Multidimensional Multimetric Novel and Simple Techniques for Iris Recognition System

Riju Kalita, Swanirbhar Majumder, and Md. Anwar Hussain
Department of Electronics and Communication Engg, NERIST(Deemed University), Arunachal Pradesh, India
Email: bubuli_99@yahoo.com, {smd, ah}@nerist.ac.in

Abstract—Iris is considered as one of the most reliable biometric object for computerized person identification system. This paper examines simple and novel techniques, based on multidimensional multiple metrics. The rectangular iris codes representing different eyes are processed using multidimensional tools like Singular value decomposition (SVD), Discrete cosine transform (DCT), and Wavelet transform to derive features for matching and recognition. While using SVD, both pattern matching and image quality degradation evaluating techniques are applied to derive two new indices to differentiate one iris from the others. The indices are derived from the correlation coefficient and the local and global errors between the two rectangular iris images, taking the impostor irises or irises of the same person as the noisy image irises. Using Morlet wavelet for the wavelet based technique, the two irises are processed based on the frequency selectivity property of wavelet transform and a Normalized Euclidean Index value is calculated that is used for matching and recognition. In DCT based technique, DCT is applied to each row of the rectangular iris code and a string is derived for each iris using the highest strength coefficient of each row and thus an Identity Code Array (ICA) is used. The techniques use different metrics for identifying an impostor from the authentic person and are simple in computation and easy in implementation for the iris recognition system.

Index Terms—Biometric, SVD, DCT, Iris images, Morlet Wavelet, Normalized Euclidean Index.

I. INTRODUCTION

Biometric based recognition systems are increasingly being used in today’s access control systems to control access to secured areas such as computer networks, airports and important sensitive establishments. Iris is considered as one of the most reliable biometric objects for integrating into a recognition system, as this physiological characteristic of a human being is stable and never gets changed unless damaged or hurt and hence can be used with high confidence for separating an authentic person from an impostor.

Ophthalmologists seem to be the first to recognize the fact that human iris patterns can be used for personal identification [1]. The first iris recognition software was developed by John Daugman [2] who devised an algorithm exploiting integro-differential operators and Gabor filters. The inner and outer boundaries of the iris were detected by the differential operators and Gabor filters were used to extract unique binary vectors constituting the iriscode from the local texture phase information [3, 4]. The average Hamming distance between two codes was considered for matching. R. Wildes [5] considered Hough transform and Laplacian pyramid as the bases for iris localization and spatially characterizing the human iris, respectively. Other researchers used various techniques to study the iris texture such as zero crossing representation of I-D wavelet transform [6], identifying key local variations [7], and use of directional information of iris image’s gradient vector field [8]. A new tool was proposed in [9] where modified Log-Gabor filters were used. The strictly bandpass characteristics of Log-Gabor filters in the angular coordinate helped to extract pure phase information of iris texture that remain unaffected from the background brightness. In both cases of using 2D complex Log-Gabor filters [3] and modified 2D Log-Gabor filters [9], the complexity of iris information is required to be preserved and hence the computational method is not simple. However, the results as shown by them are quite accurate with high performance. The problems of Gabor filters were reported to be improved by using combination of RCWF and CWT in [10].

The processing difficulties with the full iris image such as partial overlapping with eyelashes and partial opening of the eye as a normal case as observed in many people requires special care. Also to cater to the need of small database to store iris data in binary form and also to design such recognition system where the access control is integrated with a wireless network for iris data transporting, compression of iris images is required.

In this paper, we propose new and simple novel techniques, based on multidimensional multiple metrics. The rectangular iris codes representing different eyes are processed using multidimensional tools like Singular value decomposition (SVD), Discrete cosine transform (DCT), and Wavelet transform to derive features for matching and recognition. The two irises in question are taken in rectangular form and the metrics considered for SVD based processing are (i) 2D correlation coefficient between the iris images (ii) local error measure between corresponding 8x8 blocks of the two irises, and (iii) global error measure taking whole of the iris matrices, using SVD technique. In DCT based technique, DCT is applied to each row of the rectangular iris code and a string is derived for each iris using the highest strength coefficient of each row and thus an Identity Code Array (ICA) is calculated from a number of irises of the same person.
For matching and recognition the ICA is used. In the wavelet based processing, using the Morlet wavelet, the two irises are processed based on the frequency selectivity property of wavelet transform and a Normalized Euclidean Index (NEI) value is calculated that is used for matching and recognition. The computational programs are developed using MATLAB® codes.

II. METHODOLOGY

Three processing steps are considered, in SVD based iris recognition system as follows: (i) locating iris in the image, (ii) Cartesian to polar conversion to get the rectangular iris matrix in the gray level, and (iii) computation of two recognition indices based on the three metrics: Correlation coefficient as applied in pattern matching applications, Local and Global errors as applied in image degradations measurements. MATLAB codes were used to locate the boundaries of the pupil and the iris within the minimum bounding isothetic rectangle that was reshaped to a gray scale image of size 120x120 pixels. The equivalent representation of the zone of interest in the rectangular form was derived from the Cartesian to polar reference transform as suggested by J. Daugman [2]. The two parameters $\theta$ and $\rho$ [2], are varied accordingly to represent the iris annular disc in a 120x400 (full iris) or 120x200 (Partial iris) rectangular matrix form. A rectangular representation of the annular iris disc is shown in figure 1.

The processing difficulties with the full iris image such as partial overlapping with eyelashes and partial opening of the eye as a normal case as observed in many people requires special care. For such cases and also as a standard technique we have experimented with the partial iris image and compressed iris image for application in wireless communication, and to be reported separately.

III. METRICS BASED ON SVD

Two gray level rectangular iris images, one from the authentic person’s reference shot and the other from any shot of a different person or any other shot of the same person, of size 120x400 are used as input for deriving the metrics of interests. Here the second rectangular iris image is considered as a noisy or distorted image so that an image degradation scalar measure can be derived as follows.

Let $A$ and $B$ be the first and the second matrix representing two rectangular iris images each of size 120x400 pixels, and are required for recognition if they are from the same person or different persons. The first metric, the correlation coefficient ($r$) is given by:

$$ r = \frac{\sum_{i} \sum_{j} (A_{ij} - \overline{A}) (B_{ij} - \overline{B})}{\sqrt{\sum_{i} \sum_{j} (A_{ij} - \overline{A})^2 \sum_{i} \sum_{j} (B_{ij} - \overline{B})^2}} $$(1)

where $m$ and $n$ are the row and column sizes of the matrices, and $\overline{A}$, $\overline{B}$ are the corresponding mean values in two dimensions.

The mathematical tool of Singular value decomposition [12] is applied for local and global image quality degradation measurements. It is known that every real matrix $A$ can be decomposed into a product of three matrices, two of them are orthogonal matrices and the third is a diagonal matrix giving the singular values. The decomposition of $A$ is shown below:

$$ A = U S V^T $$

where $U$ and $V$ are orthogonal matrices $U^T U = I$, $V^T V = I$ and $S = \text{diag}(s_1, s_2, \ldots)$ and $I$ is the identity matrix.

For image quality degradation measurements, a Global measure $E$ is obtained by applying SVD to the full image matrices, but considering only the first three largest singular values, as given in Eq. 3.

$$ E = 100 \left[ (s_{11} - s_{21}) + (s_{12} - s_{22}) + (s_{13} - s_{23}) \right] $$

(3)

where $s_{ij}$ is the $j^{th}$ singular value of the $i^{th}$ matrix. Only three largest singular values are considered in the computation of $E$ for decreasing computational burden as well as it is observed to be sufficient and $E$ varying very little with more number of singular values.

To obtain the Local error, SVD is applied to the blocks of size 8x8 pixels of the rectangular matrices $A$ and $B$. Here we consider the first matrix $A$ as the reference rectangular iris image of the authentic person, and the second matrix $B$ as the impostor rectangular iris image which may be taken from any shot of a different person or other shots of the same person. A local error based global error $L$ is derived as in [11] and is given below:

$$ L = \frac{\sum_{i=1}^{M} |d_i - d_{mid}|}{M} $$

(4)

where $d_{mid}$ is the midpoint of the sorted $d$s, and $M$ is the number of 8x8 blocks in the image. The $d_i$ here is representing the square root of the sum of squared differences between the corresponding singular values of the two 8x8 blocks from two rectangular iris images, and is obtained as shown in Eq. 5.

$$ d_i = \sqrt{\sum_{j=1}^{8} (s^i_j - s^2_j)^2} $$

(5)
where $s_1^j$ and $s_2^j$ are the $j^{th}$ singular values of the corresponding 8x8 blocks from the first and the second rectangular irises.

We now define two indices for the recognition system from the three metrics derived above. The first index AM1, called the First Analysis Metric representing the *Normalized modified global error measure*, is derived from the metrics $L$ and $r$.

And the second index AM2, called the Second Analysis Metric representing the *Normalized local error based global error measure*, is derived from the metrics $E$ and $r$. The two indices are shown below:

$$AM1 = \frac{L}{r}, \quad AM2 = \frac{E}{r} \tag{6}$$

Here normalization is done by the correlation coefficient $r$. It is observed from our experiments that separately the three metrics do not differentiate two different rectangular irises satisfactorily but their ratios, as given in Eq. 6 show high performance for the recognition system.

The threshold $D_h$ for recognition may be based on the difference between the minimum value of $AM1$ (or $AM2$) of all shots obtained from *Different persons case* and the maximum value of $AM1$ (or $AM2$) of all shots obtained from the *Same person case*, evaluated on all irises of the database considered, as follows:

$$D1 = \frac{1}{2} (AM1_{\text{diff}} - AM1_{\text{sampe}}) \tag{7}$$

$$D2 = \frac{1}{2} (AM2_{\text{diff}} - AM2_{\text{sampe}})$$

$$D_{th} = AM1(\text{or} AM2)_{\text{sampe}} + D1(\text{or} D2),$$

$$D_{th} = AM1(\text{or} AM2)_{\text{diff}} - D1(\text{or} D2)$$

A person is considered to be authentic if from his iris the computed $AM1$ (or $AM2$) value is below $D_{th}$, otherwise declared an impostor. Hence the *False acceptance rate* and the *False rejection rate* are obtained based on $D_{th}$ for performance evaluation of the proposed technique.

IV. METRICS BASED ON WAVELET TRANSFORM

We have also applied wavelet based analysis of the iris code for extracting features for matching purposes. It is known that Continuous Wavelet Transform (CWT) offers time and frequency selectivity and localizes events both in time and in frequency. The frequency selectivity of CWT is well interpreted as a collection of linear, time-invariant filters with impulse responses obtained from the dilations of a mother wavelet, as expressed below by the convolution [13].

$$W(a,n) = x(n) * \psi_{a,0}(-n) \tag{8}$$

where, $a$ denotes the *scale* of the wavelet $\psi_r$, and $n$ is the time index.

Thus for any $a$, the wavelet transform $W(a,n)$ is the output of a filter with impulse response $\psi_{a,0}(-n)$ and input $x(n)$. As the circular convolution is equivalent to the multiplication of equal length DFTs of $x(n)$ and $\psi_{a,0}(-n)$ in frequency domain, the frequency selectivity of the wavelet is parameterized by the scale factor $a$.

Here, the Morlet wavelet as expressed below is used for five different scales.

$$\psi(t) = \exp(-t^2) \cos \left(\pi \sqrt{\frac{2}{\ln 2}} t \right) \tag{9}$$

The squared magnitude of the product of the two DFTs is used for extracting the features of a particular rectangular iris code in frequency domain.

The rectangular full iris code of size 120x400 is converted to a linear array and the first 1800 points are considered for feature extraction, although all points can also be considered. The considered array of 1800 points is segmented into consecutive blocks of 20 points, and 128 point DFT is calculated for each block. The 128 point DFT of the sampled wavelet of 20 points is then multiplied with that of the iris. The resultant 64 frequency points are segmented into 4 sections and for each section the maximum of the cumulative sum is calculated for each of five different scales of the wavelet. A total of 1800 coefficient values are thus obtained for the iris array as the extracted feature. For the two rectangular irises that is taken for matching operation, an index called *Normalized Euclidean Index NEI*, is defined as below for matching and recognition.

$$NEI = \frac{(P - Q)^2}{\text{max}(P) \text{max}(Q)} \tag{10}$$

where $P$ and $Q$ are the 1800 coefficient values, obtained as explained above, for the two irises in question. The NEI is obtained from Eq. 10 for the cases of any two irises of the same person and any two irises of two different persons. Fig 6 and 7 shows the result where the red colored bars are for the same person case and blue colored bars are for different persons. Thus it appears that the wavelet based feature extraction technique with NEI values is useful for the iris recognition system.

V. METRICS BASED ON DISCRETE COSINE TRANSFORM

For the matching and recognition metric based on DCT technique, DCT is applied to each row of the rectangular iris code and a string is derived for each iris using the highest strength coefficient of each row, which is basically finding the average energy of the signal of each
row. An Identity Code Array is calculated for each person by taking the average of the identity strings obtained from a number of irises of the same person. For matching and recognition the Identity Code Array is used as the metric and is derived as follows. The DCT of a row of the iris matrix is defined as:

\[ X^n_i(k,l) = w(k) \sum_{n=0}^{N-1} x(n,l) \cos \left( \frac{(2l-1)(k-1)}{2M} \right) , \quad k=1, 2, \ldots, M \]

where \( x(n,l) \) is the \( k \)th sample of the signal in the \( n \)th row of the \( k \)th iris image, \( M \) is the column size, and \( w(k) = \sqrt{1/M} \) for \( k=1 \) and \( w(k) = \sqrt{2/M} \) for \( 2 \leq k \leq M \). Taking the maximum of the frequency coefficients \( X^n_i \) from each row \( n = 0, 1, 2, \ldots, N - 1 \), the identity string of the \( i \)th person for the \( j \)th image is represented as:

\[ IS^n_j = [X'^0_j, X'^1_j, \ldots, X'^{N-1}_j] \quad (12) \]

where \( X'^n_j \) are the maximum values of \( X(k,l) \) for \( k = 0,1,2,\ldots, M - 1 \) and \( l = 0, 1, 2, \ldots, M - 1, \) for each row \( n = 0, 1, 2, \ldots, N - 1 \).

The Identity Code Array for the \( i \)th person is expressed as \( ICA(i) = \frac{1}{m} \sum_{j=1}^{m} IS^n_j \), where \( m \) is the total number of irises from each person and the average is taken columnwise. The matching and recognition is based on the absolute difference value between \( ICA \) and \( IS^n \). The difference value for two different person’s images is large whereas for two images of the same person the difference is small.

VI. EXPERIMENTS AND RESULTS

To verify the performance of our proposed technique, the open iris database from Bath University, UK is considered and experimented with iris images of five different persons each having fifteen different shots. It is observed that there is gray level contrast difference between the rectangular irises obtained from different shots of the same person’s eye as well as with different person’s eyes. Hence, some eye images could not be considered for our experiments. The technique reported here considers any one shot of a person as the reference authentic iris and is compared with any iris of a different person or any other iris of the same person as the impostor. From the annular iris disc, rectangular iris image in the gray level is obtained by Cartesian to polar reference transform [2]. Partial iris image is derived from the full rectangular iris by proper segmentations corresponding to \( \theta \) and \( \rho \) values.

A total of 2250 pairs of irises from same person’s case and 20250 pairs of irises from different person’s case are to be evaluated. For the SVD based processing, the three metrics \( r, E, \) and \( L \) are obtained as explained above for each pair of rectangular iris images with 400 different \( \theta \) values for each 120 different \( \rho \) values from 0.6 to 0.8, for calculating \( AM1 \) and \( AM2 \) as shown in Eq. 6.

Fig. 2 shows the plot of \( AM1 \) for randomly taken one person’s one shot as the reference and the other shots of the same person, assumed as the noisy or the degraded image, for comparison and denoted as \( P^{\rho}_{ik} \) where \( i \) refer to the \( i \)th person and \( j \) and \( k \) refer to the shot numbers. Fig. 3 shows the same for \( AM2 \). We also plot \( AM1 \) and \( AM2 \) in Fig. 4 and Fig. 5, taking any one person and one of its shots randomly, for comparison to any one shot of any other person taken randomly, as assumed as the noisy or the degraded iris image, and denoted as \( P^{\rho}_{ij} \) where \( i \) and \( j \) refer to the persons and \( k \) to shots of \( i \)th and \( j \)th person.
The above plots clearly show that the metrics $AM1$ and $AM2$ are useful in matching two irises and hence recognition of authentic person from the impostors. The max and min values are also shown, in Table 1 below, of $AM1$ and $AM2$ for the case of same persons and for the case of different persons, considering all possible combinations of two irises.

Table 1: Minimum (Min) and Maximum (Max) Values of $AM1$ and $AM2$

<table>
<thead>
<tr>
<th>Person</th>
<th>For the combinations possible for images of the same person</th>
<th>For the combinations possible for images of a person with the other persons’ images</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$AM1$ max</td>
<td>$AM1$ min</td>
</tr>
<tr>
<td>1</td>
<td>1774.36</td>
<td>1508.38</td>
</tr>
<tr>
<td>2</td>
<td>2098.13</td>
<td>2200.23</td>
</tr>
<tr>
<td>3</td>
<td>1965.76</td>
<td>7517.55</td>
</tr>
<tr>
<td>4</td>
<td>2133.38</td>
<td>20309.60</td>
</tr>
<tr>
<td>5</td>
<td>44796.31</td>
<td>5663.49</td>
</tr>
<tr>
<td>6</td>
<td>1899.35</td>
<td>1766.54</td>
</tr>
<tr>
<td>7</td>
<td>1766.54</td>
<td>1899.35</td>
</tr>
<tr>
<td>8</td>
<td>2032.81</td>
<td>1766.54</td>
</tr>
<tr>
<td>9</td>
<td>1774.36</td>
<td>1508.38</td>
</tr>
<tr>
<td>10</td>
<td>895.5</td>
<td>1508.38</td>
</tr>
</tbody>
</table>

The result of the experiment with wavelet based processing of rectangular irises is shown in Fig. 6. All possible combinations of the available irises of same persons and between different persons are considered and for each combination, $NEI$ is calculated as explained above and shown in Eq. 10. The Fig. 6 shows the plot of total no. of different combinations with particular values of log ($NEI$), the red bars are for the case of same persons and blue bars are for the case of different persons. It shows that same person case and different person case are clearly distinguished in the figure. The same experiment was repeated with partial irises of size 12x200, for the same set of persons, and the result is shown in Fig. 7. The result thus validates our reasoning that $NEI$ is suitable as measurement metric for application in biometric recognition system.

The measurement metric based on DCT technique is derived in three steps. First the Identity Code Array for each person is derived from the relation

$$ICA(i) = \frac{1}{m} \sum_{j=1}^{m} IS_j$$

Identity string $IS_j$ of the person whose authenticity is to be tested is derived for any of its irises $j$, using the relationship in Eq.10. Finally the absolute difference between $ICA(i)$ and $IS_j$ is calculated which is used for the recognition. Fig. 8 shows the plot of $|\{ICA(i) - IS_j\}|$ for each person $i$, different colored lines represent different person. It is observed that $|\{ICA(i) - IS_j\}|$ value at each element index is small and changes rapidly from index to index.

Figure 5. $AM2$ vs $P_i$: $AM2$ variation for 15 random combinations of different images of different persons, no two combinations are same.

Figure 6. No. of combinations with a particular value of log ($NEI$) for full irises. Red bars for same persons case and blue bars for different person’s case.

Figure 7. No. of combinations with a particular value of log ($NEI$) for partial irises. Red bars for same persons case and blue bars for different person’s case.

Figure 8. $|\{ICA(i) - IS_j\}|$ plot for each person $i$, different colored. Line represent different person.
Figure 9 shows the plot of $|\langle IS, ICA \rangle|$ for the $i^{th}$ person’s $j^{th}$ image and ICA of each person, the cross marked line is for $|\langle IS, ICA(i) \rangle|$ which is the smallest and thus authenticating the $4^{th}$ person. The same may be obtained for other persons.

Figure 10 plots the absolute difference between ICA of any one person and IS of any image of each person. It appears that both $|\langle IS, ICA \rangle|$ and $|\langle ICA(i), IS \rangle|$ based metrics are useful for the matching and recognition system.

CONCLUSIONS

We presented in this paper our experiments and results of multidimensional multimetric based techniques for computerized person identification system using iris images. Techniques are derived, based on SVD, DCT, and Wavelet based processing of rectangular iris codes. To verify the performance of our proposed techniques, the open iris database from Bath University, UK is considered and experimented with iris images of ten different persons each having fifteen different shots. The technique considers any one shot of a person as the reference authentic iris and is compared with any iris of a different person or any other iris of the same person as the impostor. The metrics $AM1$ and $AM2$ as derived from the SVD based processing of two irises in question are useful in matching and recognition system as shown in Figs. 1-4 and from the experimental values shown in Table 1. The Normalized Euclidean Index, $NEI$ metric as derived from the Wavelet based processing of irises, utilizing frequency selectivity property of wavelet transform, is also observed to be able to distinguish authentic irises from that of impostor, both for full and partial iris images as is shown in Fig. 6 and Fig. 7.

The last technique is based on DCT and the metric for matching and recognition is derived from the Identity Code Array of each person and the Identity string of the iris image in question. The experimental results observed from Figs. 8-10 show the effectiveness of this technique. All the techniques that are explained here are simple in computation and easy in implementation. We have also undertaken extensive experiments with partial and compressed (full and partial) irises for testing our proposed multidimensional multimetric based iris recognition techniques.

REFERENCES


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