PERFORMANCE EVALUATION OF NON-IDEAL IRIS BASED RECOGNITION SYSTEM IMPLEMENTING GLOBAL ICA ENCODING

Vivekanand Dorairaj, Natalia A. Schmid, and Gamal Fahmy*

Lane Department of Computer Science and Electrical Engineering
West Virginia University, P.O. Box 6109, Morgantown, WV 26506
{vivekand,natalias,fahmy}@csee.wvu.edu

ABSTRACT
We describe and analyze the performance of a non-ideal iris recognition system. The system is designed to process non-ideal iris images in two steps: (i) estimation of the gaze direction and (ii) processing and encoding of the rotated iris image. We use two objective functions to estimate the gaze direction: Hamming distance and Daugman’s integro-differential operator and determine an estimated angle by picking the value that optimizes the selected objective function. After the angle is estimated, the off-angle iris image undergoes geometric transformations involving the estimated angle and is further processed as if it were a frontal view image. The encoding technique developed in this work is based on an application of the global Independent Component Analysis (ICA) to masked iris images. We use two datasets: the CASIA dataset and a special dataset of off-angle iris images collected at WVU to verify the performance of the encoding technique and angle estimator, respectively. A series of Receiver Operating Characteristics (ROCs) demonstrates various effects on the performance of the non-ideal iris based recognition system implementing the global ICA encoding.

1. SYSTEM DESCRIPTION

Iris patterns are believed to be unique due to the complexity of two underlying processes (i) environmental and (ii) genetic that influence their generation. These result in textural patterns that are unique to each eye of an individual and even distinct between twins. Iris as a biometric has been known for a long time [1-4]. However, only over the past two years it has gained a substantial attention of both the research community and governmental organizations. Three critical factors that influenced the increased interest to iris biometric are (i) public acceptance, (ii) new user friendly capture devices with broad improved capabilities, and (iii) a broadened range of applications. As a result, a large number of new iris encoding and processing techniques have been developed over this short period of time. While most of literature is focused on processing of frontal view iris images [2,3,4], there have been a few new directions identified in iris biometric research including processing and encoding of “non-ideal iris” that is defined as dealing with off-angle, occluded, blurred, noisy images [8,9,10] and “iris at a distance” identified as a video or a snapshot of iris captured from a not necessarily cooperative individual at a large distance (more than a meter) [11].

In this work, we design a non-ideal iris recognition system that deals with off-angle iris images, and analyze its performance. The system processes non-ideal iris images in two steps: (i) estimation of a gaze direction and application of a projective transformation to bring the iris image into a frontal view image and (ii) processing and encoding of the rotated iris image as if it were a frontal view image. To estimate the gaze direction we use the Hamming distance between an ideal frontal view image and an off-angle iris image or Daugman’s integro-differential operator [1]. A brief description of the angle estimation strategy is given in Sec. 2. The iris image is further enhanced, segmented using the integro-differential operator, and transformed into a pseudo-polar representation (see Fig. 1). While a set of standard preprocessing steps similar to those described in [1-4] is used to prepare iris image for encoding, the encoding technique introduced and evaluated in this work is quite distinct from all previous techniques. We use the global ICA method for encoding the iris texture. We are aware of a few previously published works that use ICA method for iris image encoding (for example, [6]). However, in all these works the ICA was used in a mode of operation that extracts only local features, as proposed by Hyvarinen [7]. The purpose of this research is to explore a possibility of using global image encoding / feature extraction algorithms to process the iris. Apart from this, we extract individual iris signatures and demonstrate their independence, which results in a simplified predictive analysis of iris individuality (not presented in this paper). Prior to extracting ICA components, we perform PCA that is often used as a preprocessing step to ICA with the goal to uncorrelate components [7].

* This work was supported by a grant from NSF IUCRC Center for Identification Technology Research.
The following distinctive features characterize our approach: (i) Global iris encoding; (ii) Use of unified mask designed and applied to iris images to extract iris texture information; (iii) Use of Euclidean and Hamming distances to measure the performance; (iv) Compensation for image rotation – takes into account the effect of head tilt.

![Diagram](image)

Fig. 1: Block-diagram of the system implementing the gaze estimation and the global ICA encoding techniques for non-ideal iris.

2. ANGLE ESTIMATION

The general block-diagram of our system is shown in Fig.1. Below is a brief description of the estimation and encoding blocks.

To estimate the angle of rotation we assume that a rough initial estimate of the angle is available. We use two objective functions to refine the estimate: (i) the Hamming distance between ICA coefficients of an ideal frontal view image and ICA coefficients of a transformed iris image (this is the case when two images are available from the same iris class including the "ideal" iris image) and (ii) Daugman’s integro-differential operator as a measure of iris circularity (in case if only a single off-angle image is available). We pick the estimates that minimize the Hamming distance and maximize the value of the integro-differential operator. To be more specific, let $\Psi$ be a rotational angle and $J(\Psi)$ be an objective function that has to be optimized. For each given value of $\Psi$ in the range $\Psi \in [\Psi_{\text{min}}, \Psi_{\text{max}}]$, (i) the off-angle iris image is rotated by using the projective transformation and (ii) the objective function $J(\Psi)$ is calculated. Once the angle is estimated we apply the projective transformation to rotate the off-angle image into a frontal view image.

3. ENCODING USING THE GLOBAL ICA

The iris based identification system operates in two modes: (i) training and (ii) testing.

**Training:** Let $\tilde{X}$ be a matrix with vector columns given by $\tilde{X}_1, \tilde{X}_2, \ldots, \tilde{X}_m$, a sequence of preprocessed, normalized, and whitened iris images indexed by their class and placed. During the training mode we assume that each class is represented by a single iris image. It can be easily generalized to a multi-image case.

ICA is a blind source-separation method. It assumes that observed data can be represented as a linear combination of a number of independent signals. The unknowns are the mixing coefficients and the independent input signals. Let $S$ be a matrix composed of unknown independent input signals arranged in columns. Then the linear forward model that ICA assumes is $\tilde{X} = AS$, where $A$ is the unknown mixing matrix. As argued in [7], the results of linear mixing of non-Gaussian signals are more Gaussian than the input signals. Then to estimate the mixing matrix $A$ and one of the components of $S$, one has to define a measure of non-Gaussianity. One of the theoretically sound criteria is the maximization of the negentropy given by

$$J = H_{\text{Gauss}}(A^T X) - H(A^T X),$$

where $H_{\text{Gauss}}$ is the entropy of the data under the assumption that data are Gaussian distributed and under the constraint of the same covariance matrix for the distributions in $H_{\text{Gauss}}$ and in $H$ (see [7] for more detailed explanation). Once the mixing matrix and one of the input signals are estimated, the remaining input signals can be obtained by invoking the Gram-Schmidt orthogonalization procedure. To deal with empirical case, (1) is approximated by expressions involving empirical moments.

**Testing:** To test the performance of ICA method, we use a testing dataset that is distinct from the training set. We apply two distance measures to perform matching (i) Euclidean and (ii) Hamming distances. Let $\tilde{W}_i$ and $\tilde{W}_j$ be two vectors of ICA coefficients corresponding to two distinct normalized, preprocessed iris images $Y_i$ and $Y_j$ from the testing set. To involve the second measure, we quantize the values of individual coefficients in the vector $\tilde{W}$ to “1” or “0” if the feature value is greater than zero and less than or equal to zero, respectively. In order to take a head tilt into consideration, one of two segmented and enhanced iris images is rotated systematically on either direction (up to a few degrees) and templates are extracted for each rotated version of the image. The following minimization procedure is applied to compensate for the head tilt

$$\min_{\theta \in [-\pi, \pi]} d(S\tilde{Q}^T Y_i, S\tilde{Q}^T Y_j, \theta)$$

where $d(\cdot)$ denotes the Euclidean or Hamming distance between two projected iris images, $\tilde{Q}$ is the matrix of
essential eigenvectors derived from the empirical covariance matrix formed using the training data, and \( \bar{Q}^T \mathbf{Y}_1 \) and \( \bar{Q}^T \mathbf{Y}_2 \) are two PCA coefficient vectors corresponding to two distinct normalized and preprocessed iris images \( \mathbf{Y}_1 \) and \( \mathbf{Y}_2 \) from the testing set.

To ensure encoding of iris texture rather than eyelid and eyelash information, we design a unified mask that is formed by combining all occluding masks from individual iris images. Every iris image from training and testing datasets will be further multiplied by the mask. This mask can be explicitly incorporated in (2).

4. RESULTS

All experiments with gaze estimation were performed on a dataset of off-angle irises collected at WVU. The dataset presently consists of about 75 iris classes and within the next two months will grow to the size of 100 iris classes. Each class is represented by 4 images collected at four angles in the order 0, 15, 30, and again 0 degrees (angle values are approximate). The sample images from this dataset are shown in Fig. 2. All experiments for evaluating performance of the global ICA encoding technique were performed on CASIA dataset provided by the Chinese Academy of Science [5]. The CASIA dataset contains iris images of 108 irises with 7 images per iris class. The images in this dataset are strongly occluded and defocused.

Angle Estimation: Sec. 2 described two techniques to estimate the gaze direction. When two images (one frontal image and one off-angle) are available, the angle can be estimated using the Hamming distance. Fig. 3 demonstrates the results. For each given angle value, we compensate the off-angle iris image by the given number of degrees and compute the Hamming distance between the compensated off-angle image and the frontal view image. We pick the angle that minimizes the Hamming distance. For this specific example, the estimated angle is 16 degrees. The rough estimate was 30 degrees.

In the case if a single image is available, we use Daugman’s integro-differential operator to estimate the unknown angle. For each given angle value, we apply a projective transformation to rotate the iris image and apply the integro-differential operator to the rotated image. The estimated angle is the angle that results in the maximum value of the operator. The operator is used as a measure of circularity. The results of applying this technique are demonstrated in Fig. 4. The value of estimated angle is 18 degrees. The two described methods are in good agreement. However, visual evaluation and recognition performance indicate that a more general geometric transformation has to be applied to improve the performance of the estimator.

Evaluating performance of global ICA: The size of unwrapped images used in our experiments is 64x360. After applying the unified mask, the number of pixels in unwrapped images was reduced to about a half of the original number (high pixel count). We used the third image from 100 iris classes in CASIA dataset to train the system implementing the global ICA encoding method. The remaining data from CASIA dataset were used to test the system. The global PCA method when applied to iris images, extracted 99 essential eigenvalues. The value of 99-th eigenvalue is approximately 15 times smaller than the value of the first eigenvalue. This emphasizes the fact that the individual iris is rich in texture.

Unified Masking: We further demonstrate the effect of unified masking on the performance of global ICA encoding method. Fig. 5 displays four ROC plots describing the performance of two global encoding techniques. In this work, global PCA is used as a preprocessing step to global ICA. The ROC curves demonstrate that global PCA may be also considered as an independent encoding technique. Fig. 5 shows two sets of curves for each encoding technique: with and without application of unified masking. Note that the performance of global PCA drops when the unified mask is applied. This clearly indicates that PCA prefers large iris features to fine features and loses its discriminating power when images contain only fine features. On the contrary, the performance of global ICA improves with application of the unified mask. In this experiment Euclidean distance was used as a matching score.

 Compensation for rotation: The effect of head tilt on the performance of iris-based recognition system is demonstrated in our previous work [10]. Because of a limited space, we do not reproduce the results here.

The number of eigenvalues vs. the number of iris classes: Since the initial experiments have demonstrated that for images with a high pixel count the extracted ICA vectors (analogous to eigenvectors) are scaled versions of individual iris signatures, we proceeded with studies on influence of the number of essential ICA vectors and the number of iris classes on the performance of the designed system. Fig. 6 displays the results. They confirm our conjecture that under the condition that iris images used for training have a high pixel count and that the number of iris classes is smaller than the value of pixel count, the number of individual and independent iris signatures extracted using the global ICA has to be close to the number of iris classes used for system training to guarantee a small probability of error.
Fig. 2: Sample images from WVU non-ideal iris database.

Fig. 3: Angle estimation using the Hamming distance as a criterion.

Fig. 4: Angle estimation using Daugman’s integro-differential operator.

Fig. 5: Shown are four ROC curves characterizing the performance of two encoding techniques: (1) the global PCA and (2) the global ICA.

Fig. 6: The plot of the Equal Error Rate (EER) vs. the number of essential independent components and the number of iris classes. EER is a single point on ROC curves.

REFERENCES
5. CASIA Iris Image Database (ver. 1.0), http://www.sinobiometrics.com/casiairis.htm