An Iris Recognition System Using A New Method of Iris Localization

Ahmed AK. Tahir, Sarhan S. Dawood and Steluta Anghelus

Abstract—An iris recognition system for person identification is developed with a new method for iris localization. For pupil boundary detection, a method robust to the specular point reflection problem is developed. It consists of morphological filter and two-direction scanning methods. For limbic boundary detection, Wildes method is modified by restricting the process of Canny edge detector and Hough transform to a small Region-Of-Interest (ROI) not exceeding 20% of the image size. For eyelid detection, the method of Refine-Connect-Extend-Smooth (R-C-E-S) is used, which detect three possible cases (single eyelid, both eyelids and free iris). For iris normalization, rubber-sheet model transform is used and for iris coding Gabor filter is used. The performance of the system is evaluated for the individual stages and for the whole system using three different databases (CASIA-V1.0, CASIA-V4.0-Lamp and SDUMLA-HMT). The accuracy of correct detection reached 99.9%-100% for pupil boundary and 99.6%-99.9% for limbic boundary detection. For eyelid detection; the accuracy reached 93.2%-97.6% for upper eyelid, 95.3%-99.15% for lower eyelid and 96.7%-96.92% for free iris (iris not occluded by eyelids). The overall accuracy and the Equal Error Rate (EER) of the system for CASIA-V1.0 database are 96.48% and 1.76%, for CASIA-V4.0-Lamp, are 95.1% and 2.45%, and for SDUMLA-HMT are 93.6% and 3.2%.

***Keywords*—Iris Recognition, Iris Localization, Eyelid Detection, Hough Transform, Canny Edge Detection.**

I. Introduction

Biometrics is the process of identifying a person or verifying the identity of a person based on individual physiological or behavioral characteristics, such as fingerprints, voice, face, finger vein, iris, palm print, etc., [1]. Biometric data is personal privacy information, which uniquely and permanently associated with a person so it cannot be forgotten or stolen.

Recently, person identification by human biometric recognition systems has dominated the security issues as an essential tool for controlling border, airport security, building access, financial duties and many forensic applications, [2]. The demand for personal identification systems has increased during recent years and many recognition systems have been developed using various types of human biometry measures such as iris, fingerprints, face, palmprint, gait, finger vein, etc., [3]-[11].

Amongst these biometry measures, iris has drawn great attention because it has a unique texture for each person and for the two eyes of the same person. Besides, iris patterns are not subject to the effects of aging, therefore it remains stable throughout the life and impossible to be modified without risk, [12]. The earliest and most known of iris recognition systems have been developed by Daugman in 1993 and Wildes, 1997, [13],[14]. These two systems were used later as the foundations for the development of many other systems at the aim of improving the recognition rate. They were based on two different approaches, now are known as Daugman approach and Wildes approach. In Daugman approach, the method of integro-differential operator is used for iris localization and a rubber-sheet model transform is used for iris normalization and for the compensation of the scale and rotation variation. For iris coding, Daugman approach uses 2D Gabor filter and for iris matching, Hamming distance measure is used. In Wildes approach, Canny edge detection and Hough Transform are used for iris localization and image registration is used for the compensation of the scale and rotation variation. For iris matching, Wildes approach uses the normalized correlation measure.

The performance of iris recognition system depends on the effectiveness of the methods used for implementing the various stages of the system, such as iris localization, eyelid detection, normalization, coding and matching. In addition, it depends on the quality of the database used in testing the system. The illumination conditions and the camera properties have great impact on the quality of the iris image. Usually, iris recognition systems show better performance when sensors are used to capture images with the possibility of adjusting the image quality. For instance, Daugman system achieved 99.9% accuracy with database created by the author, while it was reported by [15] that: Daugman system achieved only 54.44% accuracy when applied to CASIA-V1.0 database. They attributed the reason to the low contrast between iris and sclera in CASIA database.

In this paper, a new system of iris recognition is proposed. The system is based on introducing new method of iris localization and using an eyelid detection method developed previously by [10]. For iris coding, Gabor filter is used and for iris matching, Hamming Distance (HD) is used. The system is evaluated using three different databases, CASIA-V1.0, CASIA-V4.0-Lamp and SDUMLA-HMT.

The remaining parts of the paper are organized as follows: a review of the related works is given in section II and the

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layout and a detailed description of the proposed system are given in section III-VIII. The results and discussions are presented in section IX and finally, the conclusions are given in section X.

II. RELATED WORK

Many research works have been done on developing iris recognition systems with the aim at improving the recognition rate. Most of these works were based either on Daugman approach or on Wildes approach or on a combination of both, with some changes at one or more stages of the system. For iris localization, Narote and others [15], used thresholding for pupil boundary detection. Ferreira and others [16], used a combination of template matching and integro-differential operation for iris localization. They achieved accuracies of 98.7% and 98.8% for iris localization using CASIA V1.0 and V3.0 databases with an overall system accuracy of 88% for CASIA-V1.0. For iris coding, Yao and others [17], used Log Gabor filters instead of Gabor filters to eliminate the effect of illumination variations. Also, Velisavljevic [18], used oriented wavelet transforms instead of Gabor filters and achieved 94.7% using CASIA-V3.0-Lamp database. Desoky and others [19] fused a set of iris images of the same eye for generating a base template as iris code. They achieved 99.33% using MMU1 database. Kovoor and others [20], used histogram equalization technique, Canny Edge Detector and Haar Wavelet Transform for iris coding. NG and others [21], used a combination of Daugman and Wildes approaches with some changes including, the use of Gaussian filter prior to Circular Hough Transform for pupil boundary detection, they used the local Log Gabor filter for iris coding. They achieved 98.62% accuracy using CASIA-V1.0 database. Pranith and Srikanth [22], used Wildes' approach for pupil boundary detection and Daugman approach for limbic boundary detection. They used the extracted corner points as features and Cross Correlation (CR) measure for matching. They achieved an overall accuracy of 95.4 % using CASIA-V1.0 database. Singh and others [23], developed a novel system using Wildes approach for iris localization and Haar wavelet transform for coding, whereas for matching they used Hamming distance. Dewangan and Siddhiqui [24], used a combination of Dauagman and Wildes approaches, except for iris coding they used LogGabor filters instead of Gabor filters and they used left and right shift in a bit-wise for Hamming distance measure to minimize the effect of rotation. Mabrukar and others [25], used a combination of Daugman and Wildes approaches, except for iris coding theyhgmhgnh used phase features from a multi-scale Taylor expansion. Shanthi and Dinesh [26], used Wildes approach for iris localization and Daugman approach for the remaining stages. They achieved an accuracy of 94.3 using CASIA-V4.0-Lamp database. Chai and others [27], also used a combination of Wildes and Daugman approaches, except for matching, they used a non-hierarchical structure for classifying set of features selected randomly from the iris code. They achieved an accuracy of 95.07% using CASIA-V1.0 database.

Systems that show major differences with Daugman and Wildes approaches, in particular for feature extraction, have also been developed. For instance, Cui and others [28], used the Principal Component Analysis (PCA) combined with super- resolution technique for feature extraction, while Miyazawa and others [29], used phase information of Fourier Transform for coding and the Phase-Only-Correlation function (POC) for image matching. Conti and others [30], introduced a unique iris recognition system using the iris minutia features for recognition. Their system also included eyelid and eyelash removal. Ling and and de Brito [31], used the frequency of occurrence for the pairs of pixels that are at the same distance from pupil center for limbic boundary detection, while for feature extraction, they used Fourier transform followed by Gabor filter. Du and others [32], used a combination of the phase and magnitude of Gabor wavelet with the scale invariant feature transformation (SIFT) for feature extraction. Gomai and others [33], used image smoothing for pupil boundary detection. For iris coding, they used the local minimum of mean intensity within sub-image followed by image thresholding. Mattar [34], used Principal Component Analysis (PCA) and Artificial Neural network (ANN) for developing a system, which achieved an overall accuracy of 92.85 using CASIA-V1.0 database. Shah and Ross [35], used geodesic active contour for iris feature extraction and achieved EER of 3.1% and 2.48% for left and right eyes of CASIA-V3 Interval database. Abdullah and others [36], used snake active contour for detecting the pupil boundary. They achieved an accuracy of 99.5% for pupil boundary detection, while Abdullah and others [37], used the approach of expanding and shrinking active contour for iris localization using CASIA-V4.0 database. Ashwini and others [38], used multiple feature extraction such as Local Binary Pattern and Local Phase Quantization and achieved an accuracy of 95% with CASIA-V1.0 database. Firake and Mahajan [39], compared three different methods for coding, the phase information of Gabor Wavelet, eigen irises of Principal Component Analysis and feature coefficient vector of Independent Component Analysis. They achieved accuracies of 92.85%, 87.5% and 90% for each of them respectively using CASIA-V1.0 database. Umer and others [40], used Histogram of Oriented (HOG) for coding and SVM for classification. They achieved accuracies of 91.21%, 97.91%, 93.12%, 90.21%, 83.46% for MMU1, UPOL, CASIA-V3.0, IITD, UBIRIS-V1.0 databases respectively. Rai and Yadav [41], used the zigzag collarette area of the iris feature extraction, Gabor filter for coding and SVM for classification. Hamd and Ahmed [42], used Fourier transform and PCA for feature extraction and Manhattan distance classifier for matching. They achieved accuracies of 96% and 94% for Fourier transform and PCA respectively using CASIA-V1.0 database. Ahmadi and Akbarizadeh [43], used Wildes approach for ris localization and Daugman approach for iris normalization and coding. However, they use Neural network with mulita-layer neural network for classification. They achieved recognition rate of 95.36% using CASIA-V3.0. Abdulmunem and Abbas [44], compared two classifiers, SVM and Backpropagation algorithm with PCA as feature extractor. They achieved 90% accuracy for PCA with SVM, while for PCA with BP the result was disappointing, achieved only 3.4% using only a small subset of CASIA-V4.0 database. Salve [45], used Wildes approach for iris localization and Daugman approach for iris normalization, while for coding 1D Gabor wavelet was used. They used SVM as classifier. They achieved accuracy of 98.5% using only 200 images of CASIA-V4.0-Lamp database. Rana and others [46], used Wildes approach for iris localization, Daugman approach for iris normalization and a combination of DWT and PCA was used for coding with SVM as a classifier.

Recently, Convolutional Neural Networks (CNN) approach was introduced as one competitive approach iris recognition, [47]. The most recent works that have used the approach of CNN for iris recognition were [48]-[51]. They used various structures of CNN with various types of databases. In general, the use of CNN approach for iris recognition differs from its use for image classification. In iris recognition, usually CNN is used as classifier and other methods of iris localization, eyelid detection, iris normalization and iris coding remain as in the conventional approach, while for image classification, in general, the process of feature extraction is done inclusively by the CNN. However, developing a CNN that performs well for iris recognition requires a good coordination between the CNN architecture, optimization algorithm, training parameters, training data [52],[53].

III. THE PROPOSED SYSTEM; METHODS AND DEVELOPMENT

In this paper, a novel system for iris recognition system is introduced. The system is based on a combination of previous and newly modified algorithms. Fig. 1 shows the layout of the proposed system. It consists of four major modules, iris localization, eyelid detection, iris coding and matching. The system is evaluated by measuring the performance of the individual stages and the overall performance of the system. The details of the system modules are given in the following sections.

IV. IRIS LOCALIZATION AND EXTRACTION

Iris is the region between pupil and sclera of the eye. The inner boundary of the iris is the pupil boundary, while the outer boundary of the iris is called limbic boundary, which separates the iris region from sclera. Iris localization is the process of extracting this region by detecting the borders of pupil and limbus.. It is one of the most important stages in iris recognition system because without successful localization of the iris, the forthcoming stages eyelid detection and iris coding may produce incorrect results and thus decreasing the system performance.

In this paper, the algorithm of pupillary border detection, which was introduced by Tahir and Bindian [54], is modified to be more adaptable for various types of databases. In addition, a new method for limbic border detection is introduced.

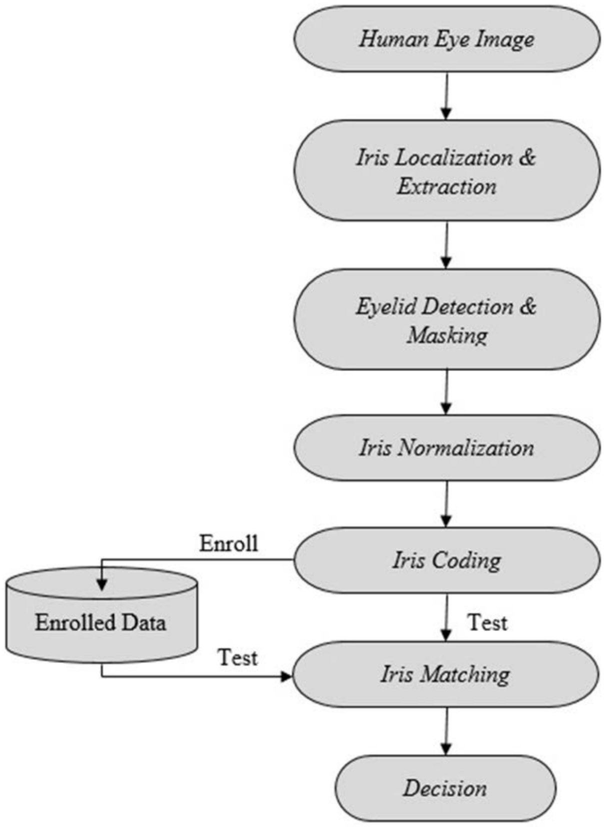

Fig. 1. The layout of the proposed system

A. Pupil Boundary Detection

Many methods for pupil boundary detection have already been introduced. The used different techniques such as Hough transform, integro-differential operator, thresholding, image scanning, histogram projection profile, etc., [13], [14], [51], [54]-[62]. Amongst them, the scanning based method, which was introduced by [54], has achieved good results for CASIA-V1.0 database. It does not use any pre-assumptions about the initial center of the pupil. However, it has one major shortcoming with images that suffer from the specular reflection points such as the images of CASIA-V4.0-Lamp and SDUMLA-HMT databases. In this paper, this method is modified to overcome the problem of specular reflection point by using morphological filter and image smoothing instead of exponential enhancement and Laplacian filter for pre-processing methods. The use of morphological filter will remove or diminish these specular reflection points, while the use of image smoothing will make the pupil area more homogeneous, so easier for detection. The other parts of the method remained as in the original work of [54]. Fig. 2 shows the procedures of applying the modified pupil detection algorithm to a sample of CASIA-4-Lamp iris database. According to this figure, the specular reflection point in the pupil region is removed by the use of morphological filter and the output of logical AND between the vertical and horizontal scans is used to draw the pupil boundary.

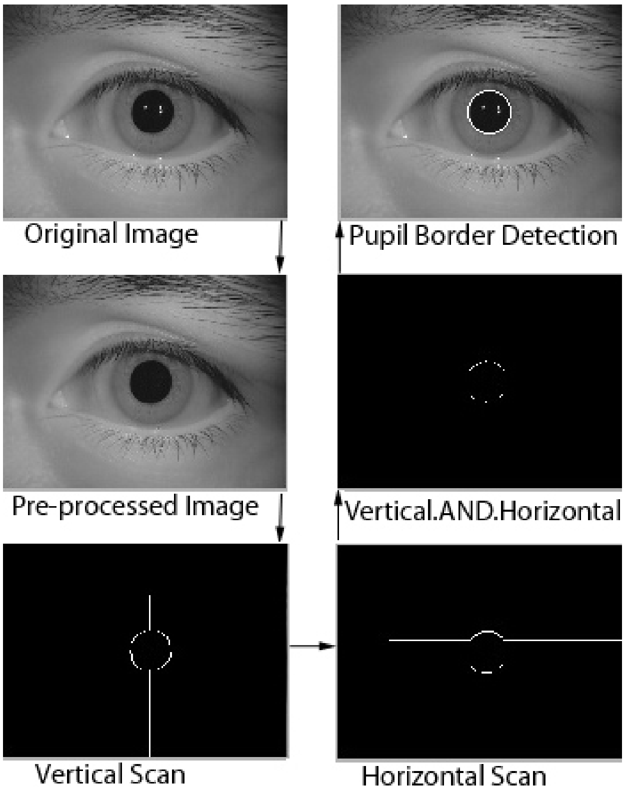

Fig. 2. Pupil detection steps

B. *Limbi Boundary Detection and Extraction*

Wildes approach for iris localization has proven to be very successful. This is due to fact that Hough transform technique is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise. However, Hough transform is considered as a time consuming process. In this paper, Wildes approach for detecting limbic boundary is modified first by restricting the use of Canny edge detector and Hough transform to a small Region-Of-Interest (ROI) and second by using histogram equalization and Gaussian filter as pre-processing prior to Canny edge detector. ROI is constructed from two rectangular regions, each on one side of the pupil. Both rectangles have the same width, which equals the diameter of the pupil, but they may have different lengths from side to side depending on position of the pupil in the image. The use of ROI has two advantages. First, it excludes the unwanted parts of the image such as eyelids and eyelashes from the process of limbic boundary detection since these parts may have bad impacts on the process of edge detection. Second, it speeds up the system by achieving substantial reduction in the processing time of Canny edge detector and Hough transform as the average area of ROI is found to be less than 20% of the total image size. Fig. 3 shows the procedures of the modified method of limbic boundary detection for a sample taken from SDUMLA-HMT database.

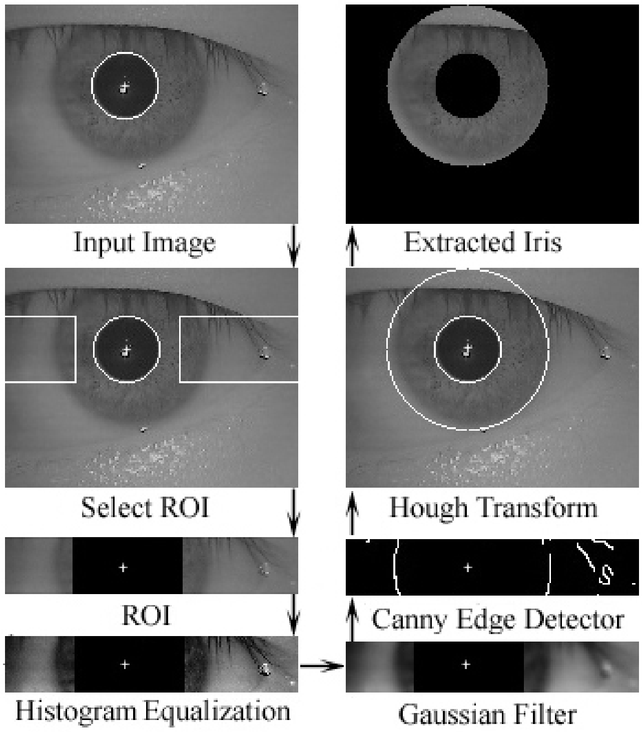

Fig. 3. The procedures of iris localization

V. EYELID DETECTION AND MASKING

The removal of Eyelid is important since they occlude some parts of iris region, therefore they may decrease the recognition accuracy [63]-[65]. Many methods and algorithms have already been developed and achieved encouraging results. The most effectives of these methods are those based on parabolic models and edge detection techniques, [10],[66]-[68]. In this paper, the method of Refine-Connect-Extend-Smooth (R-C-E-S), which was introduced by [10] is adopted, as to the author view, it is more realistic, because of three main reasons. First, it does not use pre-assumption models. Second, this method detects three cases, iris covered by one eyelid, iris covered by both eyelids and free iris, where there is no eyelid over the iris. Third, it has achieved average accuracy above 97% for upper eyelid and 99% for lower eyelid using the same databases (CASIA-V1.0, CASIA-V4.0-Lamp and SDUMLA-HMT) as in this paper.

After detecting the eyelids, the masking image is generated to be used in the process of iris transform and matching. Fig. 4 shows the major steps of the eyelid detection and masking stage for two samples taken from CASIA-V1.0 and SDUMLA-HMT databases. The input image is the extracted iris and the output image is the eyelid mask.

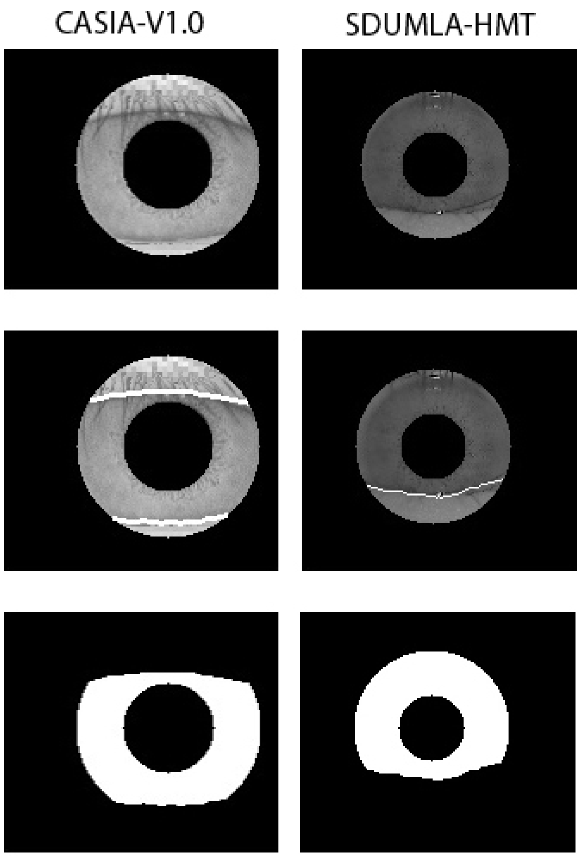

Fig. 4. The major steps of eyelid detection and masking

VI. IRIS NORMALIZATION

In order to simplify the process of coding and matching, the iris region is transformed geometrically from a ringed shape to rectangular shape using the rubber-sheet method. This transform is scale invariant, therefore it is thought to be effective when dealing with databases whose images have iris rings of different width as is the case with CASIA-V1.0, CASIA-V4.0-Lamp and SDUMLA-HMT. The number of rows and columns in the transformed iris is controlled by the number of pixels on the radial lines and the angular space between radial lines. The size of the rectangle is chosen to be 24 row by 128 columns. This means that the iris sector on each radial line is sampled to 24 pixels and the angular space between radial lines is 2.8125 degree. In case when the width of the iris ring is less than 24 pixels, some of the rows will be duplicated in the transform image and this will not degrade the recognition rate of the system.

VII. IRIS CODING

For iris coding, the real and imaginary Gabor filters are used and the number of columns in the final code will be doubled. That is, the final size of the iris code will be 24 rows by 256 columns. However, a successful use of Gabor filter needs a proper selection of some parameters that control the effectiveness of the filter. In order to illustrate how Gabor filter is designed the equations of the even and odd parts of 2D Gabor function are given below according to [69]:

$$g_{\lambda,\theta,\varphi,\gamma}(x,y)een = exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right).cos\left(2\pi i\frac{x'}{\lambda}\right)+\varphi \quad (1)$$

$$g_{\lambda,\theta,\varphi,\gamma}(x,y)odd = exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right).sin\left(2\pi i\frac{x'}{\lambda}\right)+\varphi \quad (2)$$

$$\left.\begin{aligned} x' &= xcosy\theta + ysin\theta \\ y' &= -xsin\theta + ycos\theta \end{aligned}\right\} \quad (3)$$

Where,

$g_{\lambda,\theta,\varphi,\gamma}(x,y)even$ and $g_{\lambda,\theta,\varphi,\gamma}(x,y)odd$, are the even and odd values of Gabor filter (the real and imaginary parts of Gabor filter). θ is the orientation angle of the normal to the parallel stripes of a Gabor filter and φ is the phase offset. λ is the wavelength of the sin and cosine factors of the Gabor filter kernel and β is the half-response spatial frequency bandwidth of Gabor filter. γ is the spatial aspect ratio, specifies the shape Gabor filter, σx and σy are the standard deviation in x and y directions, which depend on β and γ. The values of σx and σy are calculated from the following equations:

$$\sigma_x = \frac{\lambda}{\pi}\sqrt{\frac{ln2}{2}}.\frac{2^\beta+1}{2^\beta-1} \quad (4)$$

$$\sigma_y = \frac{\sigma_x}{\gamma} \quad (5)$$

These parameters determine the size of the Gabor real and imaginary masks. For the proposed system, the following values are selected: λ = 5, β = 1, θ = 0, φ = 0, γ = 1. The value of σx and σy are calculated using equations (4 and 5). With these parameters, the size of each Gabor mask will be (9 x9).

The direction of the iris texture in the coded iris is near to normal. This means that the change in the texture appears in the horizontal direction, therefore, the orientation angle of zero value is chosen. The left side of Fig. 5 shows the procedures of iris normalization and coding and the right side shows the process of eyelid mask generation.

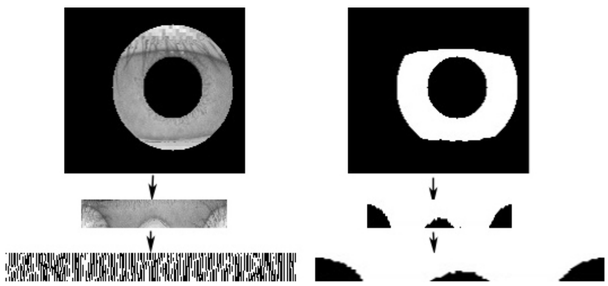

Fig. 5. The procedures of iris transform and coding

VIII. MATCHING

The pixels of the final iris code, which was generated from the previous stage, have values of zero and one, while the generated mask have values of one for the iris region and zero for the eyelid region. In the proposed system, Hamming distance (HD) is used for measuring the degree of matching between the test iris and the enrolled ones. The equation of HD measure using masking images can be found in [13]. For each test iris, one-to-N comparisons are required

IX. RESULTS, DISCUSIONS AND EVALUATION

The performance of the proposed system is evaluated by measuring the accuracy and speed of the individual stages (pupil detection, limbus detection, eyelid detection) and the whole system. Measuring the performance of these stages is important as, to the author view, the outcome of these stages have significant impact on the overall performance of the system. Three databases are used to test the system performance, CASIA-V1.0 with 756 images, CASIA-V4.0-Lamp with 1976 images and SDUMLA-HMT with 1060 images. The details of these databases can be found in [70]-[72]. To speed up the system, the images of CASIA-V1.0 and CASIA-V4.0-Lamp are down-sampled to 160 x 140 pixels, while the images of SDUMLA-HMT are down-sampled to 160 x 120 pixels.

A. Performance of Individual Stages

The performance of the processing techniques at each stage is measured explicitly. Table I shows the accuracy of pupil boundary detection, limbus boundary detection and eyelid detection.

Table I: Accuracy of individual stages

Stage	ACC% CASIA V1.0	ACC% CASIA V4.0	ACC% SDUMLA HMT
Pupil Boundary Detection	100	99.9	99.9
Limbic Boundary Detection	99.9	99.6	99.7
Eyelid Detection	93.2 *U* 99.15 *L* 96.7 *F*	97.6 *U* 98.3 *L* 97.8 *F*	95.1 *U* 95.3 *L* 96.92 *F*

U: upper eyelid, L: lower eyelid, F: free iris

According to this table, all the three stages perform well, especially the performance of pupil and limbus boundary detection. For CASIA-V1.0, the boundaries of all pupils were detected correctly. This is due to the fact that the pupil region in the images of this database had been replaced by the database source with a circular region of constant intensity to mask out the specular reflections, [70]. For CASIA-V4.0-Lamp the boundaries of only two pupils out of 1976 were detected wrongly and for SDUMLA-HMT the boundary of only one pupil out of 1060 was detected wrongly. The outer iris boundary for all CASIA-V1.0 images were detected correctly, except one, while the boundaries of eight irises out of 1976 were detected wrongly for CASIA-V4.0-Lamp and the boundaries of only three irises were detected wrongly for SDUMLA-HMT. After checking the recognition results for the images with wrong pupil and limbus boundary detection it appeared that all the images with wrong pupil detection were recognized wrongly, while not all of the images with wrong outer boundary detection were recognized wrongly. For CASIA-V4.0-Lamp, two of the eight images with wrong limbus detection were recognized correctly and for SDUMLA-HMT two of the three images with wrong limbus detection were recognized correctly. This might due to the fact that, the percentage of error in the detected limbus was small for these images. However, the most dramatic result was with the eyelids that were detected incorrectly. For CASIA-V1.0 dataset, more than 60% of the irises with incorrect eyelid detection were recognized correctly by the system. For CASIA-V4.0-Lamp and SDUMLA-HMT this percent even increased. These results lead to the conclusion that the stage of pupil detection has greater effect on the final accuracy of the system and then comes the stage of limbus detection, while eyelid detection has the least effect.

The accuracies of the pupil detection, limbus detection and eyelid detection stages of the proposed system are compared to the accuracies of the corresponding stages in previous works for CASIA-V1.0 and CASIA-V4.0, Table II, III and IV. Previous studies on CASIA-V3.0 were also included in the comparison, since CASIA-V4.0-Lamp is originally one of CASIA-V3.0 subsets. However, SDUMLA-HMT was excluded from comparison because not found for iris dataset, most of SDUMLA-HMT studies were done on finger-vein and multimodal biometrics recognition.

Table II: Comparison of the proposed pupil boundary detection method with previous methods

Method, Reference	ACC% CASIA V1.0	ACC% CASIA V4.0 /V3.0
Thresholding + raw, column gradients, [15]	100%	NA
Intensity Transform + Thresholding, [27]	NA	97.63
Minimum and Mean Intensity, [33]	100%	NA
Integro-differential Operator, [36]	NA	90.3
Active Contour + Hough Transform, [36]	NA	99.0
Morphological Operations + Snake Active Contour, [36]	NA	99.5
RCNN + GMM + MIGREP, [51]	NA	96.77
Proposed Method	100%	99.9

Table III: Comparison of the proposed limbic boundary detection method with previous methods

Method, Reference	ACC% CASIA V1.0	ACC% CASIA V4.0/V3.0
Integro-differential Operator, [15]	97.22	NA
Rotation Average Analysis of Intensity-Inversed Image, [59]	99.4	NA
Integro-differential operator, [16]	98.4	94
Template Matching, Integro-differential operator, [16]	98.7	98.8
ROI + Pixel Pairs of Minimum Intensity difference within ROI, [31]	NA	93.8
Expanding and a shrinking active contour, [37]	NA	95.1
R-CNN + GMM + MIGREP, [51]	NA	98.32
Proposed Method	99.9%	99.6

Table IV: Comparison of the proposed eyelid detection method with previous methods for CASIA-V1.0 Dataset,

Method Reference	ACC% Upper	ACC% Lower
Parabolic Hough transform, [1]	89.99	96.34
Eyelid edge fitting, parabola model , [57]	93.5	93.5
Refine-Connect-Smooth (R-C-S), [68]	87.3%	99.1%
Refine-Connect-Extend-Smooth (R-C-E-S) used in the proposed system	93.2%	99.15%

B. *Overall Performance of the System*

The system overall performance is evaluated using the three datasets, CASIA-V1.0, CSIA-V4.0-Lamp and SDULAM-HMT. Two scenarios exist for performance evaluation. The first is by dividing the dataset into two parts, one part is enrolled and the other part is used for testing the system performance. In the second scenario, which is called leave-one-out cross-validation, all the dataset samples are enrolled and have a chance of being used in the testing and training sets. In this paper, the second scenario is adopted. In doing so, all the images of the dataset are processed for iris extraction, eyelid detection, iris transform and iris coding, then stored in the storage. For identification mode, each iris code is tested against the enrolled data, except itself. This means that for CASIA-V1.0 there will be 755 Hamming distance measures and 755 comparisons per a test, for CASIA_V4.0-Lamp there will be 1975 Hamming distance measures and 1975 comparisons per a test and for SDUMLA-HMT Lamp there will be 1059 Hamming distance measures and 1059 comparisons per a test.

The overall accuracy, the False Positive Rate (FPR) and the False Negative Rate (FNR) of the system are calculated, using different threshold values of Hamming distance ranging from 0.366 to 0.4.

For CASIA-V1.0, the best overall accuracy was was 96.48% with EER = 1.76% at HD threshold-value of 0.385. For CASIA-V4.0, the best overall accuracy was 95.1% with EER = 2.45% at HD threshold-value of 0.375. For SDUMLA-HMT, the best overall accuracy was 93.6% with EER = 3.2% at HD threshold-value of 0.370.

The ROC curves of the system for the three datasets are given in Fig. 6. These curves were produced by plotting the HD values on the x-axis and the FPR and FNR values on the y-axis. The coordinates of the intersection point between the two curves represents the HD threshold-value and EER value at which the accuracy of the system is optimum.

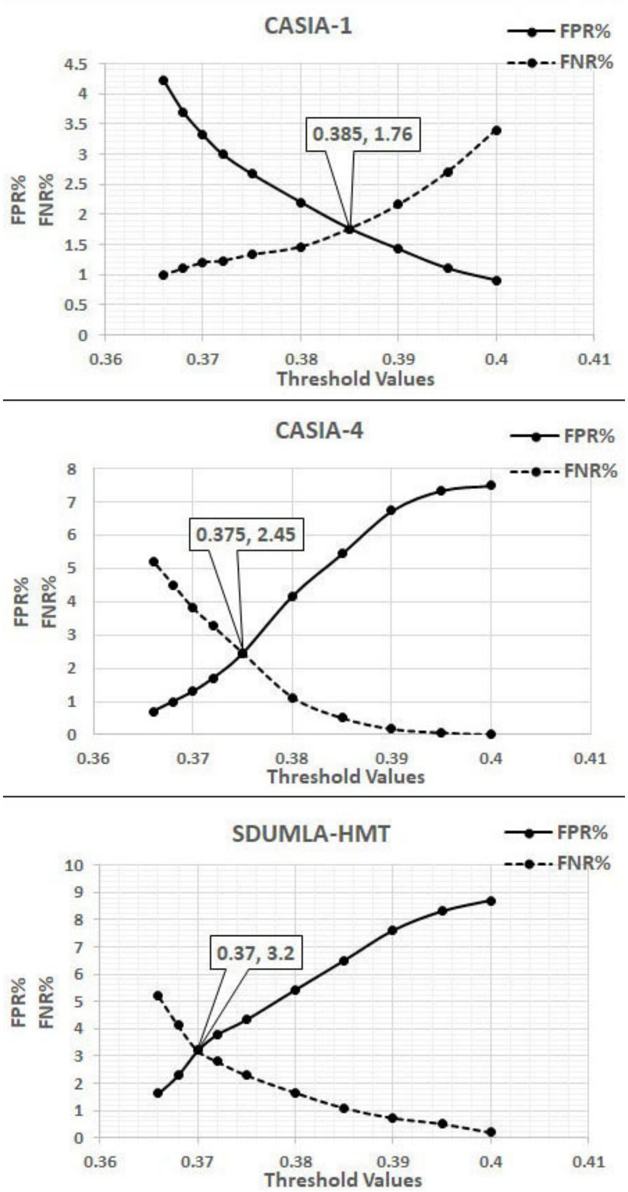

Fig. 6. ROC curves of the system for the three databases

These accuracies are reasonable taking in the consideration that standard datasets were used, which is of less quality compared to dataset captured by sensors with the possibility of adjusting the image quality. For instance, Daugman system achieved 99.9% accuracy with database created by the author, while it was reported by [15], that Daugman system achieved only 54.44% accuracy when applied to CASIA-V1.0 database.

C. *Comparison with Previous Methods*

In order to assess the effectiveness of the proposed system, its performance is compared with those of previous systems for the same datasets. Table V shows the accuracy of the proposed system and previous systems for CASIA-V1.0 and CASIA-V4-Lamp datasets. Unfortunately, SDUMLA-HMT dataset has widely been used for finger-vein and multimodal biometrics recognition, none of the previous works was found for iris dataset.

Table V: Comparison of the Overall accuracy with previous system for CASIA-V1.0 and CASIA-V4.0

CASIA-V1.0		CASIA-V4.0 / V3.0	
Method, Reference	ACC %	Method, Reference	ACC %
Corner Features, [22]	95.4	Oriented WT + HD, [18]	94.7
Neural Network, [34]	92.65	Template Matching, [26]	94.3
LPQ + LBP, [38]	95	RCHT + HOG + SVM, [40]	93.12
(Gabor Filter, [39]	92.85	Neural Network, [43]	95.36
Random feature points, [27]	95.07	PCA +SVM, [44]	90
FT, [42]	96	-	-
Proposed system	96.48	Proposed system	95.1

In order to evaluate the system speed, the average processing time for each stage and the total time needed for identifying one user for the three datasets as shown in Table VI.

Table VI: The average processing time for the individual stages of the system

Stage	Time Sec CASIA-V1.0	Time Sec CASIA-V4.0	Time Sec SDUMLA-HMT
Pupil Boundary Detection	0.052	0.040	0.045
Limbic Boundary Detection	0.110	0.085	0.095
Eyelid Detection	0.042	0.023	0.035
Iris transform and Coding	0.190	0.165	0.172
All Stages	0.394	0.313	0.347
Matching	9.7	25	13.5

These times are subject to a computer with these specifications; hp Envy 15 with Intel ® Core ™ i7 – 4510U CPU @ 2.00GHZ 2.60 GHZ, 64 – bit windows 10 operating system, x64 – based processor. The processing time for the detection of pupil, limbus and eyelid depends on the size of the iris region in the image. Although all the images of the three datasets were down sampled to the same size, the iris region of CASIA-V1.0 is larger than of SDUMLA-HMT, which in turns is larger than that of CASIA-V4.0-Lamp. Therefore, the processing time of the pupil, limbus and eyelids detection for the three dataset are not the same. These times with CASIA-V1.0 are the longer ones and with CASIA-V4.0-Lamp are the shorter ones. The matching time represents the bulk of the whole system time. It depends on the number of the stored iris codes in the enrolled database. The matching time for CASIA-V1.0 is the shortest, because testing one iris code requires 755 calculations of Hamming distance and 755 comparisons, while the matching time for CASIA-V4.0-Lamp is the longest, because testing one iris code testing requires 1975 calculations of Hamming distance and the same number of comparisons. However, the processing time of the proposed system can be reduced by a significant amount, especially the matching time, if multicores are used for improving the CPU performance of the computer.

Finally, to the author view, comparing the proposed system with previous systems for the processing time is trivial, since they used computers of different hardware.

X. Conclusion

The proposed system possesses some properties which make it competitive compared to the previous systems. These properties are mentioned below:

1) The system proved to be adaptive to different datasets, since it achieved acceptable accuracy and EER for the three datasets, CASIA-V1.0, CASIA-V4.0-Lamp and SDUNLA-HMT, which have been taken under different conditions of illumination. It is expected that the system may achieve better performance if applied to in house made dataset, where more control of the image quality can be given.
2) The methods of pupil boundary detection does not need pre-assumption of the pupil center. In addition, it is robust to illumination changes and specular reflection point.
3) The methods of limbus boundary detection is efficient computationally, since the processes of Canny edge detection and Hough transform were restricted to the pre-specified ROI only. In addition, it has achieved high performance for all three datasets.
4) The method of eyelid detection achieved high performance for the three datasets and was efficient computationally.
5) The accuracy and the effectiveness of the stages decrease as moving from the first stage to the last stage. The stage of pupil detection comes in the first place since its accuracy was the highest and all of the images with wrongly detected pupil were classified wrongly. The stage of limbus detection comes the next and the stage of eyelid detection comes the last as it achieved less accuracy and most of the images with wrong eyelid detection were classified correctly. In other words, the stage of pupil boundary detection is the most important, then comes the stage of limbic boundary detection and at last comes the stage of eyelid detection.

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