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Review on Iris Recognition System for Unconstrained Environment

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Abstract: ***Iris being the internal part of the eye, its imaging is a challenge. Most of the research carried out in this domain is with the lot of constraints. This makes iris unsuitable for use in person identification, only it can be used for person authentication. In COVID like era, Where contact less measures are being recommended or followed use of NIR based iris recognition is not very useful. Following aspects of iris recognition systems are covered in this paper namely image acquisition, segmentation, normalization, feature extraction and matching techniques. It is found that no specific method is available in literature which can be used for unconstrained environment. However modification in existing methods can be carried out and be used under unconstrained environment. This Paper is an attempt to compile all research works may be useful for unconstrained iris recognition. This paper covers all major methodologies of iris recognition system which can be used for iris recognition system under unconstrained environment. This review can prove to be useful paper for researchers begin their work in this area.***

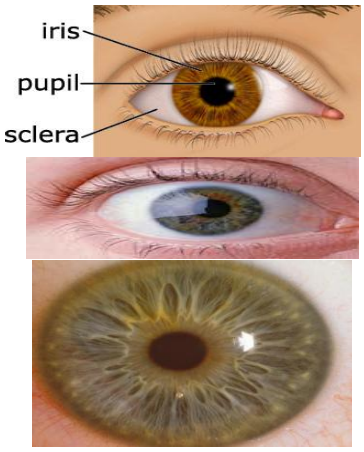
Keywords: Iris Recognition, Iris Acquisition, Iris segmentation, Iris Matching, Iris Databases, Biometrics, NIR, VW

1. Introduction

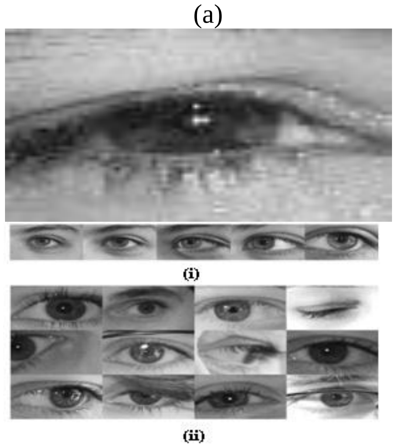
Iris is a tissue containing hole in the center called pupil. The tissue contains muscles that dilates pupil in dim light and constricts pupil in bright light [2].Iris decides the eye color. People with brown eyes have heavily pigmented iris, while people with blue eyes have less pigments. There are various types of biometrics namely face, fingerprint, Voice, Iris etc. suitable for Identification. Among all these biometric traits every biometric has its strength and weaknesses. However Iris has its own advantages in terms of:
Twins have different iris texture, Right eye texture differ from left eye texture, Do not change with age (stable) and Do not suffer from scratches, abrasions, distortions.

NIR V/S Visible wavelength image: The difference in the quality of NIR (wavelength ranges from 700nm-900nm) and VW (wavelength ranges from 400nm-650nm) images is shown in Fig.1. The basic difference in NIR and VW images is that VW images are noisy as compared to NIR image. Diversity and noise in the images of a database discussed by Prajapati et. al [3]. So it is very difficult to segment iris of VW images due to poor quality of images. Through inspection 14 ways to degrade quality of VW images were detected. The noise factors affecting the VW images may be local or global. Local factors comprise of iris occlusions (hairs, eyelids, eyelashes, glasses, specular, and lightening reflections), non linear deformations by contact lenses and partial images. And Global factors comprises poorly focused, motion-blurred, rotated off angle, improper lightening and out of iris images (without iris texture). The VW images [6] shown in Fig.1 part (b) are the examples of images acquired at a varying distances (UBIRIS.V2 database) 4m-8m and captured from moving subjects.

Iris Literature Review in this paper is divided into main five sections as shown in Fig.2: Section I covers approaches by Daugman. Section II covers image acquisition techniques used by different researchers in iris recognition. These techniques become important for images in unconstrained environments. Section III covers iris localization, segmentation and normalization techniques. Section IV covers feature extraction and matching techniques. Section V of the paper is about iris indexing, performance evaluation and freely available databases for iris community of researchers. All these sections are divided into different subsections in a sequential manner so that researcher could easily go on the portion of the paper in which interested.



(a)



(b)

Figure 1: NIR V/S VW based iris images
(a)NIR based Iris Images (b) VW based Iris images

2. Literature Review

2.1 Daugman's Approaches

Iris inner and outer boundaries [10] are located by using integrodifferential operators (act as circular edge detector).As shown in equation 1.

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

Where, I(x,y) is any image, whose iris boundary we want to find out, *r* is the increasing radius from the center (x_0, y_0) , * denotes convolution, σ as Gaussian scale, and $G_\sigma(r)$ is smoothing function. For texture recognition 2-D Gabor filter was used (given by Daugman in 1980) in doubly dimensionless polar co-ordinate system are defined by equation (2)

$$G(r,\theta) = e^{-iw(\theta-\theta_0)}e^{\frac{-(r-r_0)^2}{\alpha^2}}e^{\frac{-(\theta-\theta_0)^2}{\beta^2}} \quad (2)$$

The parameters α and β co-vary in inverse proportion to w. The Hamming distance (fraction of disagreeing bits) between the two iris codes is calculated bit by bit. Thus, Normalized hamming distance can be calculated by equation (3).

$$\frac{1}{N}\sum_{j=1}^{N} A_j\,(XOR)B_j \quad (3)$$

Where, N is total number of bits in iris code for example if iris code is of 256 byte then value of N=256X8=2048bits. A and B are two different or same iris code whom we want to compare. Here, bit by bit XOR operation is performed. Whenever two bits will be different then answer will be '1' and all such ones are added. Hence the number of bits different in two codes is known. And, for normalization total number of different bits in two codes are divided by total number of bits compared (code should consist of similar number of bits).

OFF-Axis gaze solved by "Fourier based trigonometry" [11].described by equation (4).

$$x(t) = A\cos t \text{ and } y(t) = B\sin t \quad (4)$$

Where A≠ B.if the gaze deviation is in the direction θ, then these functions are shown with the help of equation (5) and (6).

$$x(t) = [A\cos^2\theta + B\sin^2\theta]\cos t + [(B-A)\cos\theta\sin\theta]\sin t \quad (5)$$

$$y(t) = [(B-A)\cos\theta\sin\theta]\cos t + [B\cos^2\theta + A\sin^2\theta]\sin t \quad (6)$$

The direction of gaze deviation $\theta = arctan\left(\frac{-b-c}{a-d}\right)$ where a=[A $\cos^2\theta + B\sin^2\theta$],b= $[(B-A)\cos\theta\sin\theta]$, c= $[(B-A)\cos\theta\sin\theta]$ and d= $B\cos^2\theta + A\sin^2\theta]$ and magnitude of the gaze deviation in direction θ gives affine transformation parameter as shown in equation (7).

$$=\frac{(a+d)\cos(2\theta)+a-d}{(a+d)\cos(2\theta)-a+d} \quad (7)$$

Limitation of this method is that affine transformation assumes that iris is planar, whereas it has some curvature.

In 2007 Dr. Daugman proposed: a)Modeling inner and outer iris boundaries with active contours [12]. In this method by employing Fourier components whose frequencies are integer multiples of 1/(2π),closure, orthogonality and completeness are ensured. Fourier expansion of *N* regularly spaced angular samples of radial gradient edge data $\{r_\theta\}$ for $\theta = 0$ to $\theta = N-1$. A set of M discrete Fourier coefficients $\{C_k\}$ for $k=0$ to $k = M-1$ is computed from the data sequence $\{r_\theta\}$ as shown by equation (8):

$$C_k = \sum_{\theta=0}^{N-1} r_\theta\, e^{-2\pi ik\theta/N} \quad (8)$$

From these M discrete Fourier coefficients an approximation to the corresponding iris boundary is obtained as a new sequence $\{R_\theta\}$ for $\theta = 0$ to $\theta = N-1$, which is expressed as follow:

$$R_\theta = \frac{1}{N}\sum_{k=0}^{M-1} C_k e^{2\pi ik\theta/N} \quad (9)$$

A good choice of M for capturing true pupil boundary is M=17 and for capturing iris outer boundary is M=5.

Normalized score is given by equation (10).

$$HD_{norm} = 0.5 - (0.5 - \mathrm{HD_{raw}})\sqrt{\frac{n}{911}} \quad (10)$$

Where, n is number of bits to be compared. a) Matching of iris is done through hamming distance (Lowest HD means Best match) which means fraction of bits that disagree.

Raw hamming distance is calculated as fraction of meaningful bits that disagree between two irises whose two phase code bit vectors are denoted by { codeA, codeB }

$$\mathrm{HD_{raw}} = \frac{\|(\mathrm{codeA}\otimes\mathrm{codeB})\cap\mathrm{maskA}\cap\mathrm{maskB}\|}{\|\mathrm{maskA}\cap\mathrm{maskB}\|} \quad (11)$$

Smallest HD value found for different irises was 0.33.

2.2 Image Acquisition techniques

The work on image acquisition techniques is divided into different subsections: eye tracking conditions, Gaze estimation, off angle correction, Improve accuracy of low resolution images and analysis of cross sensor effects.

2.2.1Eye Tracking Methods

Holland et al. [13] analyzed the effects of eye tracking specification and stimulus presentation on complex eye movement patterns. It showed that stimulus type has little effect, eye tracking system with spatial accuracy of less than 0.5^0 and greater than 250Hz temporal resolution are useful for producing eye information.

Friedman et al. [15] explained Logit Boost, Discrete, real and gentle AdaBoost algorithm useful in detecting eyes in the face and separating iris from eyes.

2.2.2 Gaze estimation Method

Accuracy of gaze estimation depends on the relative orientation of eyes but not body to head Roberts et al. [17]. Gaze can be estimated through VBR to accuracy underpinning social gaze in the natural world. i.e. 4^0@≈4m.

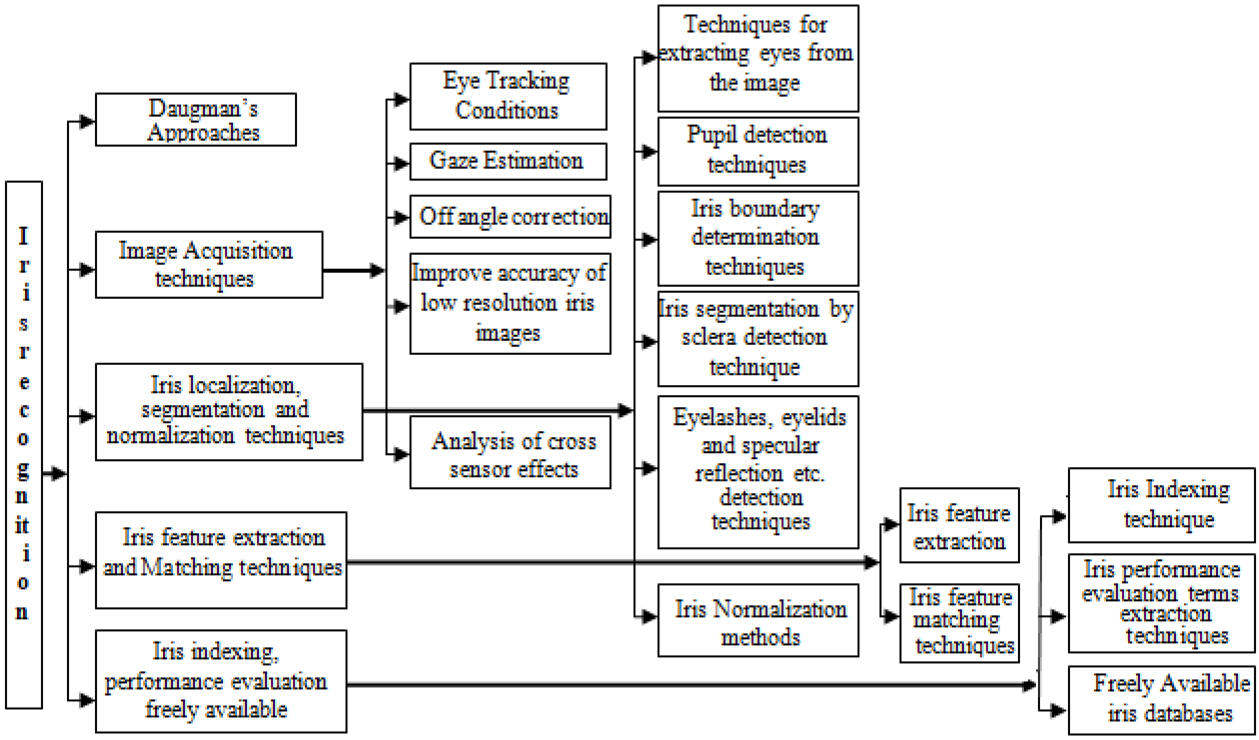


Figure 2: Five main sections and their Subsections of this Literature Review

2.3 Off angle correction Method

Frigerio et al. [18] made efforts of correcting off angle iris images with the use of 3D model of the human eye. In the 3D model, a refractive index map was created to define refraction index values for each point to cornea and aqueous humor. Price et al. [19] proposed simple human eye model based on real anatomical and optical properties.

H. Proenca [20] assessed focus, motion, Iris pigmentation, Occlusions, Area, angle, pupil dilation and iris center for VW images.

2.4 Methods to improve accuracy of low resolution iris images

Illumination compensation LN (Local Normalization) method for facial images can effectively reduce the effect of uneven illumination Xie et al. [22]. In this method they used mean value and variance of the image.

Liu et al. [23] proposed noise removing through Wavelet methods, but these produces ringing effects or in other words produces additional edges and structures. To denoise the image, image enhancement software such as Neat Image™ estimates the noise according to the camera and camera setting can be done to remove that level of noise. Noise level function (NLF) is defined as variation of standard deviation of noise with respect to image intensity.

2.5 Method for Analysis of cross sensor effects

Pillai et al. [24] proposed technique to mitigate cross-sensor performance degradation by adapting iris samples from one sensor to another. In the experimentation the results are shown with the use of four sensors i.e. LG 2200, LG 4000, adapted cross-sensor and non adapted cross-sensor.

2.3 Iris Localization, segmentation and Normalization techniques

Procedure of marking inner and outer boundaries of pupil and sclera, detecting the upper and lower eyelid boundaries, and detecting any superimposed eyelashes or reflections from cornea or eyeglasses of image of any living being is called iris segmentation. Before iris segmentation of any image first step is locating eyes in the image. All subsection of this section are: Techniques of extracting eyes from the image, pupil detection techniques, Iris boundary determination techniques, iris segmentation by sclera detection technique, EES (eyelashes, eyelids and specular reflection etc.) detection techniques, iris masking techniques and last is iris normalization methods.

2.3.1 Techniques of extracting Eyes from the image

Chen et.al [26] approach for locating eyes is based on dilation and erosion operations on which mask is applied to reduce noise and improve shape of the eye. This method can locate eyes even if eyes are closed. The technique reduces computational time.

Khosravi et al. [27] proposed method for eye location by applying morphological operator's dilation and erosion on the segmented face region and then subtracting the result from original face image. The inner eye boundary is found by modification in TASOM based ACM algorithm uses TASOM network that includes a chain of neurons in its output layer.

Asano et al. [28] proposed eye detection method to facial pose changes (Roll, yaw, pitch directions of faces) using particle filters and edge directional features.

2.3.2 Pupil detection techniques

Vasconcelos et al. [29] proposed batch-SOM (self organizing maps) based algorithm for pupil segmentation whose response is not necessarily a circle or an ellipsoid. With this BSOM method accuracy of pupil segmentation increased.

Bodade et al. [32] detected pupil on the bases of result of subtraction of different parts of image, where result of subtraction is not zero was considered pupil area, as this part is not same always.

On the bases of variation of pupil sizes (in between 5%-15%) of two images of same subject, it may be considered as real eye, else fake eye.

2.3.3 Iris Boundary determination techniques

Above authors [33] proposed algorithm for determination of iris boundary by first converting image into gray image then converting this gray image into binary image. In binary image pixels are classified based upon the intensities i.e. white group (1) and black group (0).Boundary is traced for all points with binary value as 1 in all direction starting from selected point that is first point that has value as zero.

Savoj et al. [34] proposed method of iris localization using convolution of circular filter (Daugman circle) with the image.

Du et al. [31] proposed iris segmentation algorithm for non cooperative videos obtained at a distance. They first applied quality filter to eliminate bad images.

N. K. Mahadeo et al. [35] proposed Pupil localization method based on 2-D toroidal filtering (extension of 1-D petrou-kittler edge filter). After 2-D filtering convolution of image is calculated with the filter, maximum of the convolution matrix entry gives center of pupil. As explained in this paper, pupil and iris centers are different, minimum distance is 3 pixels and maximum distance upon dilation is of 6 pixels between centers. This approach has increased speed and accuracy of pupil and iris localization. But this algorithm failed to detect iris boundaries when there are shadows, blur or poor contrast near the iris boundary. In some images algorithm was able to localize only pupil not iris and in some image localization failed completely which were of poor quality in WVU dataset.

J. Liang et al. [37] described robust method of estimating parameters of an ellipse from a set of co-planar points. Geometric methods solved non-linear problems since based on orthogonal distance between data points and the estimated ellipse.

Shah et al. [38] proposed technique different from Daugman i.e geodesic active contours segmentation method, which has ability to handle “splitting and merging” boundaries. Thus, if the iris edge details are weak then over segmentation can be avoided by GACs. In the Geodesic active contour based iris segmentation method of thin plate splines were used for minimizing energy of contours so that contour should evolve in uniform manner. GAC scheme not only finds iris boundaries but also find eyelid boundaries in order to separate iris and non iris portion. The method has the drawback when edges are weak over segmentation was found.

Proenca et al. [39] proposed segmentation method based on pixel position and their intensity .Classified pixels belonging to iris and non iris part.

Y. A. Betancourt et al. [40] proposed inner and outer iris boundary detection method on the bases of gradient variations. In this method arc whose aggregations of gradient approximation variation value is highest fits better to the iris boundary. They applied median filter for smoothening the iris image (removal of specular reflections).Fig.3 shows the image before and after applying median filter. By This method speed increased for segmentation process, which could be useful for real time system and for large data base. But, accuracy decreased as compared to other segmentation processes due inaccuracy in approximation of iris center.

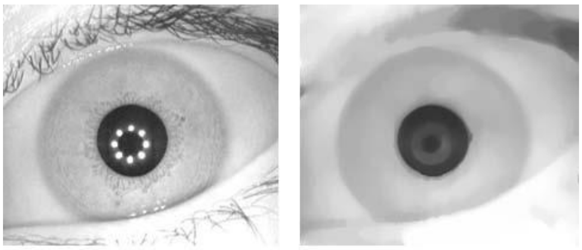


Figure 3: A. Raw image B. Image after applying median filter

Chia et.al [41] discussed intensity based segmentation method based on NOVA four spectral (red,green,blue (RGB) and NIR)) iris recognition system, which is also known by name of IRIS-4 method. In this method threshold intensity (average of highest and lowest pixel intensity) is calculated and pixels having more intensity then threshold value are denoted by ones and pixels having less then threshold intensity are denoted by binary zeros. Drawback of this method is that the exact mathematical four spectral model to distinguish different parts of eye is unknown.

Cun-Wei tan et.al [42] approach deals with the non co-operative environment, it exploits multiple higher Oder local pixel dependencies to robustly classify the eye region pixels into the iris or non-iris regions. ZMs (zernike moments) have been shown to constitute discriminate features for the image representation since they are less sensitive to noise and the information redundancy.

Timm et al. [43] proposed iris localization method based on gradients.

Zhao et. al. [44] used circular Hough transform to estimate circle center. They localized iris and pupil boundaries with iris circle and pupil circle respectively. Possible pupil, iris radius ranges was 35, 120 respectively. The method developed requires preprocessing of images i.e. Noise removal, reflection removal, eyelid detection, eyelash and shadow detection etc. They processed lower half of iris first to threshold and separate non iris portion from the upper half portion of limbic boundary circle. They also demonstrated eyelid fitting approach with the help of parabola.

Koh et al. [45] used region-based active contour model and canny edge detector for finding edges of iris.

Prajapati et al. [46] detected non circular iris boundaries using active contour method and yezzi energy. They performed experiment for authentication as well as person's identification using UBIRIIS.v2 database.

2.3.4 Iris segmentation by sclera detection techniques

Proenca et al. [47] proposed segmentation for degraded images. where, He find out proportion of sclera for each image pixels in different directions by using information of pixel color (hue, red and blue chroma).this method is very complex and time consuming.

Proenca [6] proposed segmentation method based on proportion of sclera in each direction in degraded VW eye images. Brown-black eumelanin (over 90%) has most of its radiative fluorescence under the VW light. This method is fast, takes time less than one second per image and has ability to consider real time data.

Khosravi et al. [27] used Time-adaptive self organizing map based (TSOM) active contour model for determining sclera boundary and tracking its movements. They first detected face boundary on the bases of skin color. After that detected eye region on the bases of neuron.

Some other Iris Segmentation Techniques

Yahya et al. [48] employed Chan Vese active contour method for accurate iris segmentation.

Mukhopadhyay et al. [49] surveyed methods applied on the bases of Hough Transform. Hough transform is used to detect different shapes in image like line, circle, ellipse etc.

Rad et al. [50] designed FCD algorithm (Fast circle detection) to find circular shapes brighter or darker than the background of the image based on the symmetry of gradient pair vectors. This method can also be used for finding ellipse.

Chan et al. [51] find out edge points by determining maxima points, thus curve can be located without loss of generality. This method is minimization based segmentation. Proposed active contour method for segmentation based on Mumford-Shah and level set technique.

Xiang et al. [52] proposed edge based active contour method. They found sharp edges of objects in 2D and 3D images, applied their method for finding the boundaries of object with different intensities and shapes. They compared their results with GVF (Gradient vector flow) method.

Chopra et al. [53] applied gradient vector flow method to the actual active contour model. GVF model improve accuracy and capture range while segmentation. Its accuracy is good but low speed.

Sruthi [55] segmented iris image through region growing technique useful for noisy images based on the portioning of homogeneous areas of image.

Getreuer [56] segmented images using Chan-Vese active contour method and explained changes in segmentation boundary due change in different parameters and number of iterations. He showed the importance of number of iterations while keeping μ =0.3 constant and parameter μ (adjusts length penalty) while segmenting grayscale image.

Akinfende et al. [57] segmented iris image using GUI based active contour for non-cooperative biometric recognition.

2.3.5 Eyelashes, Eye lids and specular reflection etc. detection techniques

Wildes [1] Modeled the upper and lower eyelids with parabolic arcs. The contour fitting system is performed in two steps: First the image intensity information is converted into binary edge-map. For this the threshold image intensity gradient is found out by the equation (11).

$$\left|\bar{\nabla}\, G(x,y) \oplus I(x,y)\right| \tag{11}$$

Where, $G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}}$ is a two dimensional Gaussian with center (x_0, y_0) and standard deviation σ. And $\bar{\nabla} \equiv (\frac{\partial}{\partial x}, \frac{\partial}{\partial y})$ Second, the edge points vote to instantiate particular contour parameter values.

Z. He et al. [58] worked for removing specular reflections which is one of the important tasks before iris segmentation. They used bilinear interpolation for removing specular reflections and pulling and pushing (PP) method for detection of papillary and limbic boundaries. PP method is based on N identical springs with the equilibrium length R and spring constant k. It allows efficient circle fitting to the iris boundaries by excluding most of the noisy edge points. Cubic smoothening spline provides tolerant to detection of deviated edge points. In their approach EES (Eyelashes, Eyelids and shadows) detection improved results of iris segmentation.

Prajapati et al. [59] designed method for removing specular reflections, separating eyelashes and eye lid portion from the VW images. These preprocessing techniques are based on the YCbCr image model.

2.3.6 Iris normalization methods:

In Normalization process iris image (means normalization of texture variation caused due to dilation and contraction of pupil) is transformed from Cartesian coordinate system to polar coordinate system.

Li et al. [61] proposed algorithm in which image is transformed from Cartesian coordinate system to polar coordinate system. This process normalizes the texture variation (pupil dilation and contraction) and translates the rotational shift (eyeball in plane rotation due to head tilt).

Santos et al. [62] used NIR based methods in VW iris images by approximating missing values (interpolation) in normalization process. For, highly noisy data interpolation can increase recognition accuracy.

2.4 Iris feature extraction, Classification, Encoding and matching techniques

After normalization the relevant texture information needs to be extracted. This section is divided into two subsections: feature extraction and feature matching techniques.

2.4.1 Iris feature extraction and classification techniques:

Tan et al.[64] proposed algorithm in which the features around the eye region (periocular) were exploited to supplement iris information. First scheme is known as global peri-ocular region, which is the entire region without performing segmentation and normalization. The second scheme is referred as local periocular region, which is localized region extracted and normalized with respect to the segmented iris information.

J. Liu et al. [65] proposed Mahalanobis distance learning algorithm to improve classification accuracy of low resolution iris images. This method utilizes following considerations: 1) Correspondence between heterogeneous and homogeneous matching samples; 2) the similarities between points in the same mode of a class is encouraged; and 3) Similarities between points with different labels is penalized; In this algorithm DI (discriminating index) represents the separability of genuine and imposter distributions. It is shown mathematically by equation (10).

$$DI = \frac{|\mu_{pos} - \mu_{neg}|}{\sqrt{\frac{(\sigma_{pos}^2 - \sigma_{neg}^2)}{2}}} \quad (10)$$

Where $\mu_{pos}, \mu_{neg}, \sigma_{pos}^2$ and σ_{neg}^2 represent the means and standard deviations of genuine and imposter matching distributions respectively. Larger DI value indicates better recognition performance.

Bodade et al. [66] captured feature information distributed in 12 different directions using wavelet transform. This method improved recognition rate and processing time. Inherent shift invariance is one of the advantages of this method.

Y. H. Tsai [67] proposed weighted approach (designed by Gaussian functions according to the distance to the center from the iris) combines the local binary pattern for texture classification. In this algorithm LBP code is computed for each pixel by comparing its neighborhood pixels with the center pixel value. This approach is good for solving uneven lightening condition. This method provides users a more flexible iris recognition system.

Rai et al. [68] extracted Features (zigzag collarette area of iris texture) with the help of Haar wavelet. They classified features based on combined support vector machine (main classifier) and hamming distance (secondary classifier). In this algorithm for n classes n SVM models are developed, one model for each class. More than 91% of CASIA and Chek databases were accurately classified by SVM classifier.

Mei et al. [63] proposed multi scale and multi orientation feature extraction strategy. In this strategy after the 2-D Gabor filtering results $I * G_{i,j}$, the multi scale and multi orientation data fusion process performed to construct iris codes.

Kong [69] proposed statistical analysis of iris codes with the help sample mean of iris images ($I_1, I_2 \dots I_n$) by using formula $\bar{I} = \frac{1}{n}\sum_{j=1}^{n} I_j$ and for an iris code data base B_s containing n iris codes from n irises corresponding mask database M_s .Sample probability of the K_{th} bit being one is explained with the help of equation (12).

$$\widehat{p_k} = \sum_{j=1}^{n}(b_{jk} \cap m_{jk}) / \sum_{j=1}^{n} m_{jk} \quad (12)$$

Where ∩ is AND operator symbol. The indication of changes in illumination influences bit probability and bit probabilities are not always approximately 0.5, they are highly dependent on the mean of iris images is shown through this research paper.

Bosch et al. [70] suggested automatic rectangular ROI in images having variability of position of objects and also having different background clutter (performed experiment on Caltech-101 and Caltech-256 dataset). Their classifier was able to classify image on the bases of shape and appearance.

Zhang et al. [71] proposed hybrid classifier of nearest neigh-bor and support vector machines in which they train support vector Machine (SVM) with nearest neigh-bors. Naïve version of SVM-NN has to calculate distances of query to all training examples. In place where distance function is costly to evaluate this method behaves better than DAGSVM (SVM-KNN with k=n was slow). SVM-NN is faster to train.

Lee et al. [72] proposed multicategory support vector machines (MSVM) scheme, this yields less error rate. They applied MSVM in classification of genes. They also applied MSVM in MODIS (Moderate Resolution Imaging Spectroradiometer: instrument used to know about clouds whether there will be rain or not) data and it performs better than NN method in class classification.

Berg et al. [73] identified model image on the basis of shape edge maps and recognition was based on nearest neighbor. Main bases of their algorithm were finding set of feature points that have good correspondence.

Belongie et al. [74] found correspondence between shapes which were represented by set of sampled points and used affine transformation. They applied prototype based approach like sparrow as prototype for category of Birds showed shape in terms of sample points. And, applied nearest neighbor approach for recognition. Reduced effect of jitter noise by transforming with regularized thin plate spline.

Mori et al. [75] found the mean distance of sample points from a particular point (called reference point) while estimating the shape maximum distance was half the diameter of object. From collection of different objects they tried to find from which object the particular object matches best on the bases of shape. They used non linear thin plate spline transformation to overcome variation over shapes.

Kovoor et al. [76] used canny edge detector for feature extraction. They evaluated different edge detection operators like perwitt, canny, Robert, Sobel, Zero cross and Log on the bases of mean and standard deviation value of SR(Success ratio), FRR (False Rejection Ratio) and FAR (False

Acceptance Ratio). The Operator possessing high SR mean value and low FRR, FAR mean value was chosen best for capturing high texture i.e canny.

Belcher et al [77] used Log Gabor filter as band pass filter for feature extraction and found quality score on the bases of feature information, Occlusion measure and dilation measure. For good quality image Feature information value should be more and values of occlusion and dilation should be less.

Costa et al. [9] used sobel edge detector and Hough transform for segmentation. And, found out dynamic features like pupil contraction and dilation times (in terms of number of frames), pupil diameter variations and other features like gray level mean value, gray level standard deviation, gray level variation coefficient, Angular second moment, Correlation, Entropy, Contrast etc. These dynamic features can be employed for person's identification and fraud attempts can be reduced. This work can be used in alcoholic person's identification.

Ozuysal et al. [78] classified features in Naive Bayesian manner for improving recognition rate; the naïve Bayesian method outperforms the average posteriori method.

2.4.2 Iris feature Encoding and matching techniques

Tan et al. [79] proposed encoding and matching strategy it benefits from the simultaneous exploitation of textural information from both localized and local iris region pixels. The localized iris encoding strategy owes its strength in better accommodating the imagining variations, while the global iris encoding strategy has its strength in effective encoding of less noisy iris region pixels. The strategy is known as Geometric key (Geokey) encoding and matching strategy to be useful for distant iris recognition. GeoKey are set of co-ordinate pairs assigned to each subjects enrolled in the system.

Hollingsworth *et al.* [80] proposed one of the matching strategy that estimates the fragile (inconsistent-if its value changes across iris codes created from different images of the same iris) bits in the iris codes and excludes those inconsistent bits in computing the matching scores. Such strategy has shown to be promising for close distance or for conventional iris images but is not adequate to accommodate large imaging variations observed in visible illumination images acquired at a distance.

Santos et al. [81] proposed spatial and frequency analysis method of matched bits to confirm the full matching of bits.
Miyazawa et al. [82] claimed 0 % EER using phase based matching algorithm. Matching score was calculated on the bases of maximum peak value of BLPOC function within a window.
Oktiana et al. [83] proposed cross spectral iris recognition using phase based matching of 2D DFT (Discrete fourier transform) spectrum. In this method NIR iris template is matched with VIS (visible) iris template. EER value less than 0.5% was found in this method. The Experiments were performed on Poly U dataset.

2.4.3 Iris Indexing, performance evaluation and Data bases

This section composed of three subsections. First subsection explains Indexing methods applied to reduce the code searching time. Second sub section discusses necessary and some commonly used performance evaluation terms applicable in iris recognition. And, last subsection discusses freely available databases for iris recognition.

2.4.3.1 Iris Indexing technique

Dey et al. [84] proposed indexing technique by creating index key values of iris texture features. Indexing keys were developed using Gabor energy (calculated by summing up square values of Gabor response at each pixel) features in different scales and orientations of each iris texture. Equation 13 Represents Gabor energy calculation. This technique requires fewer features hence less memory and computational time.

$$GE_{m,n} = \sum_{x,y}[|GI_{m,n}(x,y)|]^2 \tag{13}$$

According to the proposed method memory required for 10^6 and 10^9 enrollments is Approx.115 MB and 112GB respectively.

Jayaraman et al. [85] proposed image indexing scheme on the bases of averaging red and blue colors of image and on the bases of texture. In this method, histogram of color image found out whose different element show probability density function of different colors. Each bin of histogram is as considered different feature of image. These histograms can be stored as database and compared with histogram of query image for identification purpose. In their color indexing scheme they first converted RGB image to YCbCr image as this YCbCr separates illuminations from color. They found out optimum subset size k by knowing the crossing point of bin miss rate and penetration rate.

2.4.3.2 Iris performance evaluation terms

The performance evaluation terms used in iris recognition are as follows [11].

1) FAR (False accept rate)-: It is percentage of imposter iris textures that are accepted.
2) FRR (False reject rate)-: It is percentage of genuine iris textures that are rejected.
3) TPR (True Positive rate)-: It is percentage of genuine iris textures that are accepted.
4) EER (Equal error rate)-: at which FAR and FRR are equal.

Mei et al. [63] proposed one such technique, which is based on corner detection. It is evaluated by following indices:

a) Miss rate (MR), correct identity belongs to none of the code.
b) Penetration rate (PR), indicating the fraction of user identities retrieved by the system.
c) Redundancy rate (RR), repetition frequency of iris codes.

To reduce the MR every subject can be registered with more than one iris images (best value at 4 images).

2.4.3.3 Freely available iris data bases

In 2004, University of Beira Interior (UBIRIS.v2) database was released published by Proenca *et al.*[86] consist of images taken in visible wavelength from 4m-8m of distance in unconstrained conditions. In order to introduce heterogeneity in the database two sessions were performed in each session location, acquisition device, light source and some volunteers were changed. This database was made freely available from June, 2009.

CASIA 1.0 data set contains 756 images in each image pupil area is replaced by circular area of constant intensity of mask thus detection of pupil and iris boundary was made simple [87].

D. Yadav et al. [89] proposed lens detection algorithm that can be used to reduce the effect of contact lenses. Major contribution of this research paper is the preparation iris contact lens databases: IIIT-Delhi contact lens databases and ND contact lens detection 2013 databases. In IIIT-D number of subject are 202, total images in the database 6570, three types of contact lenses (none, soft and textured) were used. In NDCLD contact lens detection database the number of subject eyes (I: 287, II: 89) total images in the database 5100.Other available Iris databases are Tabulated in Table 1.

Table 1: Some More Iris Databases with their Links

S. No.	IRIS Database	IRIS Database Link
1	FRGC Iris data base	https://cvrl.nd.edu/projects/data/
2	UPOL Iris Image Database	http://phoenix.inf.upol.cz/iris/download/
3	EMDB data base(Eye Movement Biometric Database)	https://userweb.cs.txstate.edu/~ok11/embd_v1.html
4	ORL database	https://sites.google.com/site/imesecan/databases-used
5	PolyU Iris Database	https://www4.comp.polyu.edu.hk/~csajaykr/polyuiris.htm
6	MMU Iris database	https://www.kaggle.com/naureenmohammad/mmu-iris-dataset?select=MMU-Iris-Database

3. Conclusions

This review paper is categorized on the bases of work done and methodologies applied by researchers in different steps of iris recognition. It starts from Daugman's approaches or starting days of iris recognition till now based on the availability and utility of the material for unconstrained iris recognition. We hope that this review on all sections of iris recognition will help researchers working in the field of unconstrained Iris recognition.

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