restricting the searching process to the circular path within the ranges -3π/4:5π/4 and –π/4: π/4.

C.LTisse in[32], employed a combination of IDO and gradient decomposed HT for iris segmentation. Reducing the computational complexity in the standard methods is challenging job few authors tried to tackle this issue. Yu chen *et al.*,[33] in his work, proposed a method to choose a relative region-of-interest (ROI) before applying a fast CHT. The author in[34], suggested approaches to localize iris pictures under non-ideal ailments. The centres of the pupil & iris are detected by using IDO and image strips comprising the iris outer & inner contours processed further. Jinyu Zuo and Schmid[35], suggested a method for detection of the non-ideal iris image. The pupil and iris boundaries are localized by fitting a rotated ellipse. Kumar *et al.*,[36] some of the non-ideal factors for example eyelid/eyelash occlusions, specular reflections, eyeglasses, as well as non-uniform illumination was addressed by utilizing standard thresholding and edge detection based segmentation procedures. The authors Jan *et al.*,[37], use bi-valued adaptive threshold and 2D shape possessions to localize pupillary border and iris border localization is accomplished by reusing the Hough area and picture statistics in the rough iris area. At length, Fourier series and gradients have been utilized to regularize those boundaries.

Cai and Wang[38] used the least square parabolic fitting approach to detect eyelids. In [39], the authors Chen *et al.*, describes human-in-the-loop iris recognition based on identifying and interpreting iris crypts. The authors in [40], used simple edge detectors, intensity variances, and threshold models to detect eyelash and reflections. Bendale *et al.*, & Tian *et al.*,[41], [42] Employed a mixture of advanced CHT & IDO for detecting pupil & iris boundaries. Besides Tian *et al.*, employed an adaptive thresholding method to detect eyelashes. In[43], the authors proposed a hybrid technique which employed 2-d DWT and different edge detection operations for iris detection. The authors in[44], proposed a novel template matching algorithm in the iris recognition pipeline based on elastic iris blob. In [45] Zhao and Kumar, introduced a pre-processing step using improved relative total variation (RTV) method. Khan *et al.*,[46] proposed a hybrid model for robust localization of the iris, in which a mixture of CHT, Otsu's histogram based thresholding and morphological operations. Authors in[47], used RANSAC based direct ellipse fitting procedures for accurate localization in comparison with the traditional procedures. Another method suggested by Makram Nabti[48] used multiscale edge detection using wavelet maxima to detect the iris boundaries.

B. Histogram and thresholding based methods

Thresholding based segmentation methods are simple and accessible; distinguish the objects in the image based on grey level intensities or image histogram. Thresholding based segmentation methods can be broadly classified into two, bi-level and multilevel thresholding[49], [50]. When an image is partitioned into two regions (foreground & background) it is called bi-level thresholding. On the other hand, multilevel thresholding which divides the image into more than two classes (several objects and one background) based on grey level image pixel intensities. Approaches based on the histogram of an image are because of Dey and Samanta[51], [52], where the image is down sampled, and the detection of the pupil & the iris is performed by applying edge detection and thresholding procedures. In [53], the authors employed Otsu's thresholding and parabolic Hough model as a post-normalization process to detect eyelid and eyelashes. The authors Ng *et al.*,[54] proposed a method for effective localization of iris under non-ideal conditions by employing thresholding and CHT, achieves a high recognition up to 98.62%.

Table 3 State-of-the-art clustering based segmentation methods

S.No	Author	Segmentation method	Remarks
1	Proence & Alexandre[64]	Fuzzy c-means, canny edge & CHT	Low execution speed
2	Li *et al.*[66]	K-means clustering, improved HT & RANSAC	Effective detection of on-the-move & at-a-distance images
3	Tan *et al.*[68]	8-neighborhood connection based clustering & IDO	Inefficient for non-circular iris
4	Sahmoud & Abuhaiba[65]	K-means clustering & CHT	Efficient detection of visible wavelength images
5	Shelton et al.,[72]	FCM & Level set method	Reduced number of features
6	Shekar & Bhat[74]	PSO, CHT & FCM	Robust occlusion removal
7	Rapaka et al.,[75]	IPSO based Morphological reconstructed FCM	Efficient for non-ideal database

The authors Bouaziz *et al.*,[55] proposed multilevel thresholding based on metaheuristic of Artificial Bee Colony(ABC) as a pre-segmentation step in the recognition framework. Hanfei and Jiang[56] clarifies that since the sclera is white and contains maximum intensity pixels that the iris could be easily localized by employing a mixture of Otsu's thresholding and Laplacian-of-Gaussian operator. A method proposed by Ibrahim *et al.*,[57] used the local histogram and standard deviation methods to detect iris boundaries. Soliman *et al.*,[58] proposed adaptive thresholding and morphological operations to decrease the computational time. Another similar method that's been suggested is because of Zainal et al.[59], employs adaptive thresholding for pupil localization. Authors in [60], proposed a system using thresholding of Fourier spectral density image to get iris segmentation. Yingzi *et al.*,[61] proposed a PCA based K-means clustering for video iris images for better segmentation. The table 2 presents the baseline histogram based methods.

C. Clustering based methods

Clustering is just another means to partition objects in an image into several distinct components for further processing. Among the segmentation technologies available in the literature, clustering (grouping) is one of the popular techniques used for segmentation due to its effectiveness and rapidity[62]. Clustering aims to group the pixels of an image into different subgroups called clusters. Image pixel intensities belonging to the same subset are as similar as possible to each other, whereas two different groups share the maximum difference. Authors in[63], proposed a new methodology for non-ideal iris segmentation. By introducing a fuzzy clustering based pre-segmentation followed by edge detection based CHT to detect the iris. Authors in [64], employs the K-means clustering algorithm as a pre-segmentation step and followed by CHT to detect the iris boundaries of a non-ideal database. Jayalakshmi *et. al.*[11], in their comparative analysis involving FCM and K-means clustering segmentation approaches concluded that the fuzzy c-means outperform the existing clustering-based methods for iris recognition applications. Li *et al.*,[65]described methods to segment at-a-distance and on-the-move iris images. K-means clustering based on grey level co-occurrence & improved HT to segment the iris. In a different paper, Li *et al.*,[66] has suggested the RANSAC method for robust detection of the iris. Tan *et al.*,[67] proposed an eight neighbourhood connection based clustering pre-segmentation step and IDO for segmenting iris boundaries detection. Elimination of eyelids/eyelash and reflections also been addressed in this paper.

Reddy *et al.,* in [68], proposed a process, which uses the combination of CHT and K-means clustering for efficient segmentation of the iris. Additionally, CLAHE method is utilized to compensate illumination variations in the images. The Author in [69], has explained a cross entropy clustering-based method for localization of off-angle/tilted images. Khan *et al.*,[70] proposed a method to localize the iris boundaries by using K-means clustering & a CHT. Shelton *et al.*,[71] suggested a procedure to localize the iris that uses a combination of FCM clustering and level set method. In [72], the authors suggested a new method that uses a modified fuzzy circular segment to localize the iris. Shekar and Bhat in [73], introduced a recognition method where particle swarm optimization (PSO) and CHT are utilized to find iris contours. The FCM is employed to deal with the noise within the iris image. In our early work in [74], proposed an optimization based FCM as pre-segmentation and the traditional methods to localize the iris boundaries. Table 3 presents the baseline clustering based methods.

Table 4 State-of-the-art contour evolution based methods

S.No	Author	Segmentation method	Remarks
1	Vatsa *et al.* [76], [77]	Mumford shah based curve evolution	Provides good accuracy and speed
2	Daugman[78]	Active contours & discrete fourier transform	Non-circular iris boundary detection
3	Shah& Ross[83]	Geodesic active contours	Non-circular iris boundary detection
4	Roy et al.,[80], [81]	Level sets & Mumford-Shah model	Faster curve evolution process
5	Chen et al.,[82]	Merged active contours & adaptive mean shift	Less EER of 0.43%
6	Hilal et al.,[88], [89]	Active contours & CHT	Effective in detecting inner iris boundary
7	Li *et al.* [90]	Anisotropic diffusion, region based curve evolution	Computationally efficient
8	Abdullah et al., [84], [85]	Gradient vector flow active contours	Efficient detection of exact iris boundary
9	Jamaludin and Zainal[86]	Chan-vese active contours & HT	Effective detection of unclear boundaries
10	Rapaka & Kumar[93]	Optimization based multilevel thresholding & GACs	Accurate detection of non-circular iris boundaries

D. Contour Evolution methods

The majority of the approaches presented above are predicated on the premise that the iris boundaries are circular. Therefore, the majority of the authors focused on models which best match this theory. A very few authors relax this assumption and suggested methods to segment non-circular iris boundaries. Vatsa *et al.*,[75], [76] used the Mumford-Shah based curve evolution method for effective detection of non-ideal iris images. Daugman[77], suggested a way of segmenting non-circular iris boundaries. Employed active shapes based on discrete Fourier series expansion for the localization of the iris boundaries. Another approach described by Roy et al., [77]–[79], used a level set based curve evolution accomplished utilizing a stopping function and Mumford-shah model based curve evolution to detect inner and outer boundaries, respectively. Chen *et al*.,[81] introduced a hybrid method, which used an adaptive mean shift (AMS) & merged active contour (MAC) models to isolate both on-the-move and off-angle images. Another exciting method proposed by Shah & Ross[82]**,** deploy geodesic active contours (GAC), a combination geometric active contours & level sets to segment non-ideal iris images.

The authors Abdullah *et al.,* in [83], [84] proposed distinct procedures to detect iris inner and outer boundaries individually. A very simple thresholding method for detection of pupil boundary of near-infrared (NIR) images, and shrinking active contour model for segmenting pupil boundary of visible light images. Gradient vector flow (GVF) active contours incorporated by a new pressure force is employed to detect the iris boundary. Jamaludin and Zainal[85] presented a comparative study on improved active contours defined by Chan-Vese and HT and concluded that the active contour based methods are found to achieve promising results towards non-ideal iris segmentation. Yan *et al.,* in [86], has proposed a different iris segmentation method, which utilizes active contours and prior noise characteristics. Authors in [87], [88], deployed active contours to find iris inner boundary, as wealthier iris patterns are nearer to the pupil, CHT is employed to detect the iris boundary. Li *et al*.,[89] proposed anisotropic diffusion derived from partial differential equations and morphological filters to localize the inner boundary, and region based curve evolution with the aid of order statistical filtering (OSF), to localize the outer border of the iris. Conner and Roy [90] employed distance regularized level set to detect the iris. Level set based active contours do not converge to iris contours as it is sensitive to local gradient extremes [91]. Hence, a method is proposed to remove local gradients using orthogonal ordinal filters and improved Hough transform. In our early work[92], we proposed a novel segmentation algorithm in the iris recognition framework, which uses optimization based multilevel thresholding as pre-processing and geodesic active contours (GACs) to localize the iris boundaries. Table 4 presents the baseline deformable methods.

Apart from the classification of iris segmentation methods described above authors also attempted to develop segmentation and recognition methods using learning based methods [93]–[100]

IV. CONCLUSIONS

In this paper, detailed state-of-the-art iris segmentation methods have been discussed. From the literature survey, it is understood that a multitude of techniques has been proposed towards segmentation of iris based on edge details. Moreover, none of the edge based methods addressed all the challenges that were encountered in non-ideal iris databases. Minimal attempts have been made towards segmentation using clustering, thresholding and deformable models. However, the level set based contour evolution methods are grabbing the attention of the researchers now a day. Detailed iris segmentation methods for both ideal and non-ideal iris databases have been described above for quick reference of the researchers.

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