Rotation Compensated Human Iris Matching

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Abstract—**By introducing rotation compensation into a human iris matching system, improved matching is demonstrated while reducing both the computational complexity and storage requirements. This is achieved by using Fourier domain cross correlation to estimate the relative rotation of two iris images. This eliminates the need to store and compare codes from multiple orientations of the same image. Instead, only one code is stored, plus the Discrete Fourier Transform of an annular segment derived from the iris. In addition, the cross correlation function can be used as a biometric either on its own or in combination with other iris codes. A Peak to Sidelobe Ratio metric is used to discriminate matching and non-matching correlation functions. Used to preselect irises for matching, the method greatly reduces feature-vector comparisons. Alternatively a cascaded classifier approach can be used, with the correlation stage tuned to make no false rejections, followed by a Hamming distance metric on a standard iris code. The performance and robustness of the new technique are tested on the CASIA iris image database synthetically altered to generate rotated, noisy and randomly occluded normalized iris images. Improved matching performance is achieved with a 21 times reduction in matching time.**

Keywords—Iris Recognition, Correlation, Circular Shifts

Topic area—Biometrics.

I. INTRODUCTION

Personal authentication based on biometric verification is gaining increasing significance [1-3] with iris recognition in particular proving to be more accurate than other biometrics [4, 5]. Despite significant advances over the past decade, the need for robust iris recognition systems in the presence of variability in image size, position, and orientation still persists. Changes in position and size may be readily normalized in the pre-processing stage as they depend mainly on optical magnification and distance of the camera from the eye. It is also possible to compensate for non-affine pattern deformations and variations in pupil size by dilation within the iris [4]. Iris orientation, on the other hand, depends upon a large number of internal and external factors including torsional eye rotation and head tilt. Optical systems may introduce image rotation depending on eye position, camera position, and mirror angles. Most present-day matching systems rotate the iris image by various amounts about of the captured orientation to generate an array of feature vectors which are compared separately to find the best match [10, 11]. Daugman computes the iris code in a single canonical orientation and compares it with several orientations by cyclic scrolling [4]. The use of multiple comparisons in many systems leads to higher storage requirements and increased time to enrol and verify.

To address this problem, it is known that correlation based methods can be used to determine the shift or delay of one function with respect to another. Applications of correlation in object detection have been extended to biometric authentication in face, fingerprint and iris recognition. Kumar et al [6, 7] investigated the performance of advanced correlation filters for such applications since they are known to offer good matching performance in the presence of image variability. Aoki et al used phase-based image matching to achieve good results in fingerprint and iris recognition [8, 9]. In all such work the use of 2D cross-correlation requires the storage of the entire database of images along with their iris codes. Apart from a dramatic increase in storage requirements, two-dimensional operations are computationally more intensive and slow down the verification/identification process significantly.

Reducing this process to one dimension for iris verification has two major advantages, as will be seen. Apart from the obvious gain in both time and storage efficiency, there is improved accuracy due to elimination of eyelid and eyelash affected regions during the peak and displacement calculations. Here the correlation computation is carried out on a circular sequence generated by averaging a band of grayvalues from an annular region of the normalized iris image near the pupil. This has the advantage for Fourier domain calculation of being naturally periodic.

The rest of the paper is organized as follows. Section 2 reviews the relevant theory on correlation, circular symmetry and Fourier symmetry. The method as applied to rotation compensation and matching is elaborated in Section 3. This is followed by results and conclusion in Sections 4 and 5 respectively.

II. ROTATION ESTIMATION BY CORRELATION

Prior to recognition, an eye image, as shown in Fig. 1(a), needs to be pre-processed in order to eliminate unnecessary information, such as pupil, sclera, eyelids and eyelashes and compensate for variability in iris width caused by pupil dilation. In addition, grey scale adjustments must be carried out in order to obtain uniform illumination over all images.

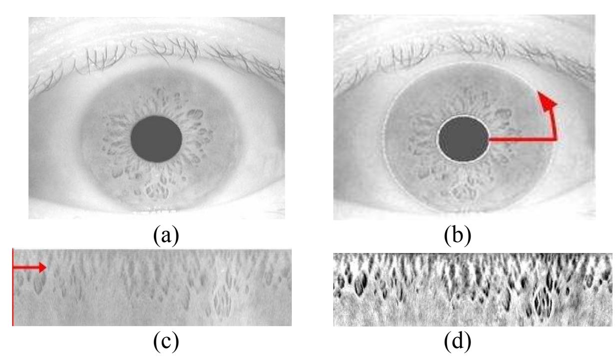


Fig. 1. a) Human eye image; b) iris outlines detected; c) resampled polar – cartesian; d) intensity enhanced.

Fig. 1 illustrates the three main pre-processing steps. First, the inner and outer iris boundaries are located to eliminate the pupil, sclera and eyelid. Then the iris image is transformed from polar co-ordinates to a 512x80 fixed size rectangular image to reduce the effect of iris dilation and contraction, of which 512x48 are later coded. The gray scale range is adjusted as a last step.

The circular symmetry about the circumferential direction in the iris image translates into horizontal periodicity in the normalized image. This symmetry can be exploited by using Discrete Fourier Transform (DFT) properties of 1D circular cross-correlation. An overview of the basic properties follows. Consider the N-point DFT of a finite sequence *x(n)* of length $L \leq N$. This is equivalent to the N-point DFT of a periodic sequence $x_p(n)$ of period N, obtained by periodically extending *x(n)* [12], that is,

$$x_p(n) = \sum_{l=-\infty}^{\infty} x(n - lN)$$

By shifting $x_p(n)$ to the right by k samples we can obtain another periodic sequence,

$$x'_p(n) = x_p(n-k) = \sum_{l=-\infty}^{\infty} x(n-k-lN)$$

Hence, we can see that the finite duration sequence,

$$x'(n) = \begin{cases} x'_p(n) & 0 \leq n \leq N-1 \\ 0 & otherwise \end{cases}$$

is related to the original sequence *x(n)* by a circular shift. In general, the circular shift of the sequence can be represented as the index modulo N. Thus we can write,

$$x'(n) = x((n-k))_N$$

From Fourier Transform properties, we know that circular convolution in the space domain is equivalent to multiplication in the Fourier domain. Similarly a space domain circular time shift is equivalent to frequency domain multiplication by an exponential,

$$x_1(n) \otimes x_2(n) \Leftrightarrow X_1(n) X_2(n)$$

$$x((n-l))_N \Leftrightarrow X(k) e^{-\frac{j2\pi kl}{N}}$$

Finally the unnormalized circular cross-correlation $\tilde{r}_{xy}(l)$ at delay l between two sequences *x(n)* and *y(n)* is calculated from their Fourier transforms $X(k)$ and $Y(k)$ as follows:

$$\tilde{r}_{xy}(l) = \sum_{n=0}^{N-1} x(n) y^*((n-l))_N$$

$$\tilde{r}_{xy}(l) \Leftrightarrow \tilde{R}_{xy}(k) = X(k) Y^*(k)$$

III. APPLICATION TO IRIS ROTATION COMPENSATION

Biometric systems in general work in two stages: enrolment and verification/identification. In our system for the human iris, during enrolment an eye image is acquired, the iris is normalized and a binary feature vector is generated using patch-based zero-crossings of FFT amplitudes as described in [13]. For each enrolled iris, a periodic sequence is extracted from the 512x80 normalized iris by averaging rows 5-9 of the image, counted from the pupil boundary. This avoids outer regions which may be obscured by eyelashes or eyelids, and is far enough from the pupil boundary to avoid irregularities. The conjugate of the 1D FFT of this is then stored along with its feature vector. During authentication, a newly acquired candidate image is normalized and the FFT of the same band is calculated for use in rotation compensation with the enrolled iris FFT. For verification the rotation calculation will be done only once, with the claimed subject's stored FFT. For identification, the calculation will be carried out with each enrolled FFT. In either case the product of the 1D FFT from the candidate iris with the stored conjugate FFT is formed, and the inverse FFT of the product is calculated to give the cross-correlation between the two sequences. After normalization, the peak sharpness is measured using methods described below and its location is noted. For similar irises a sharp peak is expected while a more flat curve would correspond to a non-match. The degree of iris-rotation is indicated by the position of the peak. The procedure is illustrated in Fig. 2. If the peak is sufficiently sharp, the normalized image from the candidate iris is shifted into alignment with the registered iris and the iris code is finally calculated for matching.

Since the preselection is based on the correlation peak, it is necessary to have a metric for independent discrimination. To make such a decision robust to image variability, it should be

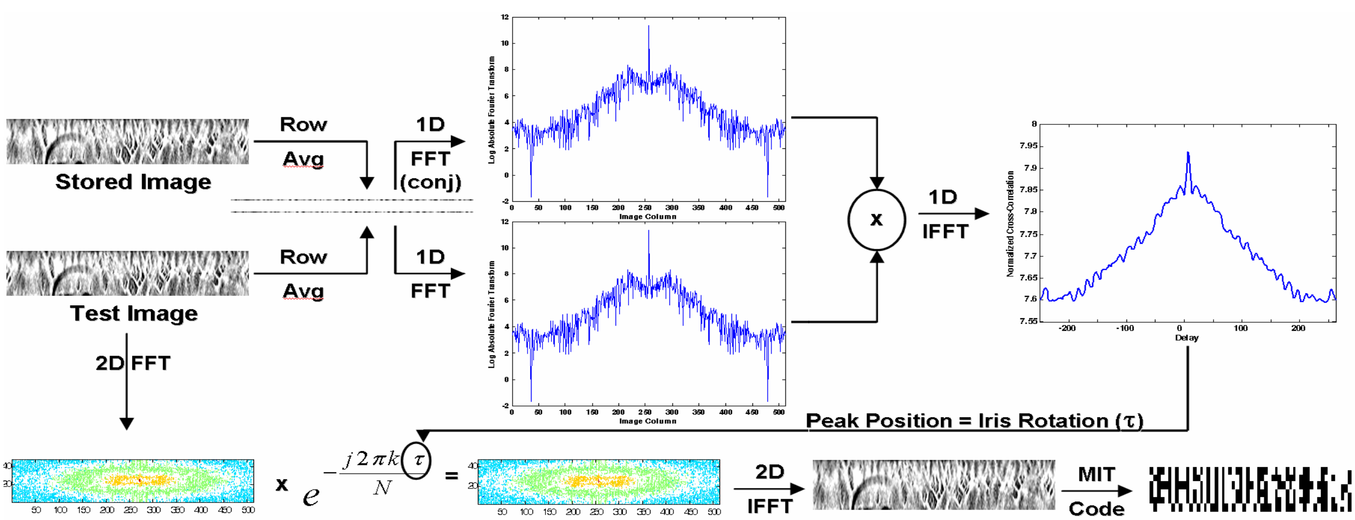
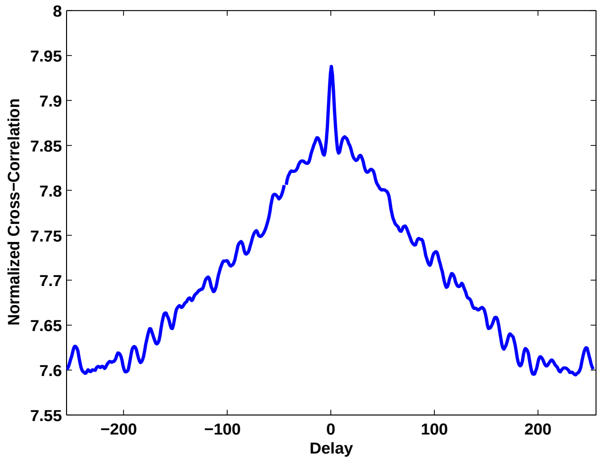
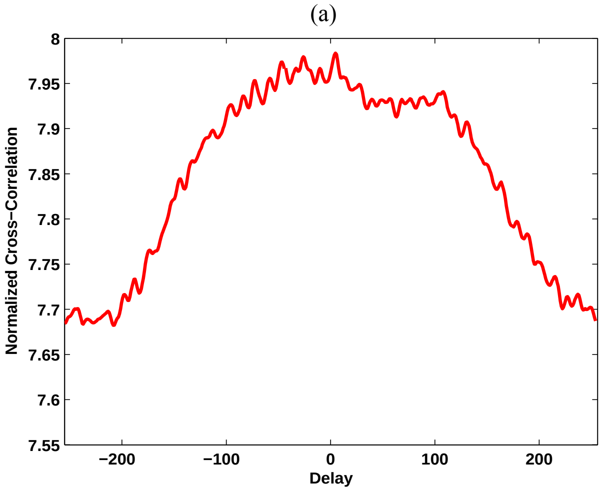


Figure 2. Procedure for Cross Correlation based Iris Image Preselection

based on a larger region of the correlation output [7]. From observations of various correlation plots such as the ones shown in Fig. 3, it was concluded that a good metric might be based on the variance in a restricted region about the peak.



(a)



(b)

Fig. 3. Normalized Cross-Correlation between a) matching and b) nearest non-matching normalized iris images

A number of metrics were tried, and good discrimination was obtained with a Peak-to-Sidelobe Ratio (PSR) [7]. For this, the sidelobe value *S* is taken as the mean of a 333 value region centered on the peak, i.e. 166 correlation values either side of the peak, excluding 13 values centered on the peak. If the peak is *P* and the standard deviation of the sidelobe values is σ the PSR is

$$PSR = \frac{P - S}{\sigma}$$

The narrow peak and wide sidelobe exploit the global dominance of the matching peak while not allowing local maxima of non-matches to bias the discrimination.

Preselection is carried out in two steps: PSRs lower than an experimentally set threshold of 1.5 are first discarded followed by removal of cases with rotation indices greater than 20 pixels on either side. Images passing the preselection were rotated into alignment before coding by the method of Monro et al [13]. Feature vectors for the selected rotated images were generated and compared with the stored ones to give the weighted Hamming distance which as used in matching/verification.

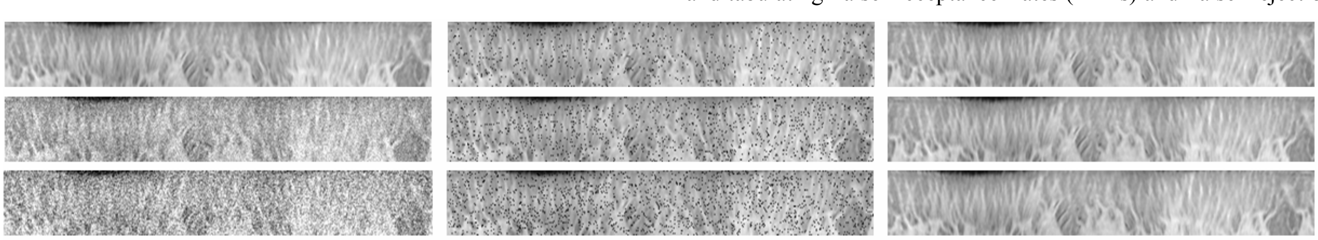
IV. EVALUATION

Experiments were carried out on the extended CASIA database [14] with one image from each of the 308 iris classes used as the enrolment set and the rest left for testing. This is different from the general practice in which at least three images are stored per class to compensate for various misalignments that may occur during iris capture. For evaluation, a new dataset was synthesized from the original normalized images by circular shifts, additive Gaussian white noise and random occlusions. Seven rotations were tried, the original and three on either side in steps of 4 pixels. Additive Gaussian noise with zero mean and varying degrees of variance was also used to distort the images. Random occlusion was carried out to simulate conditions encountered in real systems. Example images for a normalized iris are shown in Fig. 4. In total, 3696 test images were generated and compared with 308 classes giving over 1.3 million possible combinations.

Individual recognition tests based on PSR measure alone, gave a Correct Recognition Rate (CRR) of 75.6%. In this case, no feature vector generation was carried out and the match/non-match decision was based entirely on the PSR maxima obtained by correlating one test image with all the stored ones. As much higher recognition rates are normally achieved in iris matching systems, this indicated that the correlation metric is not a suitable biometric on its own.

Perfect (100%) CRR was obtained when both preselection and nearest neighbour classification by Hamming distance of the iris code were used. With a PSR cut-off threshold of 1.5 and no restriction in rotation, the average reduction in image comparisons was 30.8%. With a rotation restriction to 20 pixels on its own, the complexity reduction was greater at 77%. The combination of these two cutoffs produced a dramatically reduced set of 50 classes on average from the original 308, a reduction of 83.7%.

The Receiver Operating Characteristic (ROC) curves shown in Fig. 5. are obtained by varying the Hamming distance threshold and tabulating False Acceptance Rates (FARs) and False Rejection



(a) (b) (c)

Figure 4. Examples of test images: (a) Original normalized image followed by image with additive Gaussian noise with variance 0.01 and 0.03, (b) Random Occlusions of 3, 5 and 7 %, and, (c) circular rotation by -8, -12 and 12 pixels.

Rates (FRRs). The graph without rotation compensation is obtained using the standard method of comparing the iris code of a normalized test image with the codes of 7 different rotations of the registered image and finding the minimum Hamming distance between them. The result with rotation compensation is obtained with only one registered image coded by using preselection and rotation compensation as described above. A curve closer to the axes indicates lower system error and is a clear indication of the gain in overall system accuracy using the new method.

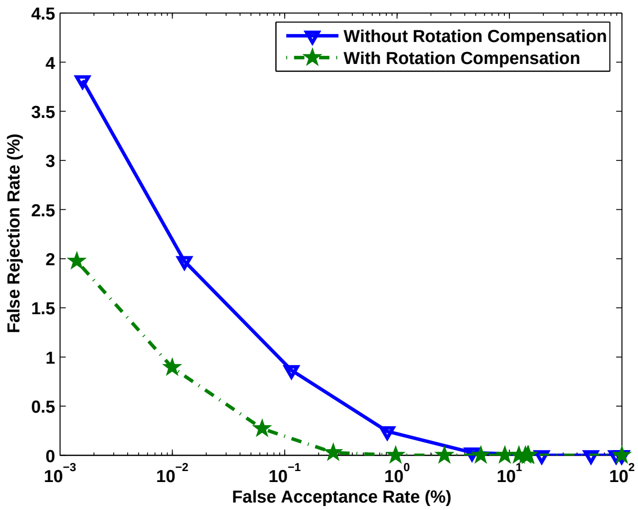


Fig. 5. ROC Curves with and without rotation compensation

Table I shows the times of feature extraction and matching in a MATLAB implementation on a Pentium P-IV 2.4GHz, 1GB RAM PC. The total time taken by the rotation compensated method is only slightly faster, but the matching alone is 21 times faster, because of the reduction in the number Hamming distance comparisons. The feature extraction is slower because of the additional FFT computations, but could be speeded up in a practical implementation by using standard FFT chipsets.

TABLE I

SPEED COMPARISON BETWEEN BASIC AND PROPOSED METHODS

Method	Feature Extraction (ms)	Matching (ms)	Total (ms)
Basic	14.5	15.4	29.9
Proposed	25.2	0.7	25.9

V. CONCLUSIONS

We have introduced a novel method of applying 1D cross-correlation techniques to compensate iris images for rotation, with major benefits for the performance and complexity of iris recognition systems. Direct orientation calculation is achieved and used to eliminate the need for storing and comparing multiple codes/images of the same eye at various rotations. The cascading of preselection followed by standard iris coding is shown to give perfect identification with 100% CRR and better ROC Curves. This is a result of reduced False Rejects in preselection and False Accepts in matching. By reducing the search space significantly, storage/time requirements are reduced whilst system performance is improved. System robustness is obtained by reducing sensitivity to eyelash and eyelid occlusions by using non-affected regions near the pupil for correlation computations. These results point towards improving performance in all iris matching systems.

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