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Improved Iris Verification System

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Abstract
Most computer based systems need to be secured. Human iris is a unique identifier for each person which is used widely. Iris recognition is preferable for person verification. Iris verification divided in two phases: the enrollment phase and the testing phase. This paper tackles developing an improved iris verification system using Chinese Academy of Science Institute of Automation (CASIA) iris database. Basma Mohamed Hesham System (BMHS) consists of four main steps. These steps are: iris and pupil localization/ segmentation ,using a Canny Edge Detection scheme and circular Hough Transform with a novel dynamic-based technique in determining iris radius range ,iris normalization (using Daugman’s rubber sheet model),feature extraction/ encoding (using the convolution with log Gabor filter wavelets) ,and pattern matching (using hamming distance as a matching technique).This proposed dynamic-based technique in determining the iris radius led to improve the iris localization /segmentation level. We compared our system with other iris verification systems. BMHS is evaluated based upon False Acceptance Rate (FAR), False Rejection Rate (FRR) and computational cost required in both open and close set. A comprehensive experimental work shows an improvement in the false rejection rate and reduction in the system computational cost on different types of iris image. [1]

Key Words: *Localization; biometric identification; pupil.*

1. Introduction
Currently, industry and academia have a high attention on biometric personal recognition and verification."Who really you are” is the base of working in most biometric systems. The iris is an element in the human body, where it was established at an early stage of human life. The iris does not change for long part of life. Construction and installation of the iris of the eye is not related to genetic factors. Iris of every person is different from the other even if they are twins [1]. Recently, human iris recognition considered as one of the most successful methods for human authentication due to its accuracy and effectiveness [2]. In addition, it is tested to be one of the most reliable approaches for automatic personal recognition/verification with high-quality images of the eye acquired in the near-infrared (NIR) wavelengths [3]. Today's, efficient and fast verification systems are the demand of the current area. Verification system means the comparison between the features extracted from the person and the feature template stored in the database. Therefore, only authorized person will be accepted. Iris verification system divided in to two phases: the enrollment phase and the testing phase.In the first phase : the Authorized person registered in the system database .A template of features extracted from his/her iris image and stored in the system data base. In the testing phase, anyone from outside the system needs to arrival to the system must insert his/her eye image .Localization and isolation to the iris from the eye image executed as the first stage. Iris segmentation and eyelash detection executed as the second stage. Segmentation is very important stage because information extracted from an iris image that does not segment successfully will be not effective [4]. Iris normalization and feature extraction executed. Then matching these features with the claimed identity feature vector stored in database is required. The system decides whether the feature vector of the given person iris similar to the feature vector of the claimed person in databases using one of the matching algorithms. Accordingly, person accepted or rejected. User will be able to access the system if the similarity between the image of the iris and its model stored in databases less than a specific threshold, otherwise the user is rejected [5].Fig. 1 illustrates the first four stages of the iris verification system enrollment phase. Iris recognition is more reliable in many usages. In Future Warfare choosing the iris recognition is considered highly efficient and secure technology [6]. There are some characteristics in the human iris make it reliable to determine the identity of the human. Uniqueness and stability are some of these characteristics [7].However, human iris face some problems such as covering part of the iris area by the eyelids and eyelashes (incomplete iris image) and strong lighting on human eye maybe affects on the iris/pupil

[1] This study has been implemented on Mat Lab 2012 platform. University of Cairo

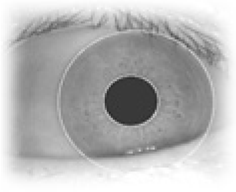

Figure 1(a). Iris localization and isolation iris from the eye

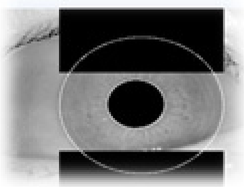

Figure 1(b) .Eyelash detection technique in the segmented iris

Figure 1(c).Normalized iris region

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Figure 1(d). Feature extracted from the normalized eye

regions. This problems lead to up growth a difference between the iris images for the same person [1]. As we know "Iris recognition system is a new technology for user Verification" [5]. This paper proposed the use of human iris in developing a robust verification system .In order to improve the performance of the proposed iris-based verification system ,We developed a novel dynamic-based technique in determining iris radius range used in the Circular Hough Transform(CHT) .We employed hamming distance in the matching phase as a classifier with threshold 0.38.

The reminder of this paper is organized as follows: Section 2, is the literature review. Section 3, shows the basic structure of the iris recognition system. In Section 4, the proposed BMHS approach to improve the verification system is presented. Section 5, the performance measures are used in this research .The results and discussion are presented in section 6.

2. Literature Review

In 2008, Vatsa and Singh proposed 1D log polar Gabor wavelet and applied on a transformed polar iris image to extract textural features and Euler numbers used to extract the topological features. Their proposed system results showed that reduction in the false rejection rate with zero acceptance rate[8].

In 2008, Salami was adopted SVM as a classifier in order to develop the iris-based verification system. They don’t mentioned which algorithm used in the segmentation phase. For normalization of iris regions, a technique based on Daugman’s rubber sheet model was employed in there proposed system. Feature extracted and encoded has been implemented by the convolution process of the normalized iris pattern with 1D Log-Gabor wavelets .They have been used SVM with polynomial kernel function of order 8. They used the CASIA[9] iris image database collected by the Institute of Automation of the Chinese Academy of Sciences. Based on obtained results, SVM classifier produced zero False acceptance rate for both open and close set condition. However, further study needed to improve the system speed which is 0.0812 sec and FRR which was 19.80 for five users [5]. In 2009, Vrček and Peer implemented authentication and verification system of the any person based on iris texture. The iris images used in there research are from the CASIA v1.0database (756 images, 108 eyes). They don’t mentioned which algorithm used in the segmentation phase .For normalization of iris regions, a technique based onDaugman’s rubber sheet model has been employed in there proposed system .They used hamming distance in matching between two persons .They observed that , there is an error in the segmentation step, the segmentation of iris did not succeed. They were can not to apply further steps. The comparison results using threshold value of the HD 0.427, has been given the rate of false approval (False Acceptance Rate) equal to 0%, and, on the other hand, gives 11.584% False Rejection Rate (FRR) [10] .

In 2010, Sudha presented a complete iris recognition system consists of an automatic segmentation system based on the Hough Transform .They localized iris ,pupil region .However, the automatic segmentation was not perfect, becouse it could not successfully segment the iris regions for all of the eye images in the two databases[11]. In 2012, Marciniak , Dąbrowski and Chmielewska stated the detailed analysis of implementation cases in the preparation of the novel iris recognition system. They have been focused on the feature extraction and encoding with the execution time analysis. They used the Hough transform in segmentation phase. Feature extraction implemented using logarithmic gabor filter. The have been studied on two involved databases: CASIA and Iris Bath. The average total time of CASIA v1 database processing is 2:30 sec. During their study the following results were obtained: FAR = 0.351% (false acceptance rate) and FRR = 0.572% (false rejection rate). And the overall accuracy equal to 99.5%. For the CASIA database v.1.0. The best result was brained with the code size of 360 × 40 bits and the following results were obtained: FAR is equal to 3.25%, FRR is equal to 3.03%, and the ratio of correct verification is equal to 97 % [18]. They conclude that, the inner half of the iris after output from the normalization phase is the most important area. This area contains the most distinctive information for each person. [12].

In 2013, Sheeba and Veluchamy developed a technique to improve performance of iris recognition system based on stationary images. Canny edge detection used during the segmentation and localization, image management tool in LABVIEW and vision module used in the implementation. Using canny edge detection for localization and detection. Also normalization of iris has been performed using the Gabor filter. The feature vectors have been extracted using Local Binary Pattern (LBP). the classification has been performed using Learning Vector Quantization (LVQ). Matching has been performed using hamming distance. To evaluate the system, they have been used CASIA iris database. Which is released by the Institute of Automation in Chinese Academy of Sciences. The CASIA V1.0 iris database is a classic iris set which contains 756 images, 108 eyes.Thesystem time complexity is4.295 sec. and the False Acceptance Rate equal to 0%, and, the false rejection rate is 1%, hamming distance used with 0.35 threshold[13].

In 2011, Sirlantzis Hoquea and Deravi proposed and developed a novel iris segmentation method. This method is able to cope with noisy images of visible and near infra red spectrum. the proposed segmentation algorithm has been able to cope efficiently with both near infra ed and visible spectrum images; as well as ,the algorithm speed can be increased significantly with a minimal reduction in accuracy by 3%. The near infra red dataset used in our experiments is CASIAv3, the Lamp subset, which has 16213 images from 411 users and CASIAv1 .the system iris segmentation accuracy on CASIAv1 is 91.97%. The execution time for the algorithm is approximately 2.97 seconds[14] .

In 2014, Gale and Salankar studied methods for iris pattern feature extraction on the basis of CASIA iris database. And they analyzed the result of the various feature extraction methods based on CASIA iris database[15].

It is seen from the literature review that ,many researchers used Hough Transform in their systems to localize and segment the iris and pupil. However, the use of Hough Transform in segmenting iris and pupil affected by the choice of iris radius range to search for. This effects on the correctness of segmented iris , and hence, the verification accuracy . Instead of using fixed range iris radius to search for in the segmentation phase. We are proposing a dynamic-based technique in determining the iris radius range. The use of such technique is expected to enhance the accuracy of segmented iris which enhances as well the overall accuracy of a verification system.

3. Structure of the Basic Iris Recognition

3.1 Iris localization/segmentation

Figure 2, gives an overview of the eye texture. An eye image contains un useful parts that not important for iris recognition system, such as the pupil, eyelids, sclera, and so on. For this reason, the first step of the iris recognition system is the segmentation. It exists in order to localize and extract the iris region from the eye image. Iris localization determines the iris region between pupil and sclera. Upper and lower boundaries of the iris are needed to be detected. "The iris region can be approximated by two circles, one for the iris/sclera boundary and another, interior to the first, for the iris/pupil boundary. The eyelids and eyelashes normally occlude the upper and lower parts of the iris region"[16]. Several systems used several algorithms in the segmentations .Circular Hough Transform and Daugman's Integro-differential Operator are the most popular algorithms .Hough Transform used to determine the parameters of simple geometric objects, such as lines and circles, present in an image. One problem faced with the implementation of the CHT was that it required different parameters to be set for each database. Radius range of iris and pupil to search for is one of these required parameters. For the CASIA database, values of the iris radius range from 90 to 150 pixels, while the pupil radius ranges from 28 to 75 pixels. The Hough transform for the iris/sclera boundary was performed first, then the Hough transform for the iris/pupil boundary was performed within the iris region, instead of the whole eye region[3].

Daugman's Integro-differential Operator is another algorithm used for localizing the iris in eye. But does not work accurate on images that contain noise such as reflections.

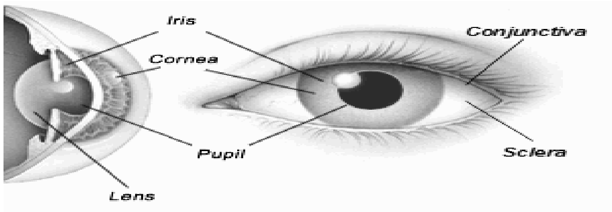

Figure 2.Texture of the human eye

3.2 Iris normalization

Inconsistency maybe exists in the images of the same person. In order to allow comparisons and overcome imaging in consistencies, transform the segmented iris texture to fixed dimension is required. Normalization is exist to convert the range of pixel intensity values to fixed range. Several systems used several algorithms in the normalization. Daugman's rubber sheet model, image registration, virtual circles, a polar to Cartesian transformation and bilinear interpolation are some of these algorithms .The most common is Daugman's rubber sheet model showed in Fig.3. "Daugman remap each point within the iris region to a pair of polar coordinates (r,θ) where r is on the interval[0,1] and θ is angle [0,2π]"[3].

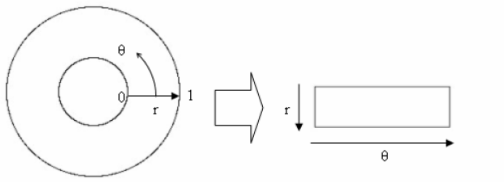

Figure 3.Daugman's rubber sheet model in the normalization process.

3.3 Feature encoding/ extraction

In this stage, the most distinct and unique information is extracted from every normalized iris image. This unique information, which is called a feature vector, will be stored in the database. To allow comparisons between two irises, features of the iris encoded in the database used against the feature of authorized/unauthorized person extracted. Many methods have been proposed to feature extraction by many researchers. Such as Laplacian and gausaian filter[3],Gabor Wavelet, Log Gabor Wavelet & PCA[17].

3.4 Feature matching

Here, a decision can be made to determine whether the two iris pattern generated from the same/ different person. There are several methods used for feature matching such as hamming distance, Weighted Euclidean Distance, normalized correlation, Key Nearest Neighbors (KNN)' Support Vector Machine (SVM)' .The most common one is the hamming distance.

4. Proposed Model

It is known that, the accuracy of the verification / recognition iris based system is highly dependent on the formulation of feature vector. Most important module in formulation iris feature-vector is the iris segmentation level. Since Circular Hough transform (CHT) is the most popular algorithm in iris segmentation systems. CHT with unknown radius range is more accurate. However, it works on a three dimensions and thus consume more computational time to find the circle parameters. In this work, CHT case with less cost (case of known radius) has been selected to segment the eye images. The case of CHT with known radius is required the radius of the circle to be detected in the image to be known. Most previous works that used CASIA database with CHT used 90-150 as a radius range to the human iris. However, the results of segmentation suffer from problems of inaccurate detection as shown in figure 4.

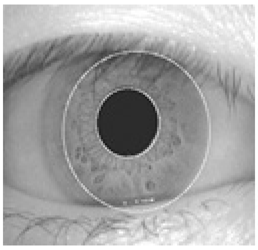

Figure 4(A). Segmentation of image 95 (iris radius 90-150)

Figure 4(b). Segmentation of image 46 (iris radius 90-150)

developed in order to achieve irises that are more accurate as shown in figure 5.

In the proposed approach, Circular Hough Transform is employed with modifications in order to improve the number of correctly segmented images. Our segmentation algorithm is based on implementing the circular hough transform with a dynamic range determination technique to detect iris and pupil boundaries exactly, thus for determine the radius and centre coordinates of the pupil and iris regions. Some steps have been implemented in order to identify iris/pupil circles in the Hough Space This steps are:

1) Employ canny filter on the human eye image to generate a binary image with clear edges.
2) Create a space that contains a cell for each pixel called accumulator H.
3) Increment all cells according to the circle equation stated number 1, the incrimination by one each time. That where any circle needs three parameters(x,y,r), This parameters passed through the Hough space to define the circle,

$$x^2 + y^2 = r^2 \quad (1)$$

The x,y are the center coordinate of the circle and r is the circle radius (this parameters selected based on a dynamic technique determination).
4) Searching for maximum point in the Hough accumulator, these points is corresponds to the radius and centre coordinates of the circle, best defined by the edge points.

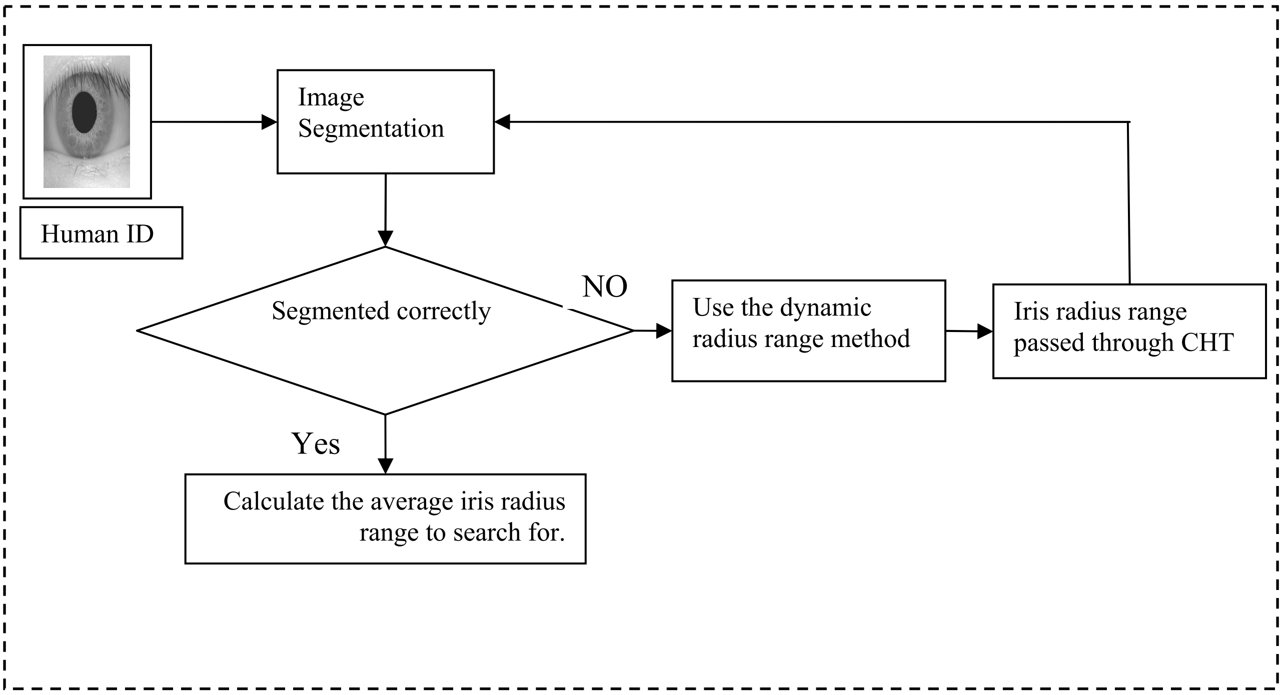

Figure 5. A dynamic-based technique in determining the most appropriate iris radius range to search for

In our proposed approach, a dynamic-based technique in determining the more suitable iris radius range to search for

The technique started with a small iris radius rang to minimize the number of circles created in the Hough space (H) and this is expected to minimize the computational time of the segmentation phase. We have been observed that, whenever we change the iris radius range passed through the CHT, the segmented images changed related to the change of ranges.

modeled as a flexible rubber sheet, which is expand into a rectangular area with constant dimensions[2].The process of the remapping iris region from (x,y) Cartesian coordinates to the normalized non-concentric polar representation is modeled as[3]:

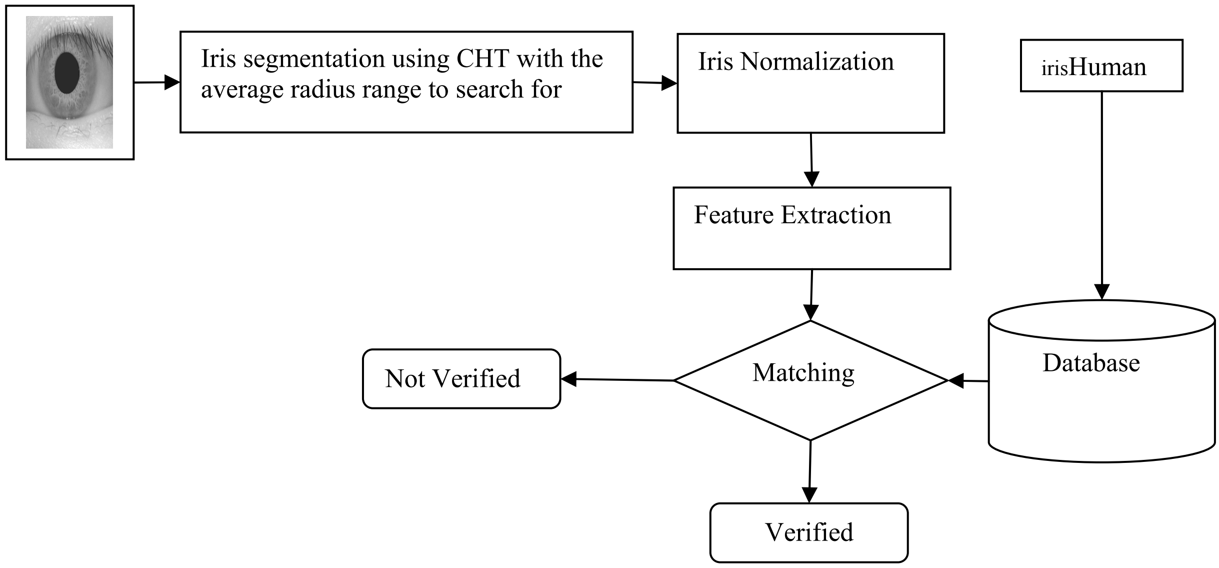

Figure 6.Structure of the Proposed System

After more suitable iris radius range is calculated in terms of segmentation accuracy. The proposed iris-based verification system consists of two phases: enrollment phase and testing phase. In the two phases image localization and segmentation, normalization, extraction feature vector are required .In the enrollment phase each person registers to the system database with show his/her identity. A template of bits is stored in the system database. In the testing phase, the system implements sequence steps are: image segmentation, iris normalization, feature extraction, template matching employed to verifying the person identity. In order to evaluate the dynamic method, this work employed automatic iris verification system. Figure 6 shows the structure of our verification system.

4.1 Iris Segmentation

Iris segmentation is the most important phase in Iris verification module. This section used Circular Hough Transform (CHT) after employed the dynamic technique. The output of this technique is the most appropriate iris radius rang used through CHT as mentioned earlier.

4.2 Iris Normalization

As mentioned in the previous, to overcome the inconsistencies between the iris images, normalization is required. Lighting, difference in distance between the camera and the person eye, all this is possible affect on image dimensions. Iris normalization converts the iris image to fixed dimension image. The normalization process will produce iris regions, which have the same constant dimensions. We employ Daugman's rubber sheet model. As in Figure 3 ,the circular iris region is

$$\mathrm{I}\big(\mathrm{x}(\mathrm{r},\omega),\mathrm{y}(\mathrm{r},\omega)\big)=\mathrm{I}(\mathrm{x},\mathrm{y}) \qquad (2)$$

where I(x,y) is the segmented iris region, (x,y) are the original Cartesian coordinates, (r,θ) are the corresponding normalized polar coordinates.

4.3 Feature Extraction

After we got the iris region and mapped it to normalized image with fixed dimensions .We extracted a template of bits from the normalized iris pattern .The extraction process is convolve the normalized iris pattern with 1D log Gabor filter wavelets. decomposed the 2D normalized image to multiple 1D signal. Each 1D signal convolved with 1 D log Gabor wavelets. Log-Gabor filters are constructed using[3]:

$$G(f)=exp\left(\frac{-\big(log(f/fo)\big)^2}{2\big(log(\sigma/fo)\big)^2}\right). \qquad (3)$$

Where *fo* represents the centre frequency, σ gives bandwidth of the filter [5].The complex valued signals output from the convolution process are phase quantized to four levels using the Daugman method. The feature extraction illustrated in Fig. 7.

The output from this level is a template contains values 1 or 0 depending on which quadrant it lies in, called feature vector. The feature vector size is 20*480 (9600) bit.

4.4 Iris Matching

Here, after applying and experimenting number of classifiers such as hamming distance, Euclidian distance, SVM, we found the hamming distance is the more accurate one to be using in matching two templates of

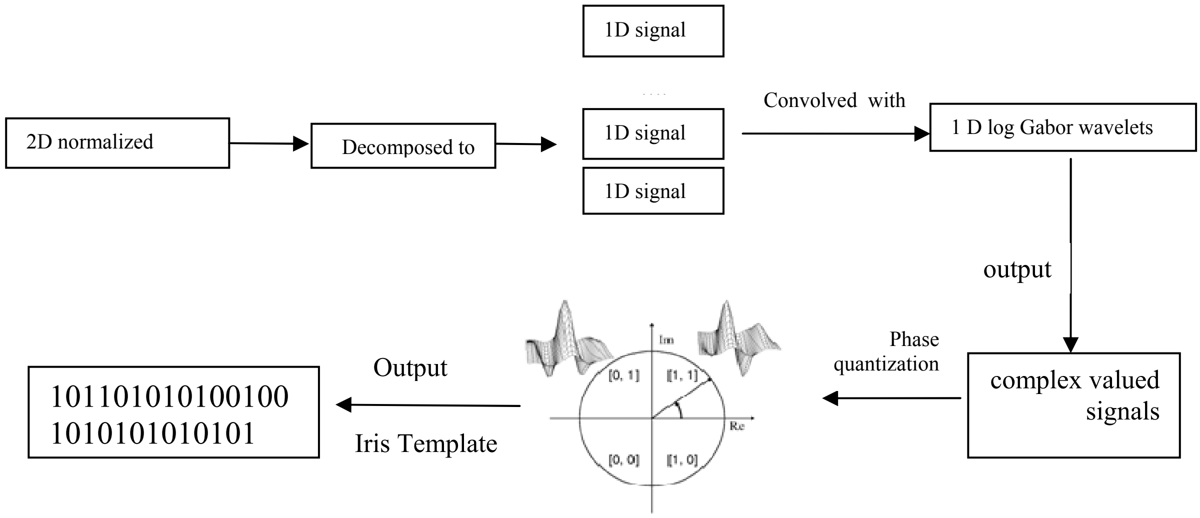

Figure 7 .The feature extraction process

bits. It was appropriate as it reduced the system computational time and reduced the FRR. Hamming distance (HD), depends on comparing two bit patterns(x,y) .The average hamming distance define as the sum of the exclusive-OR between X and Y over N such N is the total number of bits .The HD constructed using[3]:

$$HD = \frac{1}{N}\sum_{j=1} X_j (XOR) Y_j \quad (4)$$

If the HD less than 0.38 the person is authorized ,else the person classifed as unauthorized person.

5. Performance Measures

In order to measure the decision accuracy of the iris verification system,the performance protocol is defined as follows [21]. Let the stored iris template of a person be represented with *T*, and the acquired input for recognition be represented with *I*. Then the null and alternate hypotheses are:

H0 = I≠ T, input *I* is not from the same person as the original template.

H1 = I= T, input *I* is from the same person as the original template.

The associated decisions are:

D0 the person is not who she/he claims to be.

D1 the person is who she/he claims to be.

We know from mathematics that, the conditional probability of event A given event B is defined by:

$$p(A|B) = \frac{P(B|A)*P(A)}{P(B)} \quad (5)$$

In this work, the performance protocol can be measured in terms of:

1) False match rate (FMR) called false acceptance rate (FAR).

2) False non-match rate (FNMR) called false rejection rate (FRR):

The False Match Rate and the False Non Match Rate are define as follows:

FMR= P (D1|H0= True) (6)

FNMR= P (D0|H1=True) (7)

6. Database and Experimental Methodology

6.1 Iris database

The Chinese Academy of Sciences–Institute of Automation (CASIA) eye image database is used in the experiment. CASIA database contains near infrared images and it is the most always used on iris biometric experiments. CASIA Iris Image Database Version 1.0 (CASIA-IrisV1) includes 756 iris images from 108 eyes. For each eye, 7 images are captured in two sessions .To evaluate the effectiveness of the proposed system, a database of 432 grayscale eye images (108 eyes with 4 different images for each eye) was employed. About 400 grayscale eye images with 100 unique eyes are considered as authorized users and others are impostors.The experimental results were conducted on at 3.00GHz core i3 PC with 1GB RAM.

6.2 Evolution strategy

Since we have four images to each person(one for testing and three for training) ,we can evaluate the FNMR and FMR based on conditional probability. We have been in the testing 108 images. 100 images are authorized. Eight persons are unauthorized users .We have been tested each authorized and unauthorized users three times in order to verify if this user is the claimed one. User number one matched to three templates, although the other users .We can say that, we have been 100*3 images are the input images of authorized person. When the decision is 1 this means the user is accepted, when the decision is 0 this means the user is rejected. Table 1 is show part of the experimental results. FNMR as mentioned previously can be calculated as the probability of the number of authorized person rejected times the probability of the number of unauthorized person over the probability of the authorized persons.

6.3 Verification result

Low FNMR, low FMR and minimum run time are the main objectives of the proposed system in order to achieve both high usability and high security of the system. We have two sets closed set, open set. When

authorized person used other authorized person identity this means the FAR increased in the closed set. When unauthorized person used other authorized person identity this means the FAR increased in the open set. We evaluate our system in the two sets.
In the training phase, in the segmentation, we started using Hough Transform with the radius of iris and pupil to search for from 90 to 150 pixels and pupil radius ranges from 28 to 75 pixels, we have obtained that the FRR is 5.78% .Due to the 20% of images Segmented incorrectly as in fig 4(A) and 4(B) to user 46and 95.
Then we implement our dynamic-based technique in determining iris radius range. We found 110 to 150 iris radius range to search for is more suitable to give more correct segmented image for some images.
This paper shown that, 95-140 is the more suitable radius range to search for. Because only three images from 108 segmented incorrectly .The false rejection rate reduced to be 0.241% with a minimal increasing in the false acceptance by 0.231%.
This paper has shown that, the most appropriate iris radius range which give 100%segmentation accuracy to user 46 is from 110- 140 .

Figure 8 illustrates the use of CHT in segmenting iris is affected by the choice of iris radius range to search for. These effects on the verification accuracy in terms of the false rejection rate and acceptance rate. In other words whenever the iris radius range change, the FRR and FAR change.

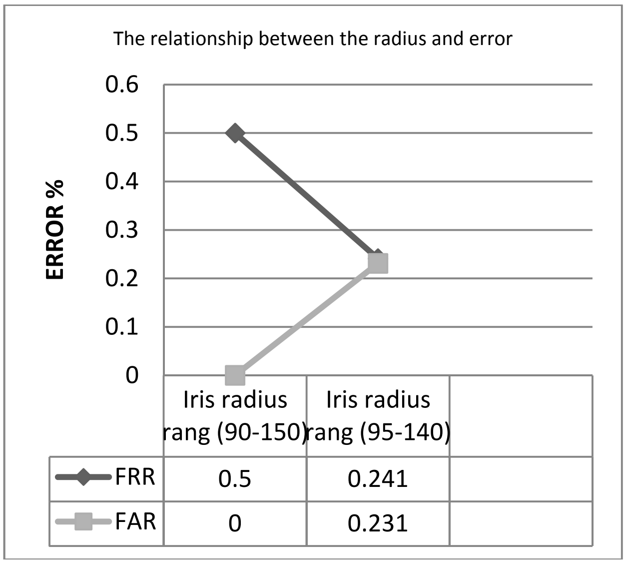

Figure 8.change of FRR,FAR with the change of iris radius range search for

In the matching stage, we tried multiple thresholds (0.35, 0.38, 0.4, 0.41 .., and 0.45). When threshold of 0.35 in hamming distance used the average of FNMR is 22.9% .When the threshold of 0.45 used the FMR will increase dramatically. So this work shown that, the best suitable threshold is 0.38 which give us 0.241 % FNMR. But on the other hand the average of authorized person used other authorized person has a minimal increase by 0.231% in the closed set, as shown in table 1 user 105 used the ID of user 71.Table 1 shows some of the testing performances of our methodology with hamming distance matching-based authorized user models.

I(Input)	T(template)	Threshold	Decision	Closed set
1_4	1_1	0.38	1	
1_4	1_2	0.38	1	
1_4	1_3	0.38	1	
37_4	37_1	0.38	1	-
37_4	37_2	0.38	0	-
37_4	37_3	0.38	1	-
105_4	105_1	0.38	0	-
105_4	105_2	0.38	0	-
105_4	105_3	0.38	1	71_2

Table 1: subset of the experimental results

The FNMR has been calculated as follows:
FNMR $= p$(number of authorized person rejected)*p(the number of unauthorized person) / p (authorized persons).
FNMR= (10/300 * 24/324) / (300/324) which is 0.241.

6.4 Comparison with Existing Methods In terms of Execution Time.

Here, in order to display the efficiency of our proposed approach, we have been implemented series of experiments. These experiments exist in order to provide a comparative analysis of our methodology with some previous methods (in terms of recognition accuracy and feature extraction and matching time).The comparative analysis based on CASIA databases. This paper has been provided the computation complexity comparison between the various known methods and the proposed methods.

Salami[5] used SVM classifier which produces excellent FMR value for both open and close set condition with increasing in FNMR. Averagetime of our methodology is less than [5] methodology. Table 2 shows comparison between this work of iris verification with other iris verification system used the same elevation measures protocol.

Methodology	FRR%	FAR%	Average time (sec)
Salami [5]	19.5	0	0.0812
Gorazd[9]	7.7	0	-
Vrček [10]	11.584	0	
Proposed	0.241	0.231	0.0624

Table 2 comparison between this work of iris verification with other iris verification system used the same elevation measures protocol.

Here, we must declare that, resolution of CASIA-V1 image is 320 × 280 pixels, which is equal to the resolution of CASIA-V3 Interval image.

The experimental results reported in Ma et al [19] employed on CASIA-V1 database were achieved in a machine of 128M RAM running at 500MHz speed. Our experimental environment is better than Ma's the experimental results achieved on at core i3 PC with1GB RAM.

Method	Feature extraction (sec)	Matching (s)	Feature extraction + Matching (s)	Recogn-ition accuracy
Ma et al. [19]	0.2602	0.0087	0.2689	94.90
Ma et al.[20]	0.2442	0.0065	0.2507	95.54
Chen [21] (CASIA-V3 Interval)	0.0896	0.0487	0.1383	99.9
Proposed	0.01299	0.0343	0.04729	98.3

Table 3: computation complexity comparison

We can see that from table 3, our proposed methods have less computational time (in the feature extraction and encoding level) than the other methods reported.

7. Conclusion

In this paper, we presented and empirically evaluated a scheme of iris-based verification system. Experimental study using Chinese Academy of Science Institute of Automation (CASIA) database has been carried out to evaluate the effectiveness of BMHS system and compare it to other systems .The main steps of iris verification have been implemented. These steps: iris and pupil localization/ segmentation, iris normalization, feature extraction/, and pattern matching. In a segmentation level, Circular Hough Transform with a novel dynamic-based technique in determining iris radius range have been developed. It has been shown that, the proposed BMHS approach is able to reduce the false rejection rate to (0.214%) with a minimal increase in the FAR 0.15 % and is able to reduce the system computational time to 0.0624 sec on CASIA iris images. The experimental results and comparison results demonstrate that, our proposed methods can effectively improve the performance of iris verification system with respect to

8. Acknowledgements

This research was supported by the Ministry of Higher Education and Scientific Research, Yemen. We are grateful to the Institute of Automation, Chinese Academy of Sciences for allowing us to use their iris image database. We thank the AL-Hikma, AL- national University in Taiz for their cooperation with us. We thank Libor Masek for his open source iris template generation software.

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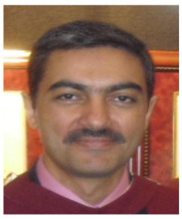

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