The BTAS*Competition on Mobile Iris Recognition

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Abstract

The security of mobile devices has become an increasingly important issue especially for the mobile-payment application. Iris recognition is an emerging technology for mobile authentication owing to its high uniqueness and distinctiveness. However, it is a challenging problem because iris images acquired by mobile devices generally have low-quality and the computational resources of mobile devices are limited. In order to track the state-of-the-art algorithms in iris recognition on mobile devices under near infra-red (NIR) illumination, we organized the BTAS Competition on Mobile Iris Recognition (or MIR2016 shortly), which is the first mobile iris recognition competition of NIR images as far as we know. All the participants have to strictly comply with the evaluation protocol to assure fairness. In this competition, three participants submitted six algorithms in total and five algorithms from two participants were qualified. The submitted algorithms were trained on the newly constructed MIR-Train database and evaluated on the unpublished MIR-Test database. We rank the submitted algorithms by the evaluated results in terms of False Non-match Rate (FNMR) when False Match Rate (FMR) is 0.0001.

1. Introduction

Mobile devices have been widely used for social communications, storing large amount of private data and online banking. It is important to build a reliable and user-friendly biometric recognition system for mobile payment and sensitive data protection. Compared with other biometric modalities, iris is the most reliable one because it is difficult to be replicated and highly unique [21]. Therefore, iris is believed to have the potential to protect the security of next generation mobile devices. Fujitsu [1] released the world's first smartphone equipped with iris authentication technology in May 2015. The Microsoft [3] Lumia 950 and Lumia 950 XL mobile handsets also include iris scanning function. Most recently, IrisKing [2] has launched China's first mobile phone using iris recognition for information security. Iris recognition on mobile devices extends the capability of a traditional biometric identification system by allowing recognition in any place and more relaxed conditions [19]. It brings about new challenges [31]: uncontrolled illumination and distance variations, limited computational resource, low resolution caused by optical and cost considerations, motion blur introduced by unstable hand positions and out-of-focus images. These challenges will greatly reduce the recognition rate on mobile devices.

Iris recognition technologies in constrained environments are mature after more than 20 years of research since the first successful iris recognition algorithm proposed by Daugman [15]. Wildes *et al.* [34] represent iris features by four-level Laplacian pyramid. Kumar and co-workers [25] implement advanced correlation filters. Sun and Tan [30] apply ordinal measures to qualitatively represent iris patterns. However, iris recognition on mobile devices is an emerging application. How to transfer traditional high-performance iris recognition algorithms to mobile applications is challenging [24]. There has some work about iris recognition on mobile devices. Most current work about mobile iris authentication is based on visible spectrum [11] [18] [28]. However, Asians have dark-colored irises which show clear texture information only under near infra-red (NIR) light. Cho *et al.* [13] are among the first to study the real-time iris localization method for iris recognition on mobile devices using NIR iris images. Jeong *et al.* [22] use adaptive Gabor filter to extract iris features for cell phones. Zhang *et al.* [37] fuse face and iris modalities on mobile devices and achieve satisfactory results. Corcoran *et al.* [14] carry out a feasibility study and design considerations for an iris acquisition system for smartphones. Thavalen-

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gal *et al*. [31] evaluate the suitability of the camera system with dual visible/NIR sensing capabilities for implementing iris recognition on smartphones. To track the state-of-the-art algorithms of mobile iris recognition using NIR images, the BTAS Competition on Mobile Iris Recognition (or MIR2016) is organized.

There are several influential iris recognition competitions such as ICE [6], IREX [7], NICE.I [9], NICE.II [10], ICIR2013 [36], CSIR2015 [5], etc. These competitions evaluate iris recognition algorithms in different conditions and their databases are acquired by dedicated iris cameras. Few competitions focus on evaluating algorithms of iris images obtained by mobile devices. MICHE [8] is a competition on mobile iris challenge evaluation, which gets iris images using the existing smartphone cameras under visible light. However, there is no mobile iris recognition competition of NIR iris images and MIR2016 is the first competition of this field as far as we know. MIR2016 is open to both academia and industry. The MIR-Train and MIR-Test databases are used for training and testing purposes, respectively. Both databases are large to conduct extensive experiments and give convictive testing results. Iris images are collected using the mobile module. It is small and can be conveniently attached to a mobile phone through micro USB. The testing results can represent the performance of iris recognition algorithms in mobile applications.

There are three participants with six algorithms in total and five algorithms from two participants are qualified in MIR2016. To assure fairness, all the participants have to strictly abide by the evaluation protocol. Each participant can maximally submit three algorithms. MIR2016 only accept qualified iris recognition algorithms which meet the following requirements due to limited competition resources: the equal error rate (EER) must be less than 5% on the training database; the average processing time for feature encoding must be less than 3 seconds and the average matching time must be less than 0.1 second on a normal personal computer. A public platform, the Biometrics Ideal Test (BIT) [4] is used to organize the competition. The remainder of this paper is organized as follows. In Section 2, the training and testing databases employed in MIR2016 are introduced. The performance measures are described in Section 3. Section 4 presents the participants and corresponding algorithms. Section 5 illustrates evaluation results and finally Section 6 concludes the paper.

2. The MIR2016 databases

Both the MIR-Train and MIR-Test databases are collected using the mobile module that composes of a NIR camera and several NIR illuminators to acquire clear iris texture of Asians. Two irises are collected simultaneously under indoor environment. There are altogether 3 collection distances, namely 20 cm, 25 cm and 30 cm. At each distance, there are 10 images. Therefore, each volunteer contributes 30 images. Images in the MIR-Train and MIR-Test databases are obtained in the same session. We acquire the images at the same place, using the same device and under identical circumstance. The MIR-Train database contains 4500 images from 150 subjects, which is publicly available on the BIT website [4] for training. The MIR-Test database includes 12,000 images from 400 subjects and is unavailable to participants to assure a fair competition and comparable results. The main sources of intra-class variations in MIR-Train and MIR-Test include distance changes, illumination variations, eyeglasses and specular reflection, defocus and so on. Each image in the two databases is an 8-bit gray-level BMP file with a resolution of 1968*1024. Example images in the training and testing database of three distances are shown in Figure 1 and Figure 2, respectively.

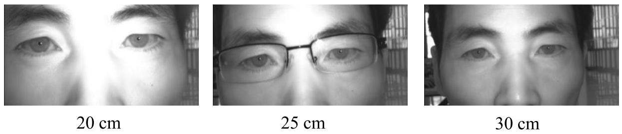


Figure 1: Example images in the training database of three distances (20∼30 cm).

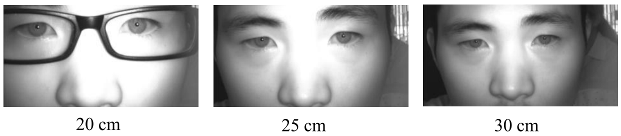


Figure 2: Example images in the testing database of three distances (20∼30 cm).

3. Performance measures

We define an image containing two irises from the same person as one class. Thus the matching score of two classes (namely two persons) is the fusion of the two iris matching scores. At the testing stage, all possible mobile intra-class comparisons are implemented to evaluate the false non-match rate (FNMR) providing a total of 174,000 intra-class match results. Two samples are randomly selected from each iris class to evaluate the false match rate (FMR). Therefore, there are totally 319,200 inter-class match results. If an intra- or inter-class comparison cannot be successfully implemented due to failure enrollment or failure match, a random variable ranging from 0 to 1 will be assigned as the matching score. Because we think the worst situation for a biometric system is a random decision rather than a definitely wrong decision. It is fair for all participants with the same rule.

Popular performance measures of iris recognition containing FNMR, FMR, EER, Receiver Operating Characteristic (ROC) and the decidability index (DI) are applied to report the competition results. The metric FNMR4, that is the value of FNMR when FMR equals to 0.0001, is used to rank the performance of submitted algorithms. It is also used to choose the best algorithm from several submitted algorithms of each company. The definitions of FMR and FNMR are dependent on the threshold θ. Given the similarity distributions of authentic and imposter, the values of FMR and FNMR change with the value of θ. The ROC curve plots FMR against FNMR, and EER refers to the point in the ROC curve when FMR is equal to FNMR. DI can measure the comprehensive performance of a classifier [15]. The higher the DI value is, the greater the difference of intra- and inter- distribution is.

4. Participants

4.1. Beijing Bata Technology Co. Ltd.

Beijing Bata Technology Co. Ltd. is a company from China. They submit two algorithms and the better one is used for evaluation, which is called 'Bata' for short. The algorithm consists of iris detection, preprocessing, feature extraction and matching.

(1) Iris detection. At first, the face is found by using the Adaboost algorithm [33] and eye positions are found by using support vector machine (SVM). Next, the iris and pupil boundary are detected by the modified Daugmans Integro-Differential operator [16] to decrease the effect of light reflection. The operator is shown in equation (1):

$$\begin{aligned} &\max_{(r,x_0,y_0)} \oint_{r,x_0,y_0} T(\langle grad(I(x,y)), \mathbf{n}\rangle) ds \\ &T : \mathbf{R} \rightarrow \mathbf{R} \\ &T(u) = \begin{cases} u, & u \geq 0, \\ 0, & u<0. \end{cases} \end{aligned} \tag{1}$$

where $I(x,y)$ represents the iris image and $\mathbf{n}$ is the unit normal vector. Ten candidate positions are got after this step. Afterwards, the approximate iris position is determined by comparing the eye position and 10 candidates. The eyelid is modeled as a circle arc and the detection method is similar to iris. Finally, the exact iris position is found around the approximate iris position by not considering the outer region of eyelid.

(2) Preprocessing. Reflection regions are found and removed by using threshold method and shape information. The iris region is transformed to a 512*64 rectangular region using Daugman's Cartesian to polar transform method [15]. The eyelash region is detected and removed using threshold method. At last, local histogram equalization enhancement is performed and the radius is 32. The schematic diagram of detection and preprocessing is shown in Figure 3.

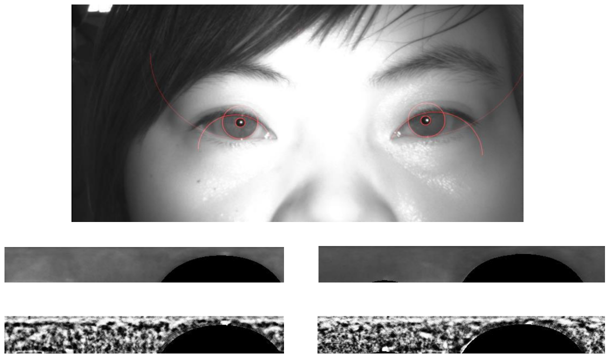


Figure 3: The schematic diagram of detection and preprocessing.

(3) Feature extraction. The Gabor wavelet coefficients [26] [32] are calculated at fixed 40*10 points of rectangular region. Coefficients of 5 frequencies and 8 directions are used. 40 dimensional magnitude vector is calculated and normalized at each point and the phase bits of each coefficient are also calculated. Then, the 100*150 eye image is extracted. Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) are performed to get the PCA-LDA feature.

(4) Matching. The magnitude feature is matched using cosine distance and the phase feature is matched using Hamming distance. The PCA-LDA feature is also matched through cosine distance. In the end, above three results are combined.

4.2. TigerIT Bangladesh Ltd.

TigerIT Bangladesh Ltd. is a company from Bangladesh. They submit three algorithms and the best one is used for evaluation, which is called 'Tiger' for short. In the multi-biometric literature [20], it has been suggested that fusion of information extracted from different classifiers provides better performance compared to single classifiers. The used algorithm consists of the following steps: enhancement of images based on the quality, detection of the eye, iris localization, normalization of the region of interest (ROI), template generation by feature extraction and scoring based on Hamming distance.

Based on the motion blur, contrast, luminosity and camera diffusion, the quality of input images are assessed and used to judge whether the image needs enhancement that includes sharpening, smoothing and histogram equalization. The original images have low contrast and may have non-uniform illumination caused by the position of the light source. These may impair the result of the texture analysis. Enhancement is performed to reduce the effect of non-uniform illumination, which is necessary to extract the iris patterns later. Eyes are detected from the image using the OpenCV eye detection method based on the trained cascade on the training set. For the training, dual-nu support vector machines [12] are used.

For iris detection, the first level of the algorithm uses intensity thresholding to detect an approximate elliptical boundary, and the second level applies circularity and intensity to obtain the accurate iris boundary. As pupil is a black circular region, it is easy to detect the pupil inside an eye image [29] [35]. Firstly, pupil is detected using thresholding operation. An appropriate threshold is selected to generate the binary image which contains pupil only. Morphological operators are applied to the binary image to remove the reflection inside the pupil region and other dark spots caused by eyelashes. Since the inner boundary of an iris can be approximately modeled as circles, circular Hough transform is used to localize the iris [23]. Firstly, edge detector is applied to binary image to generate the edge map. The edge map is obtained by calculating the first derivative of intensity values and thresholding the results.

In order to locate the iris outer boundary, pupil centre is referred as origin. The search region is a sector with radius from pupil boundary to a maximum radius. Maximum radius is defined as the distance from pupil centre to boundaries of the right or left search region. Maximum threshold is a constant defined based on the iris size. The minimum radius of the search regions starts ten pixels away from the pupil boundary. This is to avoid the effect caused by the pupil noise. In order to avoid occlusion caused by eyelashes, upper and lower eyelids, the search regions are selected on the lower iris region. After getting the outer and inner boundary, the ROI is the difference of two radius of boundary, which will be used for the normalization.

Similar to iris outer boundary localization, the proposed method selects two search regions to detect upper and lower eyelids. The pupil centre, iris inner and outer boundaries are used as reference to select the two search regions. The search regions are confined within the inner and outer boundaries of the iris. The width of the two search regions is same with diameter of the pupil. Modified Sobel edge detection is applied to the search regions to detect the eyelids. In order to reduce the false edges detection caused by eyelashes, Modified Sobel kernel is tuned to the horizontal direction, which is shown in Table 1.

After edge detection step, the edge image is generated. The eyelids are detected using linear Hough Transform method. The method calculates total number of edge points in every horizontal row inside the search regions. The horizontal row with maximum number of edge points is selected as eyelid boundary. If the maximum number of edge points is less than a predefined threshold, it is assumed that eyelid is not presented in the search regions. Figure 4 shows a sample of segmented iris image.

Table 1: Modified Sobel kernel tuned to horizontal direction.

-1	-2	-2	-2	-1
-1	-2	-2	-2	-1
0	0	0	0	0
1	2	2	2	1
1	2	2	2	1

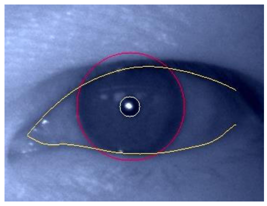


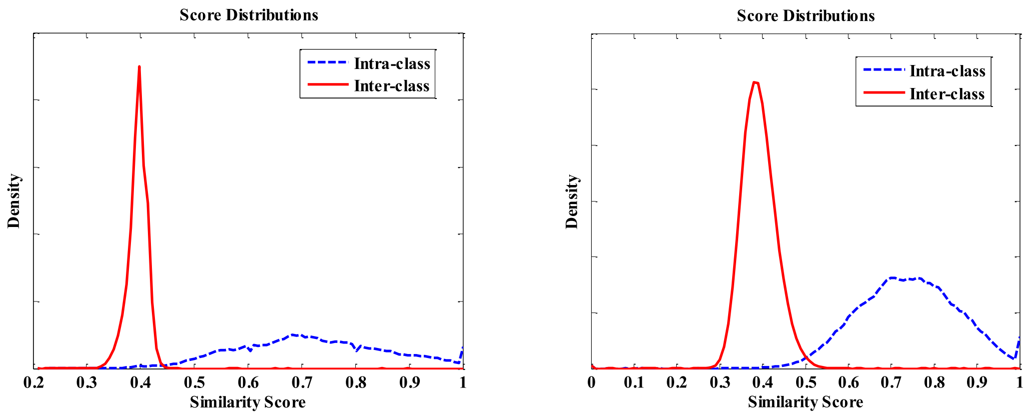
Figure 4: Segmented Iris Image.

Eyelashes appear randomly inside the iris region. It is difficult to detect the eyelashes effectively. The eyelashes are observed to have low intensity values. A simple thresholding technique is applied to segment eyelashes accurately. Reflection regions are characterized by high intensity values close to 255. A high threshold value can be used to separate the reflection noise.

Iris may be captured in different size with varying imaging distance. Due to illumination variations, the radial size of the pupil may change accordingly, therefore, the iris region needs to be normalized to compensate for these variations. Normalization remaps each pixel in the localized iris region from the Cartesian coordinates to polar coordinates. The non-concentric polar representation is normalized to a fixed size rectangular block; we choose most popular size of 240×20. We used homogenous rubber sheet model devised by Daugman [17].

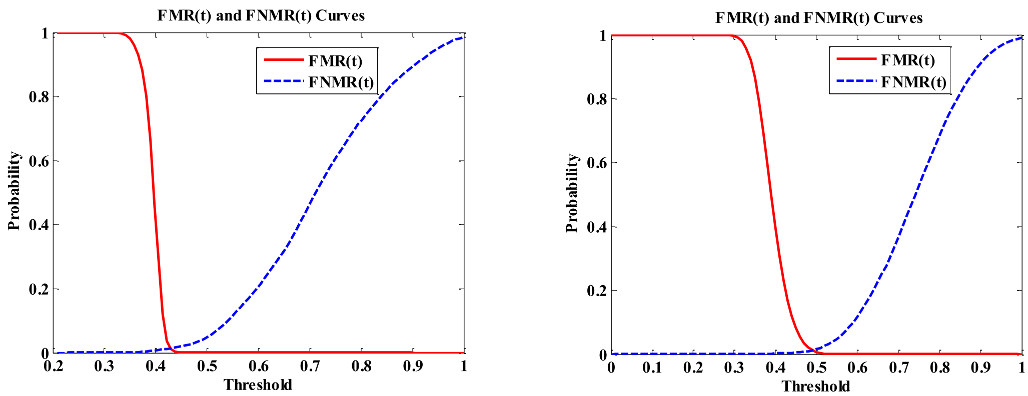
Although a recognition system can use the normalized iris directly to compare two irises, most systems first use a feature extraction routine to encode the iris's textural content. In a commonly used encoding mechanism, 2D Gabor wavelets are first used to extract the information of the iris texture. Gabor filters can provide optimum conjoint representation of a signal in space and spatial frequency [27].

The matching module generates a match score by comparing the feature sets of two iris texture. Our technique for comparing two iris texture is to use the Hamming distance, which gives a measure of how many bits are the same between two bit patterns.



(a) **Bata** (b) **Tiger**

Figure 5: Score distributions of Bata and Tiger algorithms.



(a) **Bata** (b) **Tiger**

Figure 6: FMR and FNMR graphs of Bata and Tiger algorithms.

5. Evaluation results

The MIR-Test database is used for evaluation. We calculate the values of FMR and FNMR based on the score distribution and the threshold θ on range (0, 1) to draw the FMR and FNMR graph for each algorithm. Figure 5 shows the score distribution of Bata and Tiger algorithms. The FMR and FNMR graphs are shown in Figure 6.

We add a comparison experiment using Gabor features [15] and Hamming distance matching. Simple preprocessing steps are adopted, which include three parts: eye detection, iris localization and iris normalization. There are no eyelid, eyelash and reflection regions removing procedures. Histogram equalization is not applied either. The algorithms are evaluated by FNMR4, EER and DI. Evaluation results are shown in Table 2. The ROC curves are shown in Figure 7.

We can see from the Table 2 and ROC curves that both the Bata and Tiger algorithms are better than the Gabor algorithm that we implemented. The main reason is that we adopt simple preprocessing steps. The Bata algorithm achieves a lower FNMR4 value while the Tiger algorithm gets smaller EER value and higher DI value. To rank the performance of submitted algorithms, we use the metric FNMR4 value because it is more useful in practical applications and is popular used in many biometric competitions. Hence, we rank the Bata algorithm at the first place.

Table 2: Evaluation results.

Algorithm name	FNMR4	EER	DI
Bata	2.24%	1.41%	3.33
Tiger	7.07%	1.29%	3.94
Gabor	16.8%	3.71%	3.27

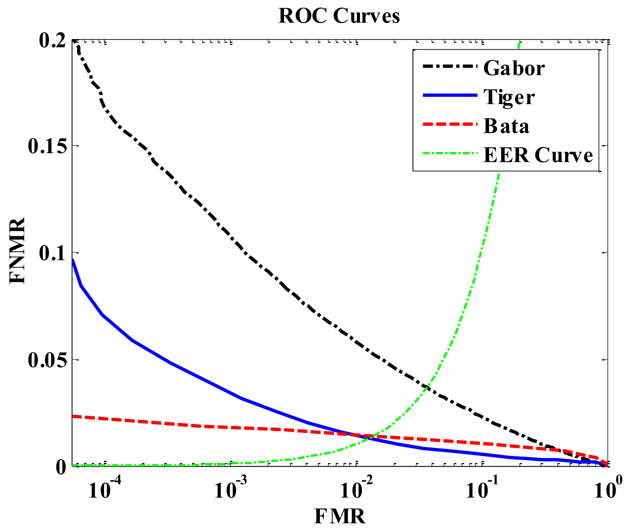


Figure 7: ROC curves.

6. Conclusions

This paper has reported evaluation results of the BTAS Competition on Mobile Iris Recognition, which aims at tracking the state-of-the-art algorithms in iris recognition on mobile devices using NIR images. To promote the development of iris recognition on mobile devices, we have released a newly constructed MIR-Train database, which contains 4500 images from 150 subjects. Two companies submitted five qualified algorithms totally and we chose their best algorithms for comparison. The submitted algorithms generally contain four parts: iris detection, image pre-processing, feature extraction and matching. Edge detection methods are widely used to segment iris. Gabor wavelet shows good performance in iris feature extraction because it can extract local texture details. Considering the acquired images by mobile devices are usually noisy and of low resolution, image enhancement methods are employed and thresholding technique is applied to separate eyelashes and reflection noise. The results of Bata and Tiger algorithms are encouraging. They show different strengths in terms of FNMR4, EER and DI values.

Iris recognition on mobile devices is still challenging not only because of low-quality images but also due to limited resources. Speed and efficiency also play key roles in realistic applications. We should pay much attention to more efficient and effective iris detection and feature extraction technologies that are specific designed for mobile uses. Since current mobile devices have GPUs, deep learning methods certainly offer an alternative to boost the performance. Besides, the face especially the periocular region can be acquired with the iris simultaneously by mobile devices. Therefore, multi-modal fusion methods deserve more investigation to further strengthen the safety use of mobile devices.

Acknowledgments

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[5] CSIR2015. http://biometrics.idealtest.org/2015/csir2015.jsp.

[6] ICE. http://www.nist.gov/itl/iad/ig/ice.cfm.

[7] IREX. http://www.nist.gov/itl/iad/ig/irex.cfm.

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