Regional Approach for Iris Recognition

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Abstract: Recent studies have explored a various set of techniques, methods and algorithms for iris recognition. Segmentation algorithms, normalization processes and well-defined distances measures are employed as decision methods to compose the outline of all currently deployed systems, including commercial ones. So far, all systems make use of the entire iris pattern of any individual, assuming that a fixed threshold applied on the distance can partially avoid problems like noise of information and acquisition errors. In this paper a new approach is presented that uses only selected sectors of the iris and a simple analysis strategy, for verification purposed. Therefore, it differs from all previous approaches that process the entire iris pattern. In addition, three Bayes-based similarity measures have been considered for iris image matching: the Whitened Cosine (WC), the PRM Whitened Cosine Transform (PWC) and the Whitin-class Whitened Cosine Transform (WWC). The experimental results, carried out using the CASIA database, are encouraging and demonstrate that the proposed approach supports several directions for further research.

Key–Words: Biometrics, Iris, Recognition, Biometrics, Ssim, Regional Analysis

1 Introduction

Recently, biometrics is becoming more and more important in modern society and a multitude of biometric systems have already been developed. The advantage of biometric technologies resides in his capability to improve systems like PINs, passwords, keys or other token-based identification systems, with the identification of humans by their traits. Moreoverm, biometrics have increased their importance even in biomedical images sector. Two types of biometric traits can be defined: behavioral and physiological. The first one refers to the way a person performs certain tasks, like signature, keystroke dynamics or gait. The second one is a measure taken on a precise part of the human body, like fingerprints, face and DNA [1, 2].
Human eyes offers a wide set of biometric traits that have been considered for personal verification, like retina, sclera and iris [1, 2, 3, 4]. The blood vessel structure of human retina can be used in a biometric technology, obtaining very good results. Unfortunately, retinal scan has some disadvantages. A retinal scanner is very expensive, more than an iris scanner, and this technology is less user-friendly than the similar one. Moreover, there are other problems in retinal scanning.

Measurement accuracy can by affected by diseases like cataracts, and also by severe astigmatism.

Figure 1: The intricate pattern of an iris

Moreover this technology is perceived by some as invasive, because it is required to the subject to stay very close to the instrument [2, 3, 4]. The net results that iris is one of most attractive and interesting part of human eye for personal verification. Face recognition is perceived as less intrusive than iris recognitin, but it is also affected by problems of flase match provided by natural aging of individuals and by the increasing use of plastic surgery. Iris is almost stable over years, and sometimes it was subject os some speculations like "iridology", a pseudo-science that claims to obtain medical diagnosis analysing human iris, which was proved as a medical fraud [1]. On the contrary, retinal scan can provide help to medical diagnosis of some disease [3].

Iris is located under the cornea. Eyelashes and eyelids protects iris from external agents, like dust or similar. At the center of iris is located the pupil, that controls the quantity of light passing through eye. Usually, iris is not only characterized by its color (that can be rare like blue and green or more common like hazel and dark) but even by its pattern, which is usually very complex and rich of details. Therefore it is not surprising that since many years iris patterns have been rightly considered useful for biometric measurement [1].

Due to intensive research, several applications of iris scanner were deployed in last years to ensure security in some critical situations. The first example is UK's I.R.I.S. (Iris Recognition Immigration System), which started operating in 2004 but which was closed to new registrations in 2011 [5]. Google uses this technology to control access to their datacenters [6]. The most interesting application is the recognitions of Gula, the famous "Afghan Girl" (figure 2) portrayed by Mc.Curry for National Geographic, in 1984 and traced 18 years later. The system that recognized Afghan Girl was implemented by Daugman himself [7]. In future, it is planned to substitute authentication for different web platforms like Facebook and eBay with iris recognition[8]. It is important to remind that these technologies aim to integrate PINs and passwords, because biometrics requires further development. An example is the well-known smartphone Samsung Galaxy SIII and SIV which permits to unlock device with a combination of face and voice recognition, but reporting this as "low protection", while PIN and password are reported as "medium-high protection". In one of the last models of Apple iPhone was included fingerprint recognition to unlock device, but the system was hacked few days after his presentation.

At the state-of-the-art, there are several approaches for iris recognition. Wildes [9] uses for segmentation a technique based on the Hough Transform, which is a standard algorithms in computer vision to detect circular objects in any image, include as default in various computer vision products like MATLab or OpenCV. Wildes [9] obtains normalization with an image registration technique which aligns a new image acquired with a selected image in a database. Feature encoding is performed using a Laplacian of a Gaussian filter, then normalized correlation is computed to match two images. An example of variation of this strategy is given by Boles [10]. Instead of using

Figure 2: Sharbat Gula, "Afghan Girl"

image registration technique, iris images are scaled to have a constant diameter that is chosen from a reference image. Once the images are normalized to the same diameter, feature extraction is performed. This is accomplished by extracting intensity values of different parts of iris along different concentric circles. Iris normalization allows ensures that the same number of points is extracted from all iris images. So, the encoding is done using the zero-crossing of the 1D wavelet. In his work, Zhu et al.[11] proposed another metric to evaluate different pattern similarity, the Weighted Euclidean Distance:

$$\mathrm{WED}(k) = \sum_{i=1}^{n} \frac{(f_i - f_i^{(k)})^2}{\delta_i^{(k)}} \tag{1}$$

Where an unknown iris template is matched with all n examples of the database and match is found at a minimum k. The most important iris recognition technique is given by Dougman [12]. Dougmans system is the basis of all commercial systems developed so far. First, image is segmented using iteratively the following integro-differential operator [13]:

$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \oint_{(r,x_0,y_0)} \frac{I(x,y)}{2\pi r} \, ds \right| \tag{2}$$

where *I* is the image and *G* is a Gaussian smoothing function. After normalization, a 2D version of Gabor filter is used for feature extraction, whereas the Hamming Distance is used for matching two iris templates [14, 15]:

$$\mathrm{HD} = \frac{1}{N} \sum_{i=1}^{N} X_i \veebar Y_i \tag{3}$$

The most important important phase is segmentation. In fact, a bad segmented image will not provide good results in terms of false positive and false negative values. For this reason, several different approaches have been proposed for segmantation step.

A first alternative approach proposes to guide in some way Daugman's integro-differential operator. In fact, a global approach can be very expensive in terms of computational costs. An alternative way is to use the Hough transform to search eye's position in any image with less accuracy and then ,when a probably location of the iris is obtained, refine the search with Daugman's operator[17]. The author himself also proposes the use of Independent Component Analysis for feature extraction and coding, while for the matching phase Euclidean distance is used. Further research and other tests in less controlled enviroments revealed another problem in Daugman's operator: the integro-differential operator fails in segmentation in presence of some artifacts in image, artifacts due to some instrumental problem. The presence of these problems reveals that using a bad-calibrated instrument or inappropriate instruments can bring to mismatched iris localizations and can compromise recognition quality [18]. For this reason, it is better to combine Daugman's operator with Hough transform, which can help to solve this problem, with other methods of preprocessing. Once image is normalized with Daugman's Rubbersheet model, the encoding is done in Tisse's work with Gabor's filter and Hilbert transform. The template obtained is compared with another template with Hamming distance. The entire coding in C language of this system also increases system's speed.
Another approach that was successfully tested consist in apply to the entire iris image, correctly extracted, normalized and scaled, a diadic wavelet representation [19]. Even in this approach, difference between templates is evalued with some distance methos, like Hamming distance, euclidean-based distance or wavelet-derived measures.
In his work, Lim [20] make use of Haar wavelet to transform a normalized iris image, obtaining a template that is only 87 bit long. The learning and decision strategy is the LVQ algorithm, basis of SOM neural networks.
A very similar strategy were analyzed by Sondhi and others [21]. In his work, Sondhi used a more complex iris localization, paying a lot of attention to preprocessing steps to eliminate artifacts and noise on image, then recognition step is performed with a Self-organizing Map. In his work were given accurate details on various settings of the neural network and on his learning system. His work also values system performance considering the machines that executes the program, to give an evaluation of the computational costs of the procedure.
Another important tecnique that lets to train a system with a few number of examples is multichannel Gabor filtering [22]. It is demonstrated that extracting an array with this filter and using a nearest neighboor classificator that uses weighted euclidean distance raises system's performance from 80% with a train set made by a single example to 99% with a train set made by five examples per individual.

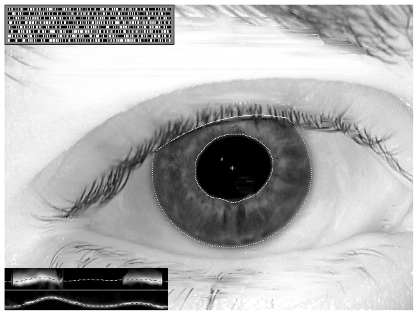

Figure 3: Iris and template

Haar transform, with Hamming distance, can be used to perform an iris template comparison with a multiscale analysis in two dimensions [23]. Even in this case, it is demonstrated that a template made by 87 bit is sufficient to distinguish a person from an impostor with a precision equal to 97%. Segmentation is performed starting from the center of the pupil and proceeding to the edge of the iris, excluding eyelids, eyelashes and sclera. Moreover, it is proven that the use of optical lenses does not affect the system.
There is another great problem: memory waste. It is demonstrated that 87 bit are sufficient to recognize a person, but the various images that are outputted from every step of computation are saved in extended format (TIFF, for example), and memory waste can be a little matter for few images, but can be a great problem when a lot of images are stored. Moreover, it is important to remark that a lot of systems adopt a client-server architecture, then an extended format can be expensive in a network system. This is another issue of these system. Daugman himself, which gave a lot of contributes for iris recognition, also has considered image compression methods [24]. In details, when image are saved, an uniform background is applied to the images to suppress everything external the eyelids, then image is saved using the JPEG and JPEG2000 format, as in figure 3. Notice that these formats uses a lossy compression. Daugman's work shows that even with an heavy compression a system lowers his performance about 2-3%, with minimum influence on results. However, Daugman says that these standards are open standards, so they are not subject to any limitation.

More recently, Liu et al. [16] presented an iris segmentation approach based on Hough Transform that is effective for determining the pupil region as well as the limbic boundary and iris region. In

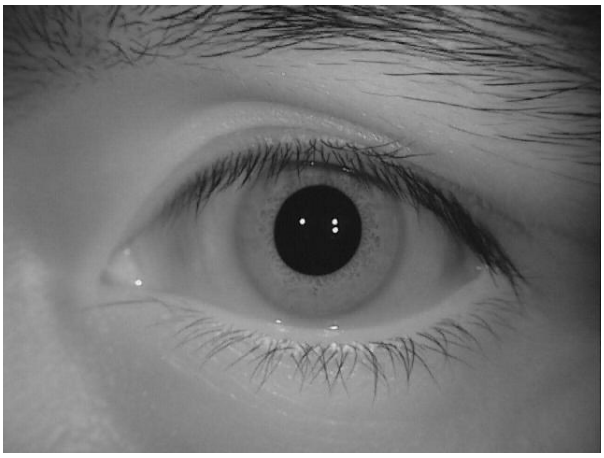

Figure 4: An Iris from CASIA database

addition it also allows improved eyelid detection using linear Hough Transform.
All these evolutions helped to realize fast and efficient methods, with the aim to use biometrics on low performance an capacity devices. An important research where given with a proposal of iris recognition system on smartphone. Smartphone technology today is very evolved, and is very important to equip these devices with data protections systems, because nowaday on smartphones people stores not only numbers and SMS, but also e-mail, credit cards and so on. The most recent iPhone made by Apple has a fingerprint recognition system, originally available on LG-KP3800 made by LG Electronics, that was violated few days after presentation. Voice and face recognition was inserted in last Samsung devices, as said before. Even iris recognition were adapted for a mobile version [25]. In their work, Park and Rhee analyze speed of a system on a low power processor (only 200 MHz). They choose iris recognition instead fingerprint because the latter one needs dedicated devices for acquisition and processing. In this case also they adapted the system to execute it without any problems on an ARM CPU.
Other contributes of similar types exists [26]. An accurate analysis of different solutions brings to definition of a lot of important characteristics for this system, non only considering the algorithm, but also considering limitations of devices. It is also interesting that this study can be adapted to other biometrics.

In this paper a new approach for iris recognition is proposed, based on a novel feature encoding and matching strategy. Instead of using entire iris template, images will be processed to find most stable regions of an iris, considering twenty image for author. Then, a ranking of these regions will be used to evaluate stability of various iris sectors, and a certain number of sectors will be used for matching phase, according to a well-defined similarity measure. The paper is organized as it follows. Section 2 reports system description. Section 3 presents the experimental results, carried out on the CASIA database [29].
The conclusion of the work and some consideration about future directions for research are discussed in Section 4.

2 System Description

The system proposed in this paper is schematically described in Figure 5. This section will address each phase of the system, that will be described in detail. This section is organized as it follows: subsection 2.1 shows the chosen segmentation procedure; subsection 2.2 shows Daugmans Rubbersheet model for normalization. Subsection 2.3 shows how Ssim was employed to evaluate stability analysis. Subsection 2.4 shows the matching function adopted and the decision rule. Figure 5 shows an outline of the system employed for this study.

2.1 Segmentation

In the segmentation step, the annulus of the iris image must be isolated from the rest of the eye image. For the purpose, it is necessary to localize the portion of the iris image derived from inside the limbus (the border between the sclera and the iris) and outside the pupil. It is also important to include the portion of iris that is not covered by eyelids (both upper and lower). In fact, eyelids can cover part of the limbus, and the pupillary boundary can be far less well defined. Of course, pupil is typically darker than the iris. Depending on pigmentation of skin and iris, eyelid contrast is quite variable. Eyelashes can make eyelids boundary irregular. Therefore, any iris localisation method has to be sensitive to a wide range of edge contrast and robust to irregular borders. In this paper, following the approach of Wildes [9], the Hough Transform has been used for iris detection in eye image, according to equation:

$$x_c^2 + y_c^2 - r^2 = 0 \tag{4}$$

that is the well-known equation of a circle.
This involves employing Canny edge detection to generate an edge map. Gradients were biased in the vertical direction for the outer iris/sclera boundary [27]. Figure 6 shows an example of segmentation. It is possible to apply methods for handling both eyelids and eyelashes, to suppress and eliminate them from image.

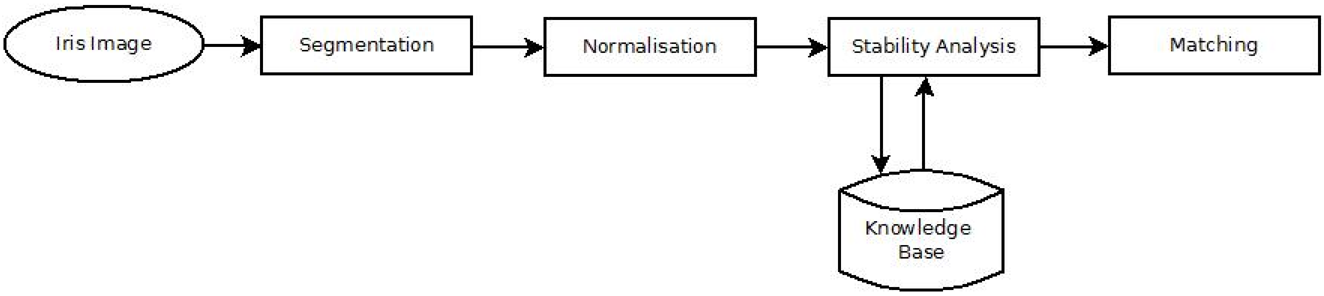

Figure 5: The system implemented

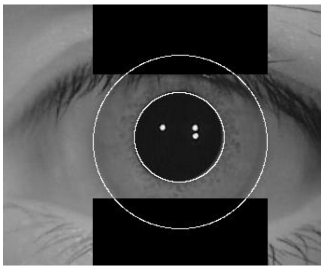

Figure 6: Iris Segmentation by Hough Transform

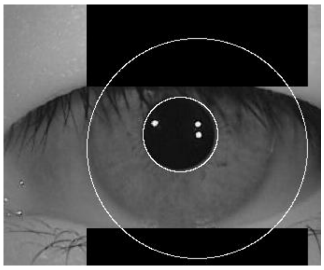

Figure 8: Example of mismatched Transform

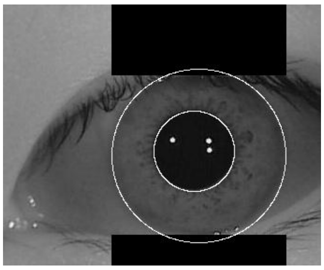

Figure 7: Another example of an iris

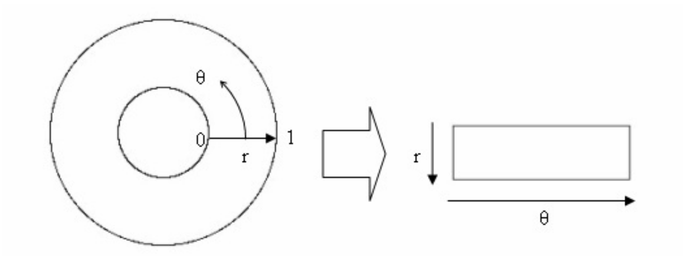

Figure 9: Dougman's Rubbersheet Model

Figure 7 also shows that another Hough Transform is required to detect and remove pupil from the images [28]. Sometimes Hough transform does not reach correctly in his task, as shown in figure 8.

2.2 Normalisation

Normalization keeps image unaltered and simplifies successive steps, transforming original image in a different one. As described by Daugman [12], pattern must be invariant to size and must consider size of pupil and is position in iris image. Moreover, it is necessary for correct execution of the recognition system to consider the non-linear transformation of pupil that stretches iris. This is a very critical task. In fact it is worth noting that pupil is not located at the center of the iris, but it is slightly shifted towards nose. This means that any mathematical model to normalize iris must consider this extremely important aspects. In literature, several models exist [10, 12]. In this paper we consider Daugman's Rubbersheet Model, represented by figure 9, that is the most complete and effective model. The model uses projected pseudo polar coordinates. In this case the grid must not be necessarily concentric, in consideration of pupil displacement. The angle - the polar variable is clearly dimensionless, as the radial variable because, as stated by Daugman, it ranges from pupil boundary to the limbus always as a unit interval $[0, 1]$. Dilation and constriction of iris is modeled by this coordinates system as the stretching of a homogeneous rubber sheet with the topology of an annulus anchored on his outer perimeter with tension controlled by an interior ring of variable radius. With this coordinates system corrects the elastic pattern deformation due to variations of pupil dimension.

The rubber sheet model devised by Daugman remaps each point within the iris region to a pair of polar coordinates. The remapping of the iris region from (x, y) Cartesian coordinates to the normalised

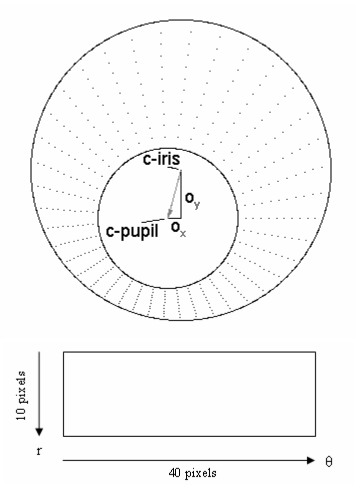

Figure 10: An illustration of pupil displacement

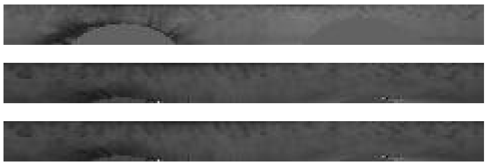

Figure 11: Three examples of normalised irises

non-concentric polar representation is modelled as:

$$I(x(r,\theta), y(r,\theta)) \longrightarrow I(r,\theta) \tag{5}$$

with:

$$x(r,\theta) = (1-r)x_p(\theta) + rx_l(\theta) \tag{6}$$

$$y(r,\theta) = (1-r)y_p(\theta) + ry_l(\theta) \tag{7}$$

where:

- I is iris image,
- (x, y) are the original Cartesian coordinates,
- (r, θ) are the corresponding normalized polar coordinates,
- x_p, y_p and x_l, y_l are the coordinates of the pupil and iris boundaries along the θ direction.

It is important to notice that Dougman's model also considers pupil's displacement. Pupil is not perfectly concentric with iris, as shown in figure 10. Pupil displacement in figure is accentuated respect the real one.

Therefore, as Figure 11 shows, this model allows the remapping of an iris image on a fixed-size rectangular template, which is effective for feature matching by Hamming distance [12] or other distance measures [9, 11].

2.3 SSIM Index for Region Selection

In the literature iris recognition is performed by considering the entire iris image. The idea of this In this paper a new approach is considered which finds and uses for personal verification only the most effective sectors extracted from the iris image. To evaluate the quality of sectors images, the low level statistical index proposed by Wang and al. [30] is considered. This index is called Ssim, and will be adopted to evaluate similarity between different images. Figure 12 shows an outline of the Ssim index, that evaluates every pixel of the image by considering it on the basis of luminance, contrast and structure.

The luminance comparison is evaluated as it follows:

$$l(x,y) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \tag{8}$$

Contrast comparison is evaluated by:

$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \tag{9}$$

Structure comparison is evaluated as:

$$s(x,y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \tag{10}$$

where C_1, C_2 and C_3 are constants added to avoid zero values. These three formulas (equations 8, 9 and 10) can be combined to obtain the Ssim index as follows:

$$\text{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_x\sigma_y + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{11}$$

This statistic is calculated on window sizes of 8×8. The window can be displaced pixel-by-pixel on the image but the authors propose to use only a subgroup of the possible windows to reduce the complexity of the calculation. This index has a range between -1 and 1, which is reachable only with identical images. In this paper, Ssim is employed to create a rank of irises sectors. More precisely, for every author, the iris images are divided into sixteen equal-size sectors. Successively, for every sector the average value of the Ssim index is computed for each sector and used to rank the various sectors. It is worth noting that this approach gives a low rank to iris sectors that are usually covered by eyelids and/or eyelashes. On the contrary, other sectors receive a high rank. Than, selecting a certain number of sectors, it is possible to apply a similarity measure for the matching step.

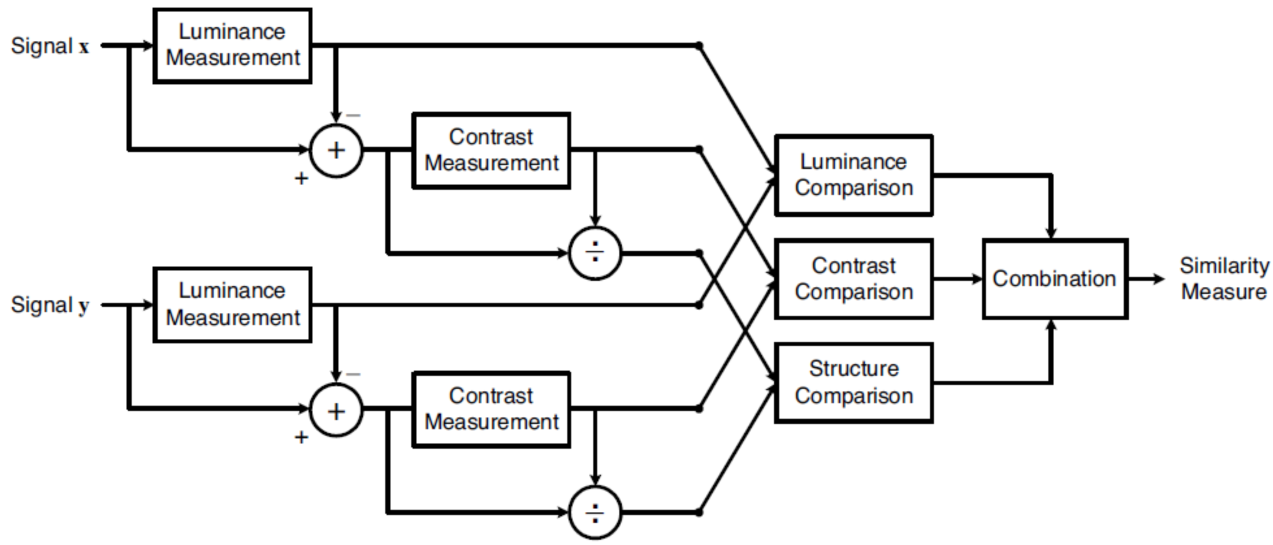

Figure 12: SSIM scheme

2.4 Bayes decision rule induced measures

Recently, new measures for image matching have been derived from the Bayes decision rule and their effectiveness has been demonstrated for some specific biometric applications [31]. In order to use the measures, some preconditions need to be satisfied:

- The conditional probability density functions of all the classes are multivariate normal.
- The prior probabilities of all the classes are equal.
- The covariance matrices of all the classes are identical to the covariance matrix of all samples regardless of their class membership.
- The whitened pattern vectors in the Bayes decision rule are normalized to unit norm.

It is possible to demonstrate that if these conditions are all satisfied, then the Bayes decision rule becomes the Whitened Cosine (WC) [31]:

$$\delta(U,V) = \frac{(W^tU)^t(W^tV)}{\|W^tU\|\|W^tV\|} \tag{12}$$

Moreover, it is worth noting that the fourth assumption is the most important. In fact, if this assumption is not satisfied, then the Bayes decision rule became the Mahalanobis distance, that is a well known classifier, but with lower performance than the WC. The whitening transform is defined as [31]:

$$W = \Phi\Lambda^{-\frac{1}{2}} \tag{13}$$

where Φ is an eigenvector matrix and Λ is the eigenvalue diagonal matrix, obtained by factorization via SVD of the covariance matrix of all examples $\Sigma = \Phi\Lambda\Phi'$.
In his work, Liu [31] kept the forth assumption and modified the third one, defining two new similarity measure, modifying the whitening transformation matrix. The two new measures are:

- The PRM Whitening Cosine Transform, that is named PWC, is defined as:

$$W_p = \Phi\Delta^{-\frac{1}{2}} \tag{14}$$

where:

$$\Delta = diag\{\sigma_1^2, \sigma_2^2, \ldots, \sigma_d^2\} \tag{15}$$

with:

$$\sigma_i^2 = \frac{1}{L}\sum_{i=1}^{L}\left\{\frac{1}{N_k-1}\sum_{j=1}^{N_k}\left(y_{ij}^{(k)} - m_{ki}\right)^2\right\} \tag{16}$$

being L the number of classes that needs to be classified.

- The Whitin-class Whitened Cosine Transform, named WWC, is obtained by factorizing the within-class scatter matrix with SVD, as follows:

$$W_w = \Phi_w\Delta_w^{-\frac{1}{2}} \tag{17}$$

The two measures along the Whitened Cosine were adapted to be used on a binary classification problem instead of a multiclass problem.

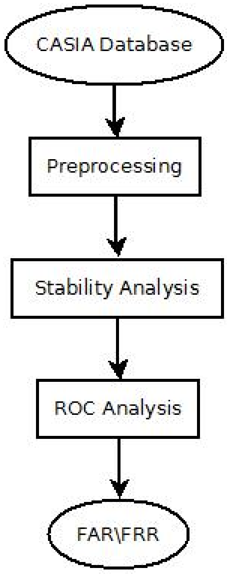

Figure 13: The experimental process

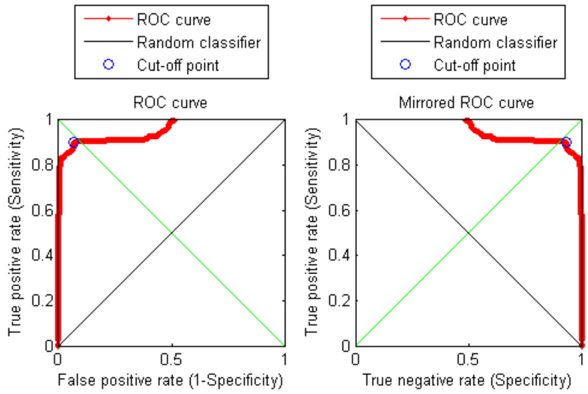

Figure 14: An example of excellent test

3 Experimental Results

The experiment tests were carried out on the iris images of the section ’Lamp’ of the CASIA database [29]. Each iris image has been processed as previously described, according to Figure 13. Then, the stability analysis has been considered to sort regions according to their stability ranking.

In the tests, the four most effective (top-ranked) sectors of eyes were used for the matching phase. For the purpose, the effectiveness of the three measures (WC, PWC and WWC) were compared by considering the Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC). An example is shown in Figure 14, 15 and 16.
Figure 14 and figure 15 report two examples of ROC tests, excellent case and good case, while figure 16 report an example of poor test.

From AUC values reported in Table 1, it results that WWC reaches in almost cases an area that is not statistically different from 0.50, which indicates a performance similar to that of a random classifier. This means that WWC fails to classify correctly data. Conversely, WC and PWC are much more effective than WWC. In some cases they provide very good classification results. A more detailed comparison among WC and PWC is performed in terms of FAR and FRR values.

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Author	WC	PWC	WWC
1	0.68	0.62	0.50
2	0.89	0.89	0.53
3	0.95	0.95	0.99
4	0.71	0.71	0.50
5	0.62	0.63	0.50
6	0.61	0.61	0.63
7	0.81	0.82	0.53
8	0.57	0.58	0.52
9	0.77	0.76	0.51
10	0.50	0.50	0.50

Table 1: AUC values of ROC curves. An AUC value close to 1 represents an excellent case of test, while a value close to 0.50 represents a fair test, similar to a random classifier.

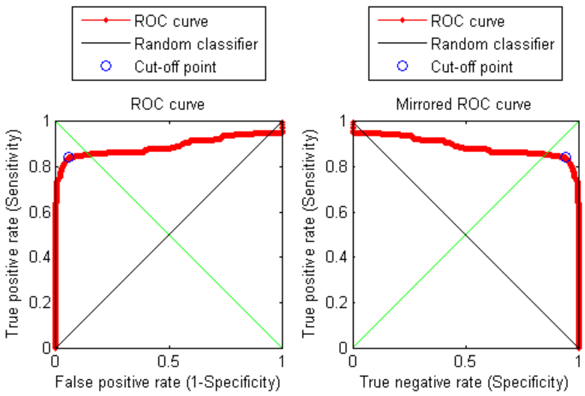

Figure 15: An example of good test

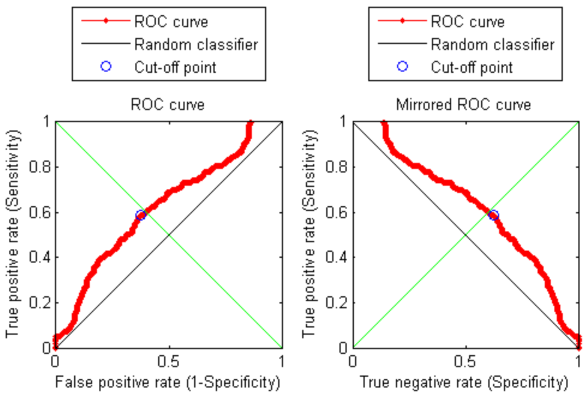

Figure 16: An example of poor test

WWC. In some cases they provide very good classification results, while author number 10 does not reach tests different than the failed one. A more detailed comparison among WC and PWC is performed in terms of FAR and FRR values.

Table 2 reports FAR values while Table 3 reports FRR values for WC and PWC. As it is possible to observe, variations between values suggest that probably there is no difference in terms of discriminant power between WC and PWC. This consideration was confirmed by the T-test, that revealed that there is no statistical significant difference between the two measures, both in terms of FAR and FRR. It is possible to conclude that the Whitened Cosine classifier and the PRM Whitened Cosine have both similar performances on regional analysis of irises sectors. Also, in figure 17 and 18 are reported boxplot for FAR and

Author	WC	PWC
1	23.3	20.3
2	5.7	5.7
3	6.9	6.9
4	25.4	25.4
5	37.4	36.5
6	48.9	48.9
7	27.3	26.5
8	26.3	25.4
9	24.8	25.7

Table 2: FAR table.

Author	WC	PWC
1	53.5	50.0
2	15.5	15.5
3	10.0	10.0
4	31.5	31.5
5	41.0	40.0
6	30.5	30.5
7	20.0	21.1
8	45.0	44.1
9	24.0	24.9

Table 3: FRR table.

FRR values. In next section it is reported a short discussion about experimental results of this study.

4 Conclusion

In this work a regional approach for iris recognition is presented. Iris recognition is performed only considering a reduced part of the iris image. For the purpose, a new technique is proposed to select the most valuable, user-dependent, regions of iris images for recognition purposes. In addition , three Bayes-based similarity measures have been considered for iris image matching: the Whitened Cosine (WC), the PRM Whitened Cosine Transform (PWC) and the Whitin-class Whitened Cosine Transform (WWC) measures. The experimental results demonstrate the foundation of the proposed approach, although much more research is necessary to evaluate its validity under real world conditions.
Another interesting enhancement for this new way of recognition should be located in the stability analysis step. For example, it should be evaluated the use of coregistration techniques to find the best alignment of normalised irises patterns, then stable sectors search will be performed. Moreover, other indexes like SSIM can be employed, or other distances measures.

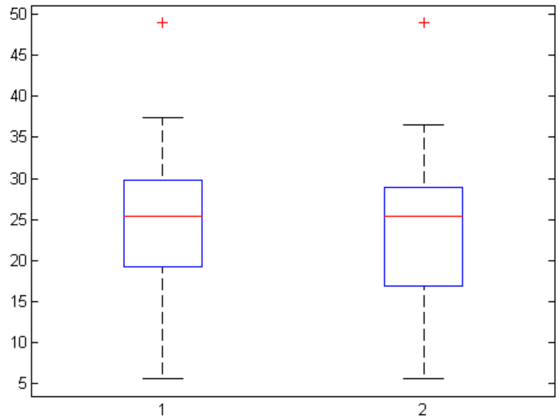

Figure 17: FAR values boxplot

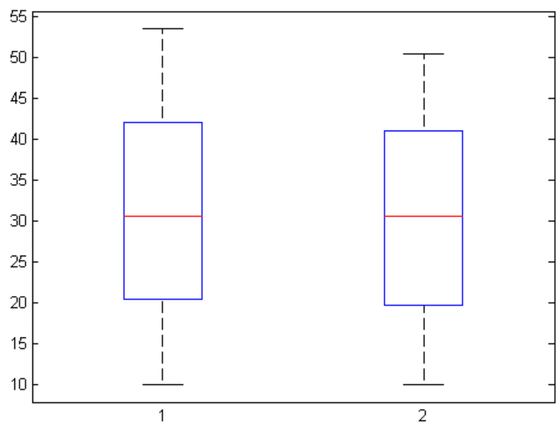

Figure 18: FRR values boxplot

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