Fusion of Gabor filter and steerable pyramid to improve iris recognition system

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ABSTRACT

Iris recognition system is a technique of identifying people using their distinctive features. Generally, this technique is used in security, because it offers a good reliability. Different researchers have proposed new methods for iris recognition system to increase its effectiveness. In this paper, we propose a new method for iris recognition based on Gabor filter and steerable pyramid decomposition. It's an efficient and accurate linear multi-scale, multi-orientation image decomposition to capture texture details of an image. At first, the iris image is segmented, normalized and decomposed by Gabor filter and steerable pyramid method. Multiple sub-band are generated by applying steerable pyramid on the input image. High frequency sub-band is ignored to eliminate noise and increase the accuracy. The method was validated using Chinese Academy of Sciences Institute of Automation (CASIA-v4), Indian Institute of Technology Delhi (IITD) and University of Phoenix Online (UPOL) databases. The performance of the proposed method is better than the most methods in the literature. The proposed algorithm provides accuracy of 99.99%. False acceptance rate (FAR), equal error rate (EER) and genuine acceptance rate (GAR) have also been improved.

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1. INTRODUCTION

Biometrics is the automatic recognition of people based on their physiological or behavioral characteristics, such as fingerprints, knuckle prints, face, voice, retina and iris [1]. The iris identification system is considered one of the best biometric technologies [2], as it remains immutable and is protected from the external environment [3]. To recognize a person from the iris image, different techniques are applied. First, the iris is isolated from all elements that surround the iris such as the pupil, sclera and eyelids [4], [5]. The segmented iris is then normalized. Next, the most distinctive features of the iris are extracted, to form a profile representing the biometric signature of the iris. Finally, classification is required to compare the segmented iris with an existing iris database [6].

Image quality is affected by several factors as shown in Figure 1: iris occlusion, image focus, iris illumination and light reflection. Iris occlusion is caused by total or partial closure of the upper or lower eyelid. In addition, eyelashes can easily interfere with the iris area [7]. On the other hand, unoptimized lighting can result in a dark, saturated or highly reflective image. All these elements are considered as insignificant noise obtained during the acquisition. They limit the visible iris region, reduce the image quality and indirectly influence the iris recognition decision.

Iris recognition system is based on two important setps: Enrollment section and verification. Enrollment involves the acquisition of images using cameras and sensors. The captured images should be based on all surrounding elements of the eye. Different pre-processing approaches were applied to improve the quality of iris image, and then feature extraction is based on different algorithm as discrete cosine transform (DCT) [8], local binary patterns (LBP) [9], discrete wavelet transform (DWT) [10], contourlet transform [11], stylometric features [12]. In verification section, the extracted features will be compared with an enrolled database image [13].

In terms of recognition performance, iris-based identification systems are characterized by a very low number of false acceptances or rejections [14]. However, despite these high performances, various difficulties remain in the identification process. These problems are mainly related to the segmentation and normalization of the iris [15], [16]. Inaccurate segmentation leads to false determination of the iris region, resulting in false iris profile formation. Incorrect normalization of the iris region leads in non-optimized sampling and representation of the iris texture. The effect of these two problems results in a mismatch when comparing iris profiles of the same class, which increases recognition errors.

The main motivation of this work is to improve the performance of iris recognition system using two feature extraction methods. For this purpose, we present an iris recognition system based on extracted features by Gabor filter and then steerable pyramid decomposition to extract other features that are not captured by the first method. In addition, our proposal presents a higher accuracy than other works presented in the literature.

In this proposed method, segmentation is first performed using circular Hough transform (CHT) to detect the iris. Then segmented iris region is normalized using Daugman's rubber sheet model. And then, the extracted features are obtained by applying Gabor filter and steerable pyramid decomposition with different scales and orientations. The remaining paper is organized as: section 2 discusses the works related with the field of iris recognition. In section 3, the proposed method is discussed and section 4 gives the performance evaluations of the proposed system. Section 5 concludes the paper.

2. RELATED WORK

Recently, many approaches on iris recognition have been proposed. In [17] an iris authentication system is presented. This method method is based on DWT for features extraction and Radon transform for contrast enhancement. Average recognition rate (RR) obtained for Indian Institute of Technology Delhi (IITD) database is 90.5% and 88.5% for Phoenix database. The method remains limited in terms of time. In [18], a feature descriptor for iris recognition is presented. This approach is based on both curvelet transform and polynomial fitting. The normalization is firstly done through curvelet transform and polynomial fitting is implemented on every curvelet sub-band to obtain a feature vector. The method proposed is tested with two databases such as Chinese Academy of Sciences Institute of Automation (CASIA)-v4-Interval and IITD. In [19] a segmentation technique of iris using CHT is presented. The approach consists on changing the segmentation used in wavelet packet decomposition from integro-differential operator to Hough transform. This last technique gives better results than the first one. Okokpujie *et al.* [20] proposed a method based on CHT and Daugman's rubber sheet model for normalization process. The features in normalized iris pattern are encoded using 1D log-Gabor wavelets. The method is tested on CASIA database with 99.17% accuracy. In [21] a novel approach is proposed to segment iris images based on rough entropy with localization. This technique has been developped to detect the iris region in different situations. Results on CASIA-V3-Interval, IITD, MMU1 (Multi Media University) databases present 97% in accuracy. In another work, Salve and Narote [22] proposed a method of iris recognition using support vector machine (SVM) and artificial neural network (ANN). The method is based on edge detection and CHT to segment the iris region then Daugman's rubber sheet model is used to get normalized iris. Features extraction are obtained by applying 1D log Gabor wavelet, feature vectors are calculated using quantization. Finally SVM and ANN are used to iris pattern classifier. The experimental tests are used by CASIA-v4 database. Results showed that the proposed method have 95.9% accuracy radial basis function (RBF) kernel and 92.5% accuracy (polynomial kernel). In [23] dense fully convolutional network (DFCN) is used in segmentation process. The segmented iris region is normalized and Gabor wavelet is applied to extract iris features and the classification is used through SVM classifier. The proposed approach is tested with CASIA and IITD databases with 98.85% and 99.8% accuracy respectively. Many different databases are used in these studies; the most popular is CASIA database. On the other hand, different methods of segmentation, normalization and features extraction are presented. The best performance measures are noticed in approaches that applied neural network and Gabor wavelet to extract iris features with SVM classifier as shown in Table 1.

Table 1. Benchmark of different studies on iris recognition

Year	Author	Approach	Database	Results
2016	Dhage *et al.* [17]	DWT for features extraction and Radon transform for contrast enhancement	IITD University of Phoenix Online (UPOL)	90.5% average RR (%) 88.5% average RR (%)
2019	Vyas *et al.* [18]	iris recognition (curvelet transform) and (polynomial fitting)	IITD	AUC= 0.9897 EER=0.0353
			CASIA-v4-Internal	AUC= 0.9292 EER= 0.1388
2016	Matin *et al.* [19]	Iris segmentation technique (circular Hough transform)	CASIA (with 1080 iris images)	Accuracy= 93.06
2016	Okokpujie *et al.* [20]	Human iris for verification	CASIA-v4	99.17% average RR (%)
2018	Sardar *et al.* [21]	Iris localization (rough entropy and circular sector analysis (CSA))	CASIA-V3-Interval IITD MMU1	ACC= 97.12% ACC= 97.19% ACC= 97.11%
2016	Salve and Narote [22]	Iris recognition (SVM and ANN)	CASIA-v4	95.9% accuracy (RBF Kernel) and 92.5% accuracy (polynomial kernel)
2021	Meenakshi [23]	Iris recognition (DFCN with multiclass support vector machine classifier)	CASIA IITD	Accuracy=98.85 Accuracy=99.8

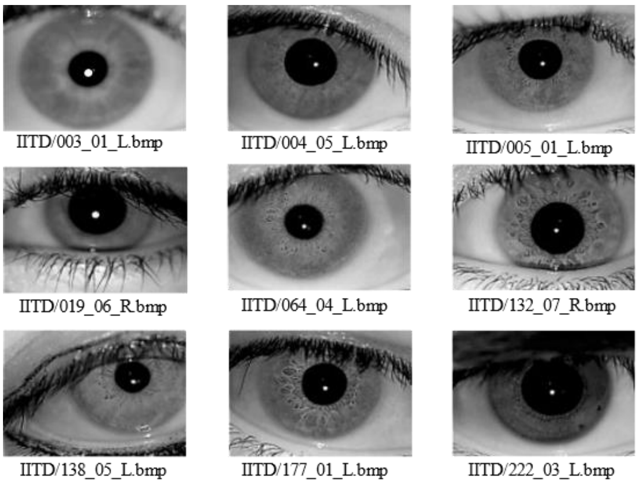

Figure 1. Image quality affected by several factors

3. BACKGROUND

In the proposed method, we realized an iris recognition system based on Gabor filter and steerable pyramid decomposition. The proposed system consists of three phases: enrolment, iris feature extraction and authentication. The enrolment process includes image acquisition, segmentation and normalization.

3.1. Image acquisition

The iris is a dark, reflective and small object. It must be photographed under special conditions. It is usually illuminated by a light source, visible or invisible. Other factors such as eye-to-camera distance and image focus are also adjusted by the acquisition system [24]. Without good conditions, various deficiencies can appear in the iris image such as: blurred image, bad contrast, presence of light reflections on the iris surface [25]. All these elements are considered as insignificant noise obtained during the acquisition. They limit the visible region of the iris, reduce the image quality and indirectly influence the iris recognition decision. An efficient segmentation of these regions is therefore necessary. In this paper, CASIA-v4, IITD and UPOL databases are used instead of capturing eye images. After image acquisition, the iris must be isolated. At first, an enhancement technique is applied to enhance the overall image quality.

3.2. Segmentation

The segmentation [26], [27] of the iris will be defined by the set of processing to extract the iris from different surrounding enviroment: pupil, white of the eye, eyelids, lashes and specular reflections.

Depending on the particularity of each iris image and on the acquisition conditions, the segmentation step allows to produce irises with different characteristics. In an identification process, no comparison between two iris profiles can be made unless they are comparable. This requires compensating all intrinsic and extrinsic variations by varying the size and rotation of the iris. The performance of the system is impacted by the reliability of the segmentation method used. CHT [28], [29] is used to locate the circular iris region (outer and inner boundaries). CHT is applied to determine the caracteristics of the pupil and iris regions (radius and center coordinates). The maximum point corresponds to the radius 'r' and $(x_{c,}y_c)$ is the center coordinates of the circle. The segmentation process determines the boundaries of the iris as shown in Figure 2 and the pupil, this part is converted into an appropriate model in the normalization step. Caracteristics of CHT are computed as,

$$x_c^2 + y_c^2 - r^2 = 0 \quad (1)$$

3.3. Normalization

Normalization [30], [31] is applied on segmented images to obtain the same size of iris images. Circular iris region is transformed into a fixed size rectangular block. Daugman's rubber-sheet model is considered as the most used method for iris normalization (transform iris from Cartesian to polar representation) [32]. For each pixel in the iris image, we can identify an equivalent position on the polar axes (r,Θ) where r is the radial distance and Θ is the rotation angle (2). In the polar representation the iris is sampled to have a rectangular shape as shown in Figure 3. The histogram equalization technique [33] is performed on the normalized iris image to harmonize the illumination and obtain a well distributed texture image as shown in Figure 4.

$$I[x(r,\Theta), y(r,\Theta)] \rightarrow I(r,\Theta) \quad (2)$$

Where:
I(x, y) is the iris region
(x,y) and (r,θ) : Cartesian and normalized polar coordinates, respectively.
θ ranges from 0 to 2π and r ranges from Rp to Rl.
x(r,θ) and y(r,θ) are defined as linear combinations of pupil boundary points.

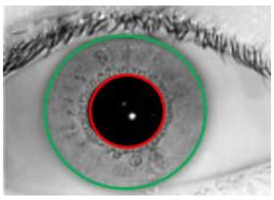

Figure 2. Iris boundaries (from IITD database)

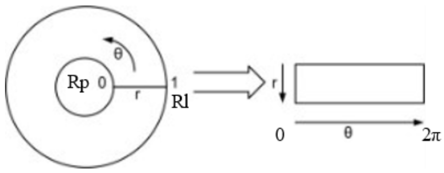

Figure 3. Daugman's rubber-sheet model

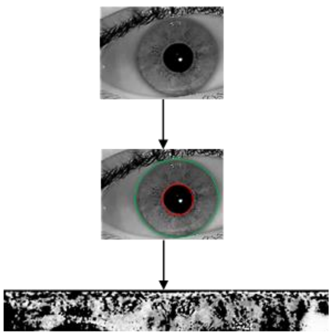

Figure 4. Normalization process

3.4. Feature extraction

Iris feature extraction will be effective to improve the performance of the recognition system. Each extracted feature allows to identify parameters that characterize the iris image. The combination of several methods helps to identify the relevant features to be able to identify the irises. The proposed method aims to provide a content-based iris authentication method using Gabor filter and steerable filter pyramids. This fusion of methods improves the performance of the iris recognition system.

3.4.1. Gabor filter

Iris features are extracted by Gabor filter [13], [34]. It's defined as a pair of a tuple of data x and y, where x and y represent axes. The Gabor filter contains a filter coefficient of an image at different angles from 0 to 2π. Gabor filter is defined as,

$$G(x,y) = exp\,(-\,\frac{x_0^2+\gamma\, y_0^2}{2\sigma^2})cos\,(\frac{2\pi}{\lambda}x_0) \tag{3}$$

Where,

$$x_0 = xcos(\theta) + ysin(\theta) \tag{4}$$

$$y_0 = -xsin(\theta) + ycos(\theta) \tag{5}$$

σ represent the spatial size of the filter, θ is the orientation angle.

3.4.2. Steerable pyramid

The steerable filters are the basic tool of the steerable pyramid proposed by Simoncelli, and Freeman [34]. It is a multi-scale recursive transformation, flexible in terms of directional analysis. This technique represents a combination of multiresolution and oriented measurement operations [35]. Unlike other existing pyramidal methods laplacian pyramid, gaussian pyramid, the number of scales and directions is variable. The iterated filter bank structure for steerable pyramid decomposition and reconstruction is presented in Figure 5.

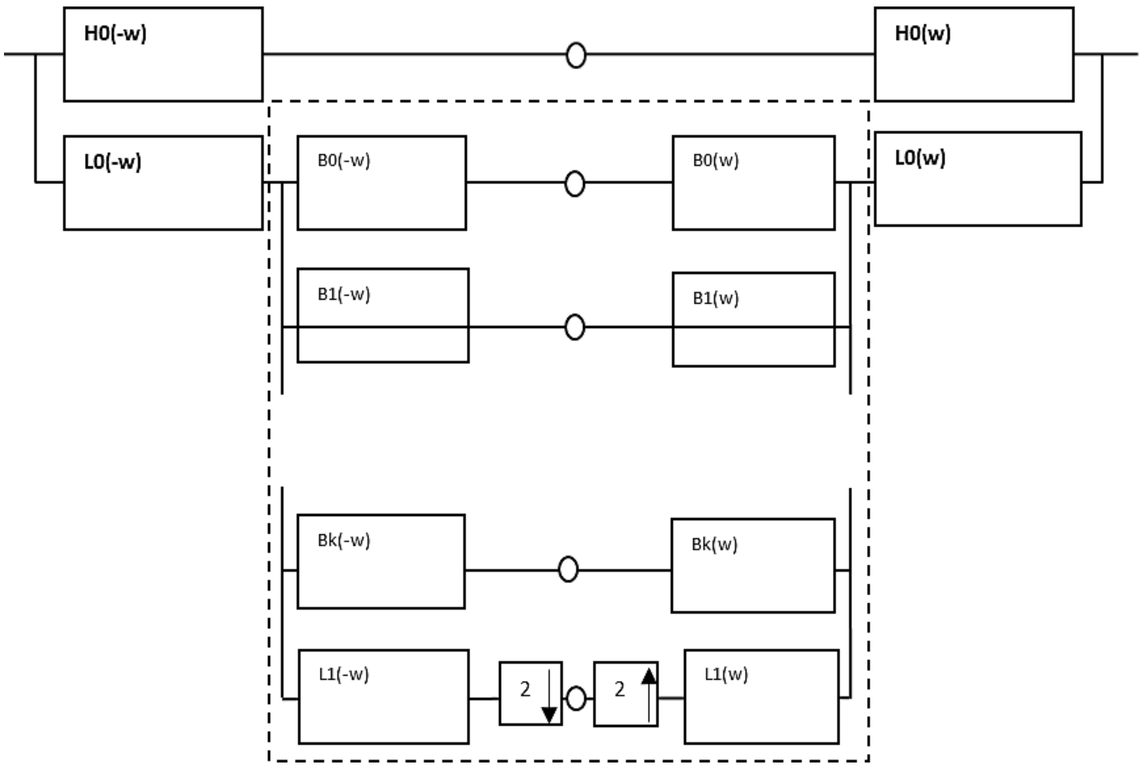

Figure 5. First level of steerable pyramid decomposition

The image is decomposed into L0 (low-pass) and H0 (high-pass) sub-bands. After that it is divided into M oriented bandpass subbands Bi and one lowpass subband L1. This lowpass subband is subsampled by a factor of 2 in X and Y directions. This pyramid can be used in various applications, the advantage is that the steerable pyramid is self-reversing, and therefore the errors introduced by the quantization of the sub-band will not appear as an out-of-band distortion of the reconstruction.

4. PROPOSED METHOD

The feature representation should contain enough information to classify the different irises and be less sensitive to noise. Only significant information is extracted. By reducing the dimensions of the feature vector, useful and sufficient information is retained to introduce the classification of the iris feature vectors. Feature extraction presented in the proposed method as shown in Figure 6 is performed in two steps: Step 1: Gabor filter is applied on normalized iris image to obtain iris features. These features are in a smooth curve shape and also contain two-dimensional singularities, which cannot be captured by Gabor filter. Steerable pyramid is a geometrical image transform, which can represent images with smooth contours and texture. Step 2: 2-levels and 4-orientations of steerable pyramid decomposition are applied on original iris image. This decomposition is not enough for an efficient and finest characteristic of an iris image. Four this reason each image in different scales and different orientations is decomposed (block size is 8x8) and the maximum entropy is calculated and used as a feature selection to reduce the number of obtained features. Entropy is defined as,

$$Entropy = -\sum(p \times \log(p)) \quad (6)$$

Where p contains the counts of the histogram.

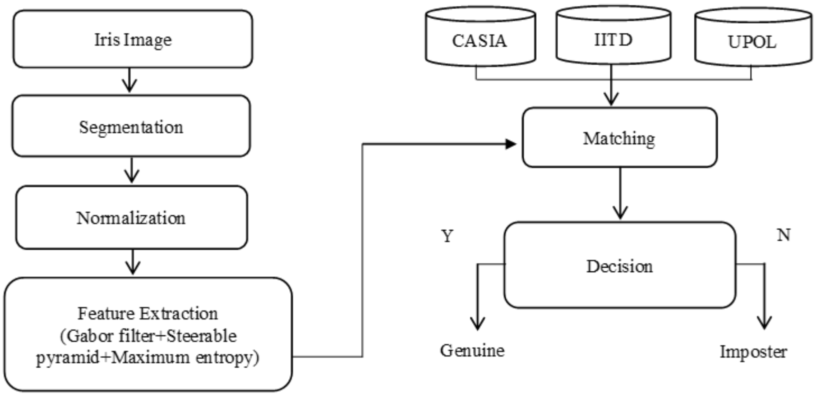

Figure 6. Proposed method of iris recognition

5. RESULTS AND DISCUSSION

The proposed approach is tested on 3 databases: CASIA-Iris-v4 (22.840 images), IITD (1120 images) and UPOL (384 images). The accuracy obtained is 99.99%, 99.98%, 99.59 respectively. The combination of Gabor filter and steerable pyramid is used to increase the accuracy and to reduce the computational complexity. This technique produces iris features to increase the efficiency of matching process. With the performance measures used in our case, it's seen that both accuracy as shiown in Tables 2 and 3, and equal error rate (EER) shows significant improvement in case of fusion of Gabor filter and steerable pyramid. The proposed method used Hamming distance (HD) [36] to compare the extracted iris features and different metrics are used to evaluate the performance of the system such as: False acceptance rate (FAR), genuine acceptance rate (GAR), EER and accuracy.

5.1. HD

The comparison between individuals is done through their iris codes. Once two iris codes are extracted, we calculate their Hamming distance HD which is given by,

$$HD = \frac{1}{N}\sum_{i=1}^{N} X_i (XOR) Y_i \quad (7)$$

Where: X and Y represent two binary patterns. N is the number of bits.

5.2. FAR, false rejection rate (FRR) and GAR

The frequency of unauthorized access due to imposters using a false identity. This metric is used to measure the biometric performance of the verification system. False acceptance occurs when an individual's biometric data does not match the existing biometric template of another individual. On the other hand, FRR defines the probability that a system does not identify a person who should normally have been identified. A false reject follows when a person does not correctly match their own existing biometric template. Finally, we can present the GAR metric as the frequency of authentic accesses relative to the total number of attempts. GAR is calculated by,

$$GAR = 1 - FRR \tag{8}$$

5.3. Equal error rate

This rate is calculated from the first two criteria and is a common performance measurement point. This point corresponds to the point where FRR=FAR, i.e. the best compromise between false rejections and false acceptances. A low EER value indicates a high accuracy of the biometric system.

Table 2. Comparison of accuracy using CASIA-v4 and IITD databases

Methods	Accuracy CASIA-v4	Accuracy IITD
Matin *et al.* [19]	99.17%	-
Salve and Narote [22]	95.9%	-
Okokpujie *et al.* [20]	93.06%	90.5%
Vyas *et al.* [18]	92.92%	98.97%
Meenakshi [23]	98.85%	99.8%
Sardar *et al.* [21]	97.12%	97.19%
Proposed method (Gabor filter+steerable pyramid)	99.99%	99.98%

Table 3. Comparison of accuracy with other methods in the literature

Methods	Accuracy
Bharadwaj *et al.* [36]	98%
Vyas *et al.* [18]	98.97%
Ahmed *et al.* [13]	99.99%
Proposed method (Gabor filter+steerable pyramid)	99.99%

As seen in Table 2 and 3, the accuracy rate of the proposed method (99.99% for CASIA-v4 and 99.98% for IITD databases) is higher than other presented methods in the literature. The results obtained show that using different methods to extract features increases the identification rate. This means that the proposed method is more effective than using a single feature extraction method.

Table 4 gives the estimation of FAR, FRR, recognition time, EER and Accuracy for each database. It can be deducted that the recognition time of the proposed method is 2.32 sec, 2.59 sec and 2.36 sec for the three databases CASIA-v4, IITD and UPOL respectively. We also observed that the accuracy and EER improve significantly, with a decrease in EER and an increase in accuracy. FAR and GAR obtained from the three databases are very low, which shows the high accuracy value obtained for the proposed approach.

Table 4. Comparison of performance value in different databases

Performance value	CASIA-v4	IITD	UPOL
FAR	0.01%	0.025%	0.2%
GAR	0.99%	0.98%	0.38%
Recognition time	2.32 sec	2.59 sec	2.36 sec
EER	0.01%	0.02%	0.41%
Accuracy	99.99%	99.98%	99.59%

6. CONCLUSION

In this work, an iris recognition method has been proposed. Circular Hough transform for iris segmentation and Daugman’s rubber-sheet method for normalization are applied. Feature extraction is done by combining Gabor filter and steerable pyramid with different scales and orientations to extract finest features of iris images and to reduce computational complexity. The proposed method has been validated by simulating three databases: CASIA-v4, IITD and UPOL. Hamming distance is used to measure the similarity between iris templates. The results of the conducted experimentations show clearly that our proposed method gives a higher accuracy and can be used to improve the existing iris recognition system. The limitation of our method is the execution time and as all feature extraction methods, it cannot capture all the features of an image. In the future work, our studies will be dedicated on the use of other traditional techniques of image processing to extract more efficient features and we aime to fusion traditional and deep learning teachniques to show if the fusion perform better than using the single feature extractors separately. Also, multiple classifiers will be used to specify the best one.

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