An Iris Image Synthesis Method Based on PCA and Super-resolution

Jiali Cui, Yunhong Wang, JunZhou Huang, Tieniu Tan, Zhenan Sun
Center for Biometric Authentication and Testing,
National Laboratory of Pattern Recognition, Institute of Automation,
Chinese Academy of Sciences, P.O. Box 2728, Beijing, P.R.China, 100080
E-mails: {jlcui, wangyh, jzhuang, tnt, znsun } @nlpr.ia.ac.cn

Abstract

It is very important for the performance evaluation of iris recognition algorithms to construct very large iris databases. However, limited by the real conditions, there are no very large common iris databases now. In this paper, an iris image synthesis method based on Principal Component Analysis (PCA) and super-resolution is proposed. The iris recognition algorithm based on PCA is first introduced and then, iris image synthesis method is presented. The synthesis method first constructs coarse iris images with the given coefficients. Then, synthesized iris images are enhanced using super-resolution. Through controlling the coefficients, we can create many iris images with specified classes. Extensive experiments show that the synthesized iris images have satisfactory cluster and the synthesized iris databases can be very large.

Keywords: Biometrics, iris recognition, iris image synthesis, PCA, super-resolution.

1. Introduction

To meet the increasing security requirement of the current commercial society, personal identification is becoming more and more important. Traditional methods for personal identification include the token-based methods that use specific things such as ID cards or keys for authentication and the knowledge-based methods that use something you know such as password for identification. However, these methods are usually not reliable. For example, token may be lost and knowledge may be forgotten. Therefore, a new method for personal identification named biometrics has been attracting more and more attention. As a promising way of authentication, biometrics aims to recognize a person using the physiological and (or) behavioral characteristics such as fingerprints, face, gait, voice, and so on [1]. As a new branch of biometrics, iris recognition shows satisfactory performance.

The human iris is the annular part between pupil and sclera, and has distinct characteristics such as freckles, coronas, stripes, furrows, crypts, and so on. Compared with other biometric features, personal authentication based on iris recognition can obtain high accuracy due to the rich texture of iris patterns. Therefore, iris recognition has many potential applications such as access control, network security, etc.

Although the history of iris recognition comes back to the 19th century, automatic iris recognition is a newly emergent issue in biometrics. Flom and Safir [2] proposed the concept of automated iris recognition in 1987. Since then, iris recognition has been receiving many researchers' attention [3-15] and a great deal of progress has been achieved in the last decade. For instance, Daugman [3,4] realized an iris recognition system in 1993 and the identification accuracy is up to 100%. The principle of Daugman's iris recognition algorithm is the failure of a test of statistical independence on iris phase structure encoded by quadrature wavelets [3,4]. Wildes developed a device to capture iris images from a distance, and a super-resolution method was used to obtain clear images [5]. In our previous work [12-15], we used Gabor filters, multi-channel filters or wavelet for feature extraction and obtained satisfactory performance.

Although significant progress has been achieved in iris recognition, some problems remain unsolved. To evaluate the performance of the existing iris recognition algorithms and provide more knowledge of essential information of iris characteristics, we need larger iris databases. However, it is difficult to capture so many iris images from the volunteers because the iris images have close relation with personal privacy. Driven by the applications of synthesis method in fingerprint recognition [16], this paper focuses on the construction of iris databases with synthesis method. The main idea of the algorithm is that the iris images can be classified and constructed with the coefficients on the given bases and the iris image classification can be done through selecting the high dimensional spheres those coefficients belong to. As much as we know, there are no papers about iris image synthesis. So, this paper focuses on iris image synthesis due to its importance.

The remainder of the paper is organized as follows. Section 2 introduces the iris recognition method based on PCA and the results on the CASIA Iris Database. Section 3 describes the proposed iris image synthesis algorithm in detail and gives the experimental results of the synthesis method. Section 4 concludes the whole paper.

2. Iris Recognition Algorithm Based on PCA

Because clustering must be taken into consideration in iris image synthesis, an iris recognition based on PCA is first presented to put iris synthesis in context. Most existing iris recognition methods are based on the local properties such

as phase, shape, and so on. However, iris image synthesis based on local properties is difficult to implement. Recently, Bae *et al.* [11] attempted to use the Independent Component Analysis (ICA) to extract iris feature. Although ICA, Linear Discriminant Analysis (LDA) and PCA can all be used for global feature extraction, PCA has superiority in image construction, because we can control the construction errors by selecting the cumulative variance. Euclidean distance and nearest neighborhood (NN) classifier are adopted here.

Experiments are done on the CASIA Iris Database. The CASIA Iris Database is adopted because it is challenging. The first version of CASIA Iris Database is shared on our page and more than 140 researchers have applied for it. The second version of CASIA iris database is more challenging than the first version. It includes more than 1500 iris images from 122 volunteers, about 95% of which are from Asia and other 5% are from America, Russia, and so on. The images are captured using the sensor designed by Pattek Corp. and each image has 640*480 pixels. The capturing course is during two sessions and the time interval is 3 months.
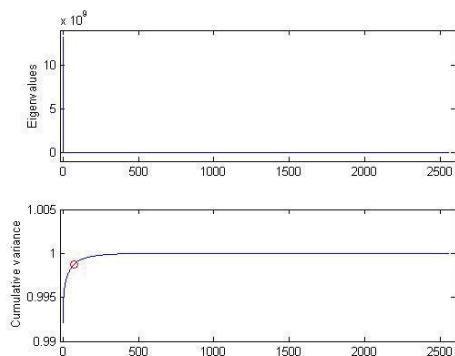

Figure 1. The distribution of variance, where 'o' denotes that the largest 75 variances are up to 99.8% of all the variance.

Here, we select 5 images from each class for computing the principal components. For each iris image, we first transform the annular iris into a polar system and obtain a normalized iris. Suppose I_k is the k th normalized iris image vector,

$$S = \sum_{k=1}^{N} I_k I_k'$$ (1)

where N is the total number of training iris images. $V = \begin{bmatrix} v_1 & v_2 & v_3 & ... & v_M \end{bmatrix}^T$ is the eigenvalue vector of S with $v_1 \geq v_2 \geq ... \geq v_M$. The distribution of variance is shown in Fig.1.

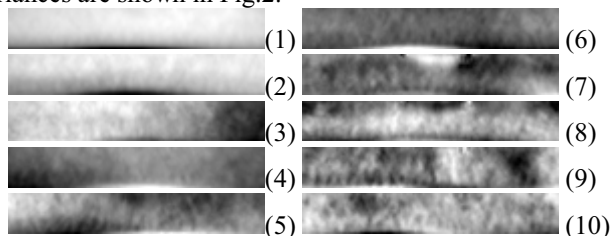The main 10 components corresponding to the biggest 10 variances are shown in Fig.2.

Figure 2. The main 10 principal components

To evaluate the performance of the iris recognition algorithm, we select 5 images from each class for training and leave others for test. Some coefficients of intra-class and inter-class are plotted in Fig.3.
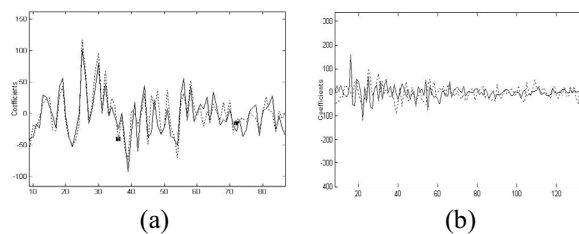

Figure 3. Some examples of the coefficients distribution of intra-class and inter class (a) intra-class (b) inter-class

To reduce the computational cost, we do some experiments to evaluate the performance of the PCA method with different number of principal components. The results are shown in Fig.4.
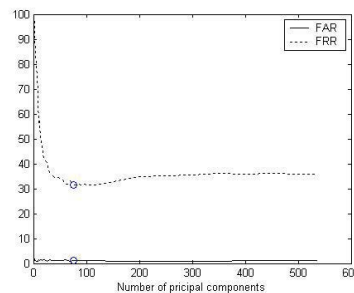

Figure 4. The performance of the PCA method with different number of principal components

From Fig.4, we can find that:

(1) Selecting more than 75 components does less to the performance of the method.

(2) The method has high FRR, because it has poor power of rotation invariant. However, the method shows the intra-class stability and inter-class randomness (shown in Fig.3), which is useful for iris image synthesis.

So, in the following experiments, 75 components are employed. The accuracy is listed in Table.1

Table 1. The accuracy of the iris recognition method based on PCA and NN classifier

Number	T	Training FRR	Training FAR	Test FRR	Test FAR
75	276	35.8%	1.0%	31.5%	1.2%

In Table 1, 'Number' is the number of the principal components and 'T' denotes the threshold of the NN classifier. In the experiments, the FAR is about 1%.

From all the iris coefficients of iris images, we obtain the boundaries of the coefficients, which are plotted in Fig.5.
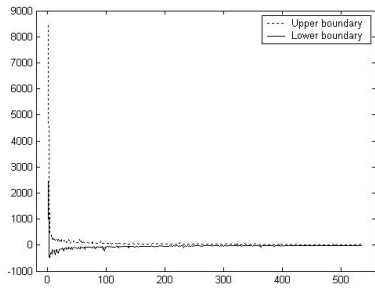
Figure 5. The boundaries of the coefficients

We can think that if we want to construct an iris image, the coefficients should lie in the boundaries. Moreover, because the boundaries are learned from the existing iris samples, they can be somewhat extended.

3. Iris Image Synthesis Algorithm Based on PCA and Super-resolution

Image synthesis plays an important role in image processing. Fingerprint synthesis has applications in constructing very larger databases. The capacity and clustering of a synthesis method are the two problems we should focus on.

How many classes can we construct? The question can be approximately modeled as how many spheres can be put into a box, namely sphere packing problem (SPP). Unfortunately, the problem is not solved yet. We can analyze the problem approximately as follows.

Given T (Threshold), an interval can be divide into $ceil(w1/(T+M))$ parts, where $ceil(x)$ denotes the minimum integer no less than x. $w1$ and S are the interval width and margin, respectively. In 2D space, a box can be divide into $ceil(w1/(T+M)) * ceil(w2/(T+M))$ areas. The illustration is shown in Fig.6.
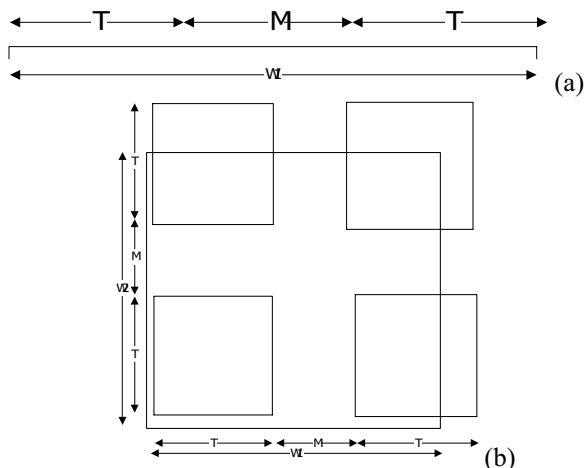

(a)

(b)

Figure 6. The approximate analysis of the SPP (a) in 1D space (b) in 2D space

The results can be extended into n-dimension space. The classes that our algorithm can construct is estimated by Eq.(2)

$$C = \prod_{i=1}^{K} ceil(w_i /(T+M)) \qquad (2)$$

From Fig. 5 and Table 1, we can find that the proposed synthesis method based on PCA can construct a database containing 286720 classes according to Eq.(2). The declaration must be made that:

(1) When the boundaries are extended and the margins are smaller, the classes should be more than 286720.

(2) The analysis is just approximate and the real number may be large more than 286720.

The procedure of the iris image synthesis with specified classes are as follows.

(1) For the same class, we first give the center of the class, which corresponds to an iris image. For other iris images the same as it, we control the coefficients to lie in the sphere centered at the given iris image with a radius. The detailed steps are as follows.

i) Suppose $X_0 = (x_{0,1} \quad x_{0,2} \quad ... \quad x_{0,75})$ is a vector corresponding to the center of a class, search x_1 and let x_1 satisfy $|x_1 - x_{0,1}| < \delta$, where $\delta << T$

ii) Search x_2 and let x_2 satisfy $|x_2 - x_{0,2}| < \delta$ and

$$|x_2 - x_{0,2}| < \sqrt{T^2 - |x_1 - x_{0,1}|^2}$$

iii) Search x_i and let x_i satisfies $|x_i - x_{0,i}| < \delta$ and

$$|x_i - x_{0,i}| < \sqrt{T^2 - \sum_{k=1}^{i-1}|x_k - x_{0,k}|^2}$$

(2) For different class, we first search the center of class center, then step (1) is adopted. The searching can be randomly done.

Limited by our real conditions, the iris image vector I_k (in Eq.(1)) is down sampled. So, it is useful to enhance the synthesized iris images. Super-resolution method, which is used in our previous work [18], is adopted to enhance the synthesized iris images. After enhancement, the iris texture is mapped onto a template and we can create iris images with different rotation. Some last results of the synthesized iris images are shown in Fig.7.
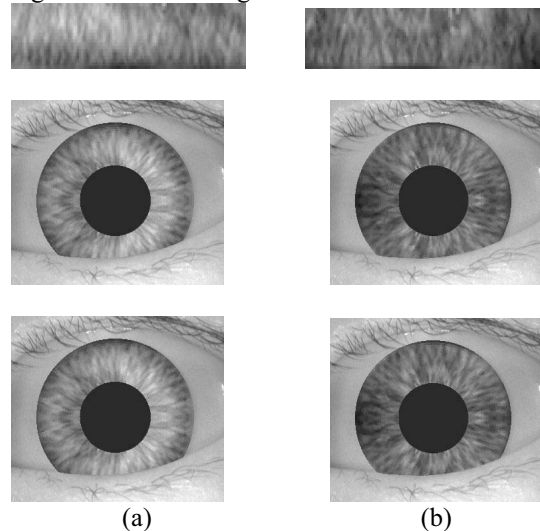

(a)   (b)

Figure 7. Some samples of synthesized iris images (a) and (b) denote different classes respectively

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In our experiments, we created 10000 classes and each class has 51 iris images. For the images we constructed, we use Daugman's iris recognition algorithm [3,14] to evaluate the cluster of the synthesized iris images, because it is a well-known iris recognition algorithm. The distance distribution of intra-class and inter-class is plotted in Fig.8 In Fig.8, when the threshold is 0.27 (learned from training), the FAR and FRR are all zero. The results show that the method has satisfactory clustering.
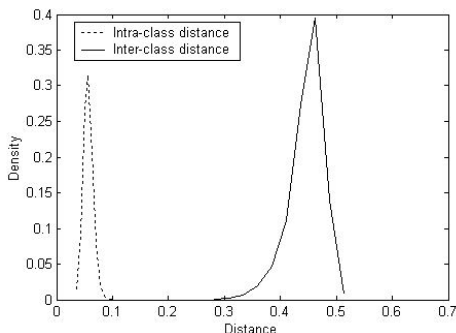

Figure 8. The intra-class and inter-class distance distribution

4. Conclusions

In this paper, an iris recognition algorithm based on PCA is first presented. Global feature vectors are extracted because it is useful for image reconstruction. Based on the proposed PCA method, an iris synthesis method is proposed. In the iris synthesis method, iris images belong to the same class are constructed through letting the coefficients lie in the same sphere centered at a sample iris image in a high-dimensional space. To construct different classes, we search in a limited high-dimensional space. Super-resolution method can be used to enhance the synthesized iris images. Theoretical analysis and extensive experimental results show that the algorithm has good clustering. Moreover, the distance between different classes and the clustering of the same classes can be controlled by some parameters (δ, T, M), so the method has elastic modifying power of constructing iris databases with different challenges. In our future work, we will focus on the synthesis method based on local property to characterize the iris feature with more high verisimilitude to meet the mechanism of iris forming. The simulation of the iris deformation and eyelid occlusion is also the topic of our future research.

Acknowledgements

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