AN IMPROVED IRIS RECOGNITION SYSTEM BASED ON THE FUSION OF THE CURVELET AND DTCWT

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(Received July 07, 2020; Accepted December 25, 2020)

Abstract - In recent years, iris recognition has been emerged as one of the most popular biometric techniques because it guarantees high universality, distinctiveness, permanence, collectability, performance, acceptability, circumvention. In the paper we propose an improved system for iris recognition with high accuracy by fusing curvelet and dual tree complex wavelet transform. In our system, the main features are extracted from pre-processed/normalized iris images using both curvelet and Dual Tree Complex Wavelet Transform (DTCWT) tranforms. After performing different classifiers independently, all the results are fused to get final classification in the decision level to increase the accuracy of system. Finally, the random forest classifier and CATIA dataset are used to measure the performance of the proposed method. The experimental results show that the technique of the paper based on fusion of the curvelet and DTCWT is promising when compared with other existing similar techniques.

Key words - Iris recognition; curvelet; wavelet; transform; DTCWT.

1. Introduction

Nowadays, as people's interests in security issues increase, the scope of application of biometrics technology is increasing. And iris recognition has become one of the most promising techniques in solving these issues because it guarantees high universality, distinctiveness, permanence, collectability, performance, acceptability, circumvention [3].

Generally speaking, iris is an internal organ which is responsible for controlling the diameter and size of the pupil and the amount of light reaching the retina. It is the annular portion between the dark pupil and white sclera and its rich texture information could be exploited in biometric recognition systems. During the first two years of our life, the visual textures of our iris get stabilized and then the iris textures carries distinctive information which are useful of identification.

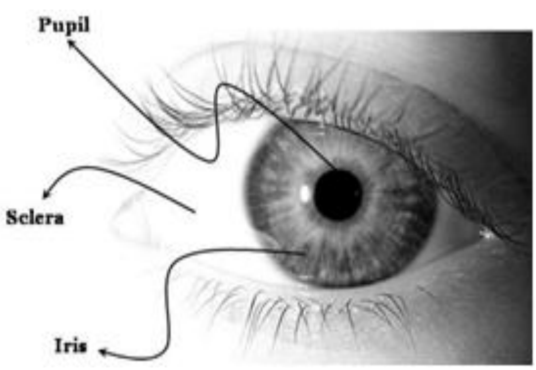

Figure 1. *Human Iris*

Cheung [25] made an important conclusion about the probability that two irises could produce exactly the same iris pattern is extremely small (approximately 1 in 10^{78}). If we consider the population of the earth is around 10^{10}, then the probability can even be small enough to be treated as zero. Moreover, human iris is always stable regardless of emotion, pose, age or makeup, and the 2D Fourier spectrum shows periodicity only in the printed iris while there is no such property in the natural iris.

As the iris secures high variability, stability and non-counterfeiting, many studies of biometric recognition are concentrated all over the world. However, the research on real-time iris recognition system with high accuracy and low complexity is still challenging [3], [20].

2. Related works

Generally, iris recognition system includes 5 steps like image acquisition, iris segmentation, iris normalization, feature encoding and feature matching [4], [12], [15], [19], [21], [22].

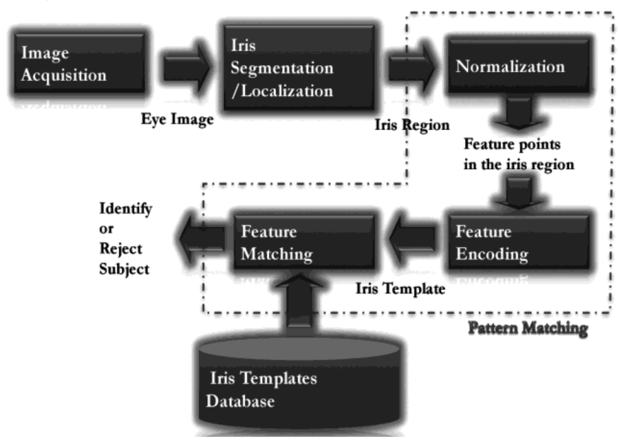

Figure 2. *Diagram of Iris Recognition*

Vatsa *et al.* [4] proposed curve evolutionary approach to effectively segment iris images and to apply different enhancement algorithms simultaneously. To create a single high-quality iris image, different localized regions were selected from each image enhanced by the support machine and then combined together. Iris segmentation, quality enhancement, match score fusion, and indexing were implements by using fusion algorithms to realize the textural and topological matching. Ali *et al.* [8] used various edge detection methods to segment the iris boundary from the image and histogram and wavelet techniques to extract feature vectors. Masood *et al.* [11] introduced the histogram of the iris image to effectively identify the pupil and the iris boundary, extract the feature vector by the wavelet transform, and use the two sub regions of iris to reduce the computation time and increase the effectiveness of the system.

George *et al.* [13] proposed a simple, efficient and fast method of extracting a series of differential features by applying the first gradient operator to the gray scale image. Since the gradient-based features are somewhat robust to changes of the contrast or brightness in the iris image samples, the difference is mainly due to light differences and camera changes. Initially, the iris area was remapped to a rectangular area with dimension of 360x60 pixels, and a new statistical method was proposed for detecting important parts include the eyelashes and eyelid points. After that, the rectangle iris image was divided into N superimposed sub-images (blocks), from which feature sets of different mean direction gradient density values were evaluated to use as the texture feature vectors. To determine the similarity between these feature vectors and the template feature vectors stored in the dataset, the classical Euclidean distance-based classifier was used as a matching metric. Umer *et al.* [17] applied RCHT transform to perform iris segmentation and normalizes only two separate domains of the iris pattern to extract features based on the multiscale morphologic operators. Simultaneously, the iris feature is expressed as the sum of the dissimilarity residues received using the morphological top-hand transformation.

Minaee *et al.* [18] introduced scattering transform-based and textural features and applied Principal Component Analysis (PCA) on extraction to significally reduce the dimensionality of the feature vectors while preserving most of the information of their initial values. For each new test sample, template matching is performed by using minimum distance classifier. Biu *et al.* [23] generated a binary bit sequence of iris to enhance the authentication process, which contain several vital information that is used to calculate the mean energy and maximum energy that goes into the eye with an adopted threshold value. Rana *et al.* [24] integrated principal component analysis based on the discrete wavelet transform to extract the optimal features and reduce the execution time required for performing classification. The iris image was transformed into four frequency sub-bands using the Discrete Wavelet Transform (DWT) and only one frequency sub-band was selected for further feature extraction.

In recent years, research has been actively conducted to increase recognition effectiveness by applying curvelet transformation to pretreatment and feature vector extraction in biometrics [5], [6], [7], [9]. The multiscale directional curvelet transform allows an almost optimal nonadaptive sparse representation of objects with their edges. Over the recent years, the increasing interest for it has been generated more widely in the community because of its capacity in combining different applied mathematic and signal processing techniques together.

Ahamed *et al.* [10] presented a method for iris recognition in the curvelet region and reduced pre-processing time and computational complexity by removing artefacts such as external boundary detection, eyelids and eye brows. Sun *et al.* [14] performed pre-processing including iris localization, eyelash shading and normalization of iris using approximate accuracy of curvelet transform, sparse representation ability, principal component analysis and linear discrimination analysis in order to answer the question about accuracy and computational complexity of iris recognition system. Guesmi *et al.* [16] proposed the iris feature extraction method based on the curvelet transformation to reduce the dimension of the iris image and improve the recognition rate. The performance of the system is improved by dividing the image into sub-band sets by automatically extracting the curves and the most discriminative features of each corresponding sub-bands.

Most of the iris recognition systems raised to date use only single features extracted from space or transformation domain for verification, and the accuracy of such systems is not so high. In this paper, we improve the performance of iris recognition system by fusing curvelet and discrete wavelet transform. Curvelet and DTCWT features are extracted from pre-processed and normalized iris images and used for classification independently. At decision level, their results are fused to get final classification to increase the accuracy of system. The main improvement in our method is that, after extracting of two sets of features like DTCWT and Curvelet for the iris recognition system, the classification results are fused to get more accurate decision in matching step.

The paper is organized as follows: Section 3 briefly provides the concepts to be used. In Section 4, the propose iris recognition method is described in detail. Experimental results of the method are analysed in Section 5 and the conclusion and future research directions are mentioned in Section 6.

3. Curvelet Transform

Curvelet transform was developed by Emmanuel Candes *et al.* [1] to overcome the inherent limitations of the classical wavelet transforms. Because the basis functions of wavelet transform are isotropic, they require large number of coefficients to represent the curve singularities. In other side, curvelet transform is a multi-scale and multi-directional geometric transform with needle shaped basis functions. These functions are needle shaped and have high directional sensitivity and anisotropy, thus the curvelet transform obeys parabolic scaling. Thanks to these properties, the sparse representation of curve singularities in curvelet transform is almost optimal. In concrete terms, the curvelet transform at different scales and directions spans the entire frequency space, so the edges and other singularities along curves could be represented much more efficiently than traditional transforms, i.e., requiring fewer coefficients to achieve a given accuracy of reconstruction.

The curvelet decomposition can be equivalently stated in the following forms:

- Sub-band Decomposition: The object f is filtered into different sub-bands:

$$f \rightarrow (P_0 f, \Delta_1 f, \Delta_2 f, \dots) \quad (1)$$

- Smooth Partitioning: Each sub-band above is smoothly transparented into "squares" of an appropriate scale:

$$\Delta_s f \to \left(w_Q \Delta_s f\right)_{Q\in Q_s} \qquad (2)$$

- Renormalization: Each resulting square is renormalized to the same unit scale:

$$g_Q = 2^{-s}\,(T_Q)^{-1}\left(w_Q \Delta_s f\right), \quad Q\in Q_s \qquad (3)$$

- Ridgelet Analysis: Each renormalized square is analysed in the ortho-ridgelet system:

$$\alpha_\mu = (g_Q, \rho_\lambda), \quad \mu = (Q, \lambda) \qquad (4)$$

4. Proposed method

The domain features of both curvelet and wavelet transform are fused to generate final classification result to enhance the recognition rate, thus improving the accuracy of the system. The block diagram of proposed method is shown as in Figure 3.

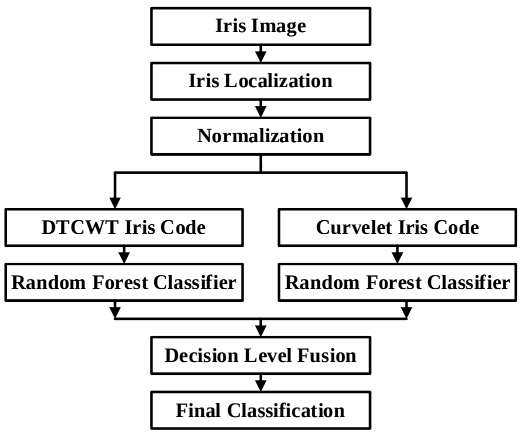

Figure 3. *Block diagram of proposed method*

4.1. Iris localization

In this step the iris region of the given eye image is localized by finding the edge points and its approximate boundary is formed as a close contour circular.

From the fact that pupil is always the darkest region of the eyeball, we can localize the original eye image *I* by analysing its image histogram. By setting a threshold at the valley point greater then but nearest to the peak at the lowest grey level, the pupil region can be approximately taken. Small components are removed using morphological area filter from this binary image to get the clean image *IB*. The centre and radius of the inner iris circular region are obtained by applying the Restricted Circular Hough Transform (RCHT) on the boundary points in the image *IB*.

To detect outer boundary, high intensity changes between neighbouring pixels both along horizontal or vertical direction from the centre of inner boundary are investigated in smooth eye image *I*. We apply RCHT on all the edge pixels within this square of 2D centring the inner boundary centre to obtain the outer contour circular of iris region. The localized iris region of the eye image is the region bounded by its inner and outer boundaries as Figure 4.

Figure 4. *Iris localization*

4.2. Iris normalization

Because varying levels of illumination, rotation of the iris image and other factors create the pupil dilation, the captured iris image can have different sizes. The normalization process takes place to resize the iris region by same constant dimensions. After localization, the iris region is normalized and then mapped to change the shape from circular to rectangular form. The process unwraps the iris region and maps all the points which lay between the iris boundaries. As a result, the shapes were converted from the original Cartesian coordinates *I(x,y)* into their equivalent normalized polar coordinates *I(r,θ)*. The relation between these coordinates is explained by the following mapping equation:

$$I\left(x(r,\theta), y(r,\theta)\right) \to I(r,\theta) \qquad (5)$$

with

$$\begin{aligned} x(r,\theta) &= (1-r)x_p(\theta) + r x_l(\theta) \\ y(r,\theta) &= (1-r)y_p(\theta) + r y(\theta) \end{aligned} \qquad (6)$$

where, $r \in [R_P, R_I]$; the values R_P, R_I, θ are the pupil's radius, the iris's radius and the angle between 0 and 360, respectively.

The rectangular iris region from the radial direction r and the angle θ can be obtained from the above equation and the normalization result is as follows:

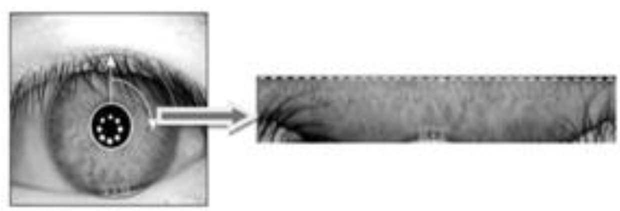

Figure 5. *Iris normalization*

4.3. Feature extraction

4.3.1. DTCWT feature

We apply 5 level 2D DWT on the normalized iris image to provide sixteen sub bands at each level including 4 sub bands of low frequencies and remaining 12 sub bands of high frequencies. At every level, the size of input image is reduced to half of the size of original image. Every couple of two corresponding sub bands with the same pass bands are linearly combined by averaging and differencing to obtain the sub bands of 2D CWT at each level. The combination could be like $LH_a + LH_b/\sqrt{2}, LH_a - LH_b/\sqrt{2}$, $HL_a + HL_b/\sqrt{2}$, $HH_a + HH_b/\sqrt{2}$, $HH_a - HH_b/\sqrt{2}$. Magnitudes of real and imaginary bands are used as extracted features for the next step.

It is worth to noting that on each decomposition, the 2D separable DWT produces three high frequency bands including *LH, HL, HH.* The DTCWT which is implemented using 2D real wavelet transform which produces six complex wavelets. They provide directional information by taking both real and imaginary parts from each of these complex wavelets above. These parts and final magnitude coefficients are obtained by using following equations:

$$m_{ac} = \sqrt{m_a^2 + m_c^2}$$
$$m_{bd} = \sqrt{m_b^2 + m_d^2} \quad (7)$$
$$M = [m_{ac}; m_{bd}]$$

Where, m_a, m_b, m_c and m_d corresponds to DTCWT high frequency coefficient vectors at 5-level DTCWT. The final feature vector for the matching step is obtained by concatenating magnitude of m_{ac} and m_{bd} from Equation (7).

4.3.2. Curvelet feature

This paper applied the curvelet transform on the normalized and enhanced iris to get the structural activity which can be analysed statistically to generate iris feature vector. We calculate the features from all these sub-band images which were generated using curvelet decomposition.

The iris image is decomposed into 5 scales and the number of generated directional sub-bands images varies from scale to scale. It generates 32 sub-bands images at second scale and 64 sub-bands images are obtained at scales 3 and 4. To extract features from sub-bands images and represent them in a compact form, we encode all sub-band images by their four statistical features. In this way, we have one sub-band which is coded by four features values in the first scale, and thirty-two sub-bands which are coded by 128 feature values in the second scale. One sub-band which is coded by 4 feature values are taken in the last fifth scale. Thus, our curvelet features vector contains 4 rows corresponds to these scales.

4.4. Feature Matching

In the matching step, the Euclidean distance classifier is used to calculate the distance between two feature vectors that produce a similarity score. In order to improve the accuracy of the iris authentication system, the results obtained by inputting the DTCWT feature vector and the curvelet feature vector to the random forest classifiers are fused. Here we use decision level fusion to get the final decision from both classifiers. The Boolean OR operator is used to fuse the results of the two classifiers.

5. Experimental results

Our results were obtained by testing the proposed iris recognition system on computer running Windows 10 platform with 2.4 GHz Core i7 processor and 8GB RAM. The programs have been developed using MATLAB.

Three iris datasets including ICE 2005, CASIA, and UBIRIS were used to evaluate the performance of the proposed algorithms. The iris images of these dataset contain the irregular spatial patterns captured using different devices with different characteristics. The captured targets are under varying between different ethnicity and assist a comprehensive performance evaluation of the tested algorithms.

We divided datasets into train, validation and test and evaluated the identification performance of the proposed method comparing with previous methods. Table 1 shows the accuracies for the different methods and datasets.

Table 1. *Accuracy comparison on different datasets*

Method	Accuracy		
	CASIA 3	ICE 2005	UBIRIS
Curvelet [22]	97.5%	95.9%	93.9%
Wavelet [15]	96.4%	94.4%	92.1%
Curvelet + PCA+LDA [14]	98.2%	97.9%	96.6%
Our method	98.4%	98.1%	97.2%

The experimental results on the different datasets demonstrated that our method has better identification performance when comparing with previous methods.

Figure 6 is the ROC curve of different methods on CASIA dataset to measure the recognition accuracy. The CASIA dataset contains 22 051 iris images refering to more than 1600 classes. The images have been captured using different imaging setup, thus the quality of images varies from high-quality images with extremely clear iris textural details to images with nonlinear deformation due to variations in visible illumination. After sketching the ROC curves, we have decided to choose the optimum threshold value as 1.5 where the accuracy value is around 98.4%. In Figure 6, it can be seen that the proposed fusion strategy reduces the FRR and improves the overall accuracy on all the datasets. It is noted that the result is not perfect due to low quality of the iris images.

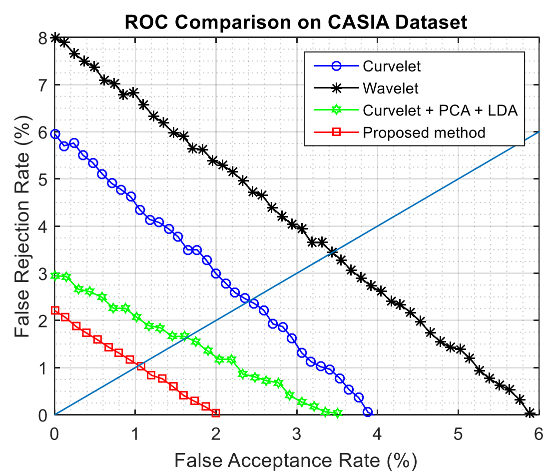

Figure 6. *ROC plot showing the performance of our method in comparison to other methods on CASIA dataset*

6. Conclusion

This paper aimed to establish a methodology to improve the iris recognition system by introducing fusion of features. DTCWT and curvelet transforms are used to extract feature vectors from localized and normalized iris images and Euclidean distance is utilized to measure similarity between two feature vectors. Random forest classifier determines the final decision from classification results with both of feature vectors. Experimental result shows that the proposed method can improve the current iris recognition technique. The selection of classifier to fuse independent results from different features and fusing way to combine them to express the specialties of different transform domain features may be the future research direction.

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