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OSIRIS: An open source iris recognition software☆

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ABSTRACT

In this paper, we present the evolution of the open source iris recognition system OSIRIS through its more relevant versions: OSIRISV2, OSIRISV4, and OSIRISV4.1. We developed OSIRIS in the framework of BioSecure Association as an open source software aiming at providing a reference for the scientific community. The software is mainly composed of four key modules, namely segmentation, normalization, feature extraction and template matching, which are described in detail for each version. A novel approach for iris normalization, based on a non geometric parameterization of contours is proposed in the latest version: OSIRISV4.1 and is detailed in particular here. Improvements in performance through the different versions of OSIRIS are reported on two public databases commonly used, ICE2005 and CASIA-IrisV4-Thousand. We note the high verification rates obtained by the last version. For this reason, OSIRISV4.1 can be proposed as a baseline system for comparison to other algorithms, this way supplying a helpful research tool for the iris recognition community.

1. Introduction

Authentication by biometric verification is becoming increasingly common in security applications such as banking, border control, access control, and forensics. Nowadays, a particular attention is given to iris biometrics, due to its high reliability for personal identification. Iris recognition relies on the analysis of the random pattern of the iris by mathematical Pattern Recognition techniques. This modality is actually relatively recent since the first automatic system able to identify people based on iris texture was proposed by Daugman [1].

Iris is considered as a very interesting biometric modality due to its uniqueness, its stability over time and its protection from external degradations (internal organ). All these factors lead to remarkably high identification accuracy. However, recognition performance is a critical issue when iris acquisition is less constrained or/and when the database becomes very large. Such problems, that emerge when the iris is acquired in more realistic conditions, are at the center of research works carried out by both the scientific community and companies in the field.

Since 1993, many commercial algorithms have been proposed by different companies such as IrisScan (a start-up founded by Daugman), Iridian, IrisGuard, Oki, Morpho, etc. However, to our knowledge, there are only few open source algorithms for iris recognition. Probably, the most known system is MASEK developed in 2003 [2]. The source code, written in MATLAB, has been largely used by the research community for comparative evaluations. However, the performance of MASEK became obsolete relatively to recent state-of-the-art results, obtained by more robust and accurate algorithms. Recently, a new open source software named VASIR was proposed by the National Institute of Standards and Technology (NIST). VASIR (Video-based Automated System for Iris Recognition), implemented by Lee et al. [3] is an open source software for automated iris recognition at long distance. It performs two-eye detection, best quality image selection, and iris verification for identifying a person.

Such open source systems are extremely useful for the research community. Indeed, they provide an accessible tool for comparative evaluation (baseline) for other algorithms; they also encourage development through the modification of some of their components, contrary to commercial products which are in general black-box systems. Moving forward in this direction, the BioSecure Association [4] has proposed an open source iris recognition system, OSIRIS, in 2007. The system is free and licensed under the GNU General Public License. OSIRIS is designed as a modular software system, adequate to study modifications of its components and their effects on performance. In addition, the code can be extracted or/and re-used for other issues. OSIRIS is composed of four modules: segmentation, normalization, feature extraction and matching. Those modules are classical for iris recognition and follow the main steps proposed by Daugman approach [5]:

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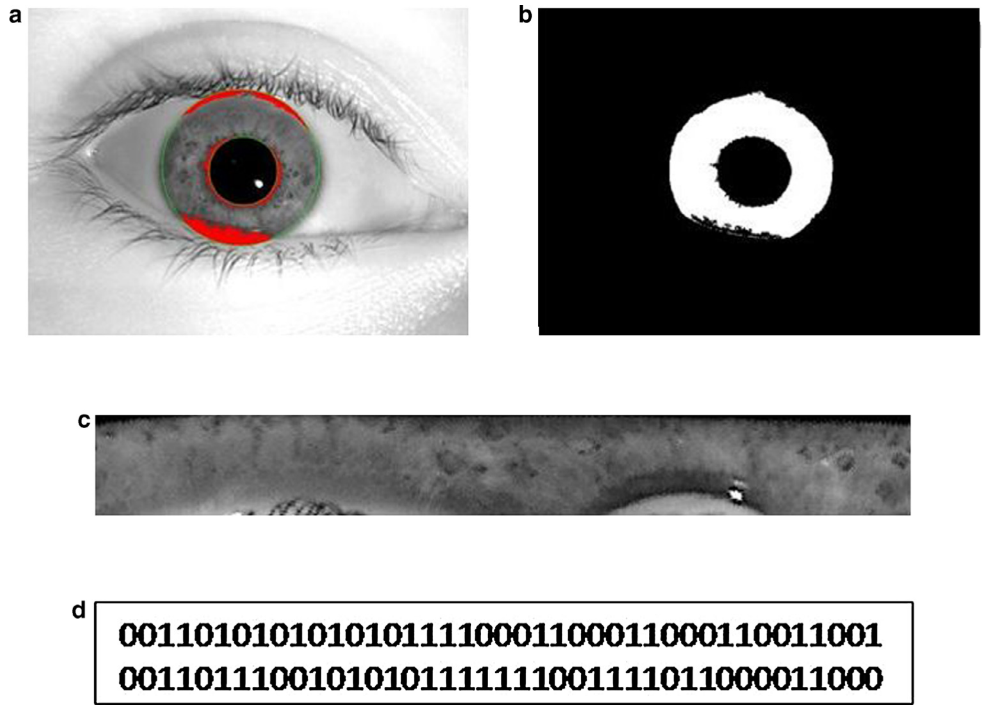

Fig. 1. Standard components in a classical iris recognition system: (a) iris segmentation, (b) iris mask, (c) normalized iris image, and (d) irisCode.

1. Iris segmentation: The first task consists in isolating the iris texture from other elements of the image such as eyelids, eyelashes, spotlights and/or shadows. These elements are considered as artefacts and have to be handled at this stage. Feature extraction and template matching are therefore limited to this iris region. In addition, the segmentation module generates a binary mask (used in the template matching module), which indicates which pixels of the image belong to iris texture.
2. Normalization: The iris texture is mapped into a size-invariant band called the normalized iris image. This dimensionless coordinate system of the resulting image copes with the problem of pupil dilation. This transformation is carried out by exploiting a parameterization of the iris boundaries obtained by the segmentation module. The normalization process allows the alignment of any two iris images to be compared.
3. Feature extraction: This stage aims at extracting the texture characteristics of a given iris. Discriminative features of iris texture are the basis for the comparison (matching) of any two images. The resulting template is a binary image, called irisCode, given as input to the matching module.
4. Template matching: The final stage of iris recognition systems consists in deciding whether two templates belong to the same iris or not. To this end, a similarity or dissimilarity score is computed between the two templates to compare. The decision of acceptance or rejection is taken by comparing the matching score to a threshold. The key at this stage is to fix this threshold appropriately, in order to take the correct decision.

Fig. 1 shows the standard elements in a classical iris recognition system.

Several versions of OSIRIS have been implemented, aiming at improving recognition accuracy. From a version to another, some modules have been modified in order to decrease the error rate of the overall recognition system. OSIRISV2[1] is the first version available online since 2009. Its implementation is very simple: actually, its segmentation module is based on a Hough transform. OSIRISV2 was widely used in the past due to its competitive results relatively to the state-of-the-art and in particular with regard to MASEK Reference System. However, with the progress of research, it became obsolete due to its weakness at the segmentation step, which led to high error rates at the recognition step. For this reason, this module has been completely modified in the more recent version OSIRISV4 [6] and replaced by a more sophisticated approach. Consequently, performance has been greatly enhanced and for further improvement, OSIRISV4 has been upgraded by modifying the normalization module. Indeed, to unwrap the iris texture, a novel contour description is proposed by relaxing geometric parametric constraints (circles or ellipses), previously used in OSIRISV4 (circular constraint). This parameterization provides more accurate iris boundaries (closer to the real contour) allowing a more efficient matching as demonstrated in the present paper on commonly used iris databases. This version, namely OSIRISV4.1[2], is the latest open source software for automated iris recognition and available online since 2013. However, its description had never been published up to now.

In this manuscript, the evolution of the open source OSIRIS reference system is related through its most reliable versions, namely OSIRISV2, OSIRISV4. We also describe the new version OSIRISV4.1, which has recently raised the interest of the scientific community. We also show on some experiments the relative performance of these versions.

The remainder of this paper is organized as follows: in Section 2, we describe each module of the two previous versions OSIRISV2 and OSIRISV4. Section 3 explains the novel approach based on non geometric contour for iris normalization proposed in the last version OSIRISV4.1. The interest of OSIRIS for the research community is shown in Section 4, through a summary of works that have used this software. Then, Section 5 reports the evaluation of all these versions on ICE2005 and CASIA-IrisV4-Thousand databases. Finally, conclusions are given in Section 6.

1 http://svnext.it-sudparis.eu/svnview2-eph/ref_syst/Iris_Osiris/.

2 http://svnext.it-sudparis.eu/svnview2-eph/ref_syst/Iris_Osiris_v4.1/.

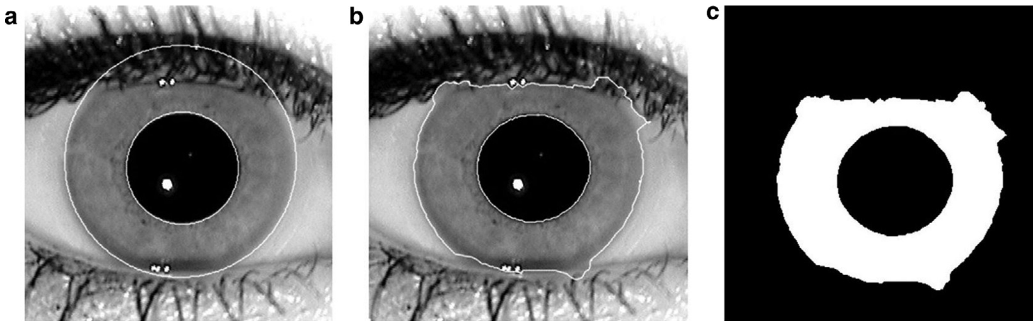

Fig. 2. Segmentation results given by OSIRISV2: (a) Initial contours, (b) accurate contours, and (c) the associated mask (OSIRISV2 online documentation [8]).

2. The evolution of OSIRIS

2.1. OSIRISV2

OSIRISV2 had been developed in 2009. The segmentation is done in 2 steps: (i) a rough localization of iris contours is performed by using Circular Hough Transform, (ii) these two circles are then used to initialize an Active Contour following the method proposed by Xu and Prince [7], in order to refine iris contours as displayed in Fig. 2. The refined contours are then exploited for generating a mask that indicates those regions containing only iris texture.

Normalization is based on Daugman's rubber sheet model in which two non-concentric circles are used to model the iris borders. The iris texture is then unwrapped with respect to these two circles. This transformation is explained in detail in Section 3.

Next module consists in the extraction of iris features by filtering the normalized image with a bank of 2D-Gabor filters of different resolutions and orientations, applied at specific points of the iris texture. The phase of each resulting Gabor coefficient is then encoded on two bits, depending on the sign of its real and imaginary parts, resulting in a binary template, the irisCode. In the matching module, the comparison is based on the Hamming distance. This score measures the dissimilarity between the two irisCodes (low (resp. high) when they come from the same (resp. different) iris). These two modules are inspired by Daugmans approach.

In practice, the evaluation of OSIRISV2 has shown the weakness of the segmentation phase. For instance, on ICE database [9] the Equal Error Rate (EER) was 5.41% and the False Rejection Rate (FRR) at False Acceptance Rate (FAR) of 0.1%, was 17.46%. This weakness motivated the following new version of OSIRIS with improved accuracy of the segmentation process.

2.2. OSIRISV4

This version uses the same normalization, feature extraction and matching modules as OSIRISV2. However, the segmentation part has been greatly improved. Indeed, the contours of the iris in this version correspond to an optimal path retrieved by the Viterbi algorithm for joining in an optimal way, the points of high gradients under the constraint that the resulting curve has to be closed [6]. The Viterbi algorithm is then exploited at two resolutions: at a high resolution, accurate contours are recovered, while at a low resolution the optimal path corresponds to coarse contours. More precisely, at high resolution, the contour is searched by exploiting all the pixels in the image. In the low resolution case, fewer points on noisy regions (close to eyelids and eyelashes) are used to retrieve the iris contour. Consequently, the coarse contour is non-regularly sampled, contrary to the accurate contour, as illustrated in Fig. 3.

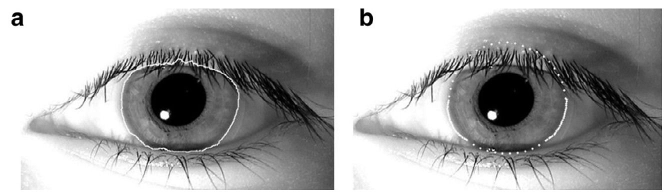

Fig. 3. Examples of accurate (a) and coarse (b) iris borders for a given eye image extracted from [6].

Normalization that follows is based on modeling the borders by circles, as in OSIRISV2. Such circles are computed from the coarse contours detected by the Viterbi algorithm at low resolution, using a least-square based method for circle fitting. Note that such circles do not need to match exactly with the maximum of pupil and iris gradient points, contrary to circles obtained through the Circular Hough Transform in OSIRISV2. Indeed, due to the sensitiveness of least-square fitting method to outliers, coarse contours, which contain less noisy points in regions showing occlusions (eyelids and eyelashes zones), are used instead of accurate contours. The two non-concentric resulting circles are then used to unwrap the texture.

For recognition purposes, non-iris regions have to be masked. To this end, this version of OSIRIS exploits the accurate contours found by the Viterbi algorithm in order to mask eyelashes. However, this mask is not efficient for detecting all the occlusions in the image. Therefore, another mask based on an adaptive filter is generated in order to remove the remaining eyelashes and other occlusions such as shadows and specular reflections. This mask results from a simple classification of pixels (iris or non-iris), and corresponds to the Full Width at Half Maximum (FWHM) of the Gaussian density function, modelling the histogram of iris pixel intensities. This mask is then combined to that given by accurate contours in order to build a final mask. As shown by Sutra et al. [6] performance of iris recognition improves when using the refined final mask instead of the mask based only on accurate contours. The difference between OSIRISV2 and OSIRISV4 is illustrated in Fig. 4a and b.

3. Improvement of OSIRISV4: OSIRISV4.1

OSIRISV4.1 version is an upgrade of OSIRISV4. The difference between both versions lies in the normalization step. In the previous version V4, normalization is based on modeling the iris borders by circular contours in order to unwrap the texture as proposed by the pioneer normalization algorithms in the literature [1] and [10]. Even in more recent works [11], [12], and [13], the iris is modeled by two concentric circles. However, it is clear that using such a simple parameterization of contours is not optimal to recover the iris zone. Indeed, as iris contours are not exact circles, any circular model will induce errors. Moreover, Proencça and Alexandre [14] have shown that small errors in the estimation of circles parameters change the resulting normalized image and that this can dramatically impact performance of the overall system. Indeed, two normalized iris images resulting from different acquisitions of the same person, may present a high discrepancy and consequently lead to wrong authentication. Therefore, having an accurate description of the iris boundaries is an essential issue to avoid significant degradations of overall system performance.

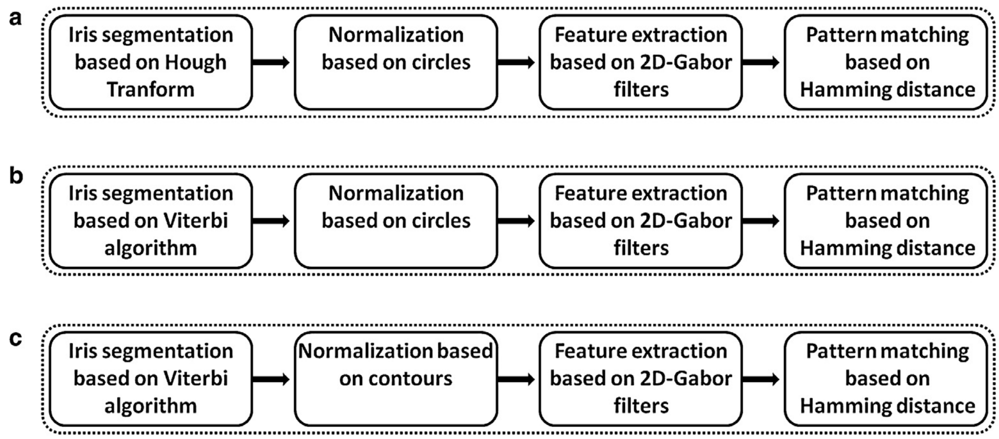

Fig. 4. Flowchart of: (a) OSIRISV2, (b) OSIRISV4, and (c) OSIRISV4.1.

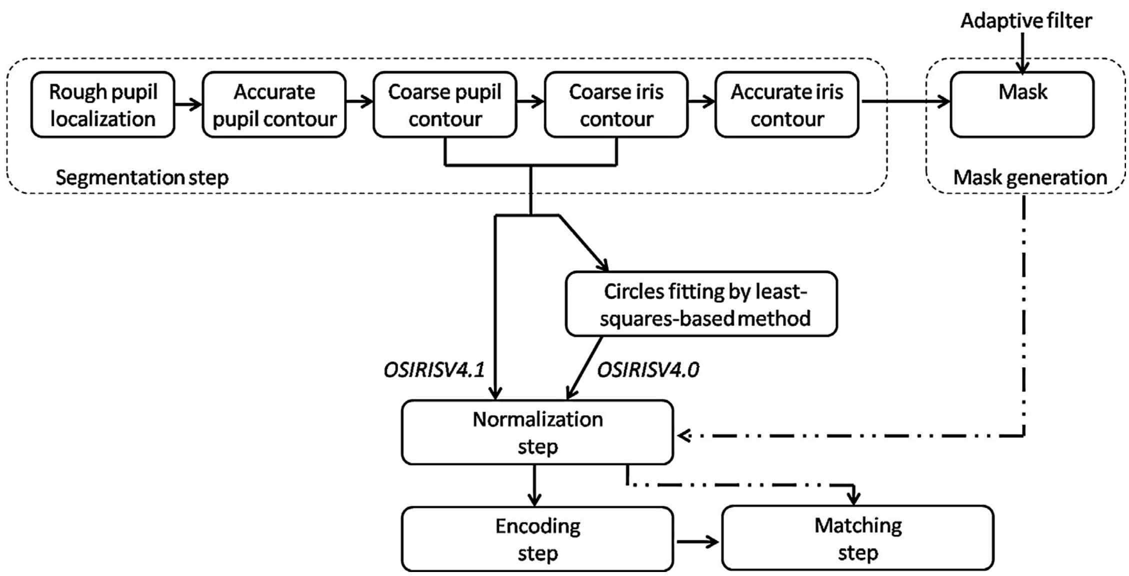

Fig. 5. The difference between the two iris recognition systems: OSIRISV4 and OSIRISV4.1.

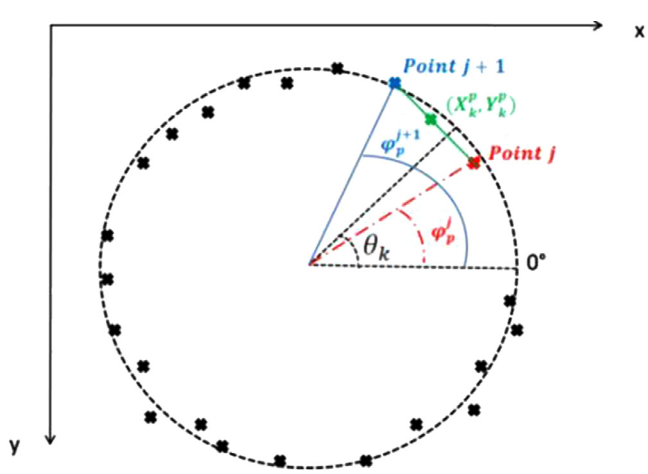

Fig. 6. On computing the new coordinates of points (X_k^p, Y_k^p). The figure is extracted from OSIRISV4.1 online documentation [21].

Beyond circles, other types of parametric contours are proposed in the literature to model the shape of the iris such as ellipses [15], [16], and [17] and polynomial curves [18]. In another spirit, parametric contours given by Fourier series are also used to describe the border of the iris in works of Daugman [19] and Proençça [20]. Such parameterization, which does not make an assumption of the contour as a known geometric curve, allows obtaining a more flexible and generalized iris contour description. Our model in OSIRISV4.1 fits in this category. Actually, the iris boundaries used at the normalization step are the coarse contours resulting from the Viterbi optimization of a cumulative gradient function around the center of the pupil. Contrary to [19] and [20], fewer points are used in noisy areas which correspond to usual locations of occlusions (close to eyelids and eyelashes) comparatively to other regions. Therefore, the obtained contour corresponds to a sequence of non-regularly sampled points (as in Fig. 3b). This way, the number of possible erroneous contour points is reduced. These coarse contours are finally used in Daugmans rubber-sheet model in order to unwrap the iris texture.

We note that outer coarse contours look like a circle even in the upper part where occlusions occur (upper eyelids). This is due to the Viterbi algorithm that imposes regularity in the search of the contour points. More precisely, the obtained contour is a series of radii $R(n)$ in polar coordinates, where index n stands for the angle (varying from 1° to 360°). A non-regular sampling of the angles is considered as follows: in difficult areas (where occlusions might occur), one contour point is selected every eight pixels, while in other regions, one contour point is selected every two pixels. The Viterbi algorithm is used to find an optimal path through the gradient map. It imposes the search of the radius $R(n+1)$ in the restrained interval $[R(n)-1; R(n)+1]$. In Fig. 3b, the upper part of the iris boundary

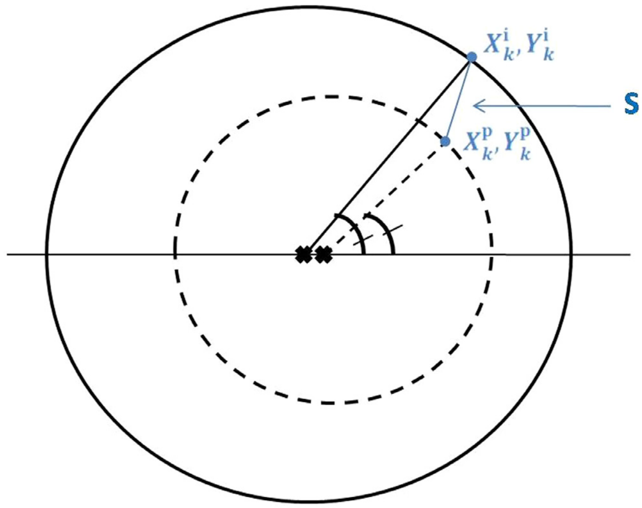

Fig. 7. Illustration of segment S formed by (X_k^p, Y_k^p) and (X_k^i, Y_k^i) . Note: Coarse boundaries are modeled by circles for simplification. The figure is extracted from OSIRISV4.1 online documentation [21].

corresponds to the difficult area (possible occlusions), where contour points are sparse. Therefore, the radius does not change roughly and the final contour looks like a circle. In this way, the area considered as iris in two normalized images resulting from different acquisitions of the same person will be similar, independently of the presence of occlusions. Fig. 5 illustrates the difference between the components used in the two iris recognition systems OSIRISV4 and OSIRISV4.1.

The new normalization follows the following steps. First, let W and H be respectively the width and height of the desired normalized image. Regarding to Daugman's approach, we compute a regular sampling of angles θ_k where k ranges from 0 to W, so that $\theta_0 = 0$ and $\theta_W = 2\pi$:

$$\theta_k = 2\pi k/W, k \in [0, W] \quad (1)$$

Let (x_p, y_p, ϕ_p) and (x_i, y_i, ϕ_i) respectively be the coordinates of a point of pupil coarse and iris coarse contours where (x, y) are the x-coordinate and y-coordinate of the radius relatively to the estimated center of each coarse contour and ϕ the angle of the non-regular

Table 1
OSIRIS citations for each version since 2009.

Year	OSIRISV2	OSIRISV4.1
2009	2	X
2010	2	X
2011	3	X
2012	3	X
2013	2	X
2014	2	9
2015 (until March)	0	2
Total of papers	14	11

sampling. ϕ follows the non-uniform sampling of the coarse contour as explained above. The next step consists in estimating the new point (X_k^p, Y_k^p) with a sampling as close as possible to θ_k from the coarse pupil contour. To this end, we interpolate the two nearest points of the coarse contour j and $j+1$ to θ_k as follow:

$$X_k^p = (1-\alpha)\cdot x_p^j + \alpha \cdot x_p^{j+1} \quad (2)$$

$$Y_k^p = (1-\alpha)\cdot y_p^j + \alpha \cdot y_p^{j+1} \quad (3)$$

with

$$\alpha = \frac{\theta_k - \phi_p^j}{\phi_p^{j+1} - \phi_p^j}$$

This process is illustrated in Fig. 6. In a similar way, the new points (X_k^i, Y_k^i) of the iris contour are computed. The pupil and the iris centers are not necessarily the same. Often the pupil center has a nasal and inferior position relative to the iris center [22]. To cope with this problem, we define a segment S formed by (X_k^p, Y_k^p) and (X_k^i, Y_k^i) as shown in Fig. 7.

S is then rescaled so that it fits with the height H of the normalized image. On the normalized image, the pixel on hth row and kth column will take the same value as the pixel located at $(x_{k,h}, y_{k,h})$ on the original image as follow:

$$x_{k,h} = (1-h/H)\cdot X_k^p + (h/H)\cdot X_k^i \quad (4)$$

$$y_{k,h} = (1-h/H)\cdot Y_k^p + (h/H)\cdot Y_k^i \quad (5)$$

with $h \in [0, H]$

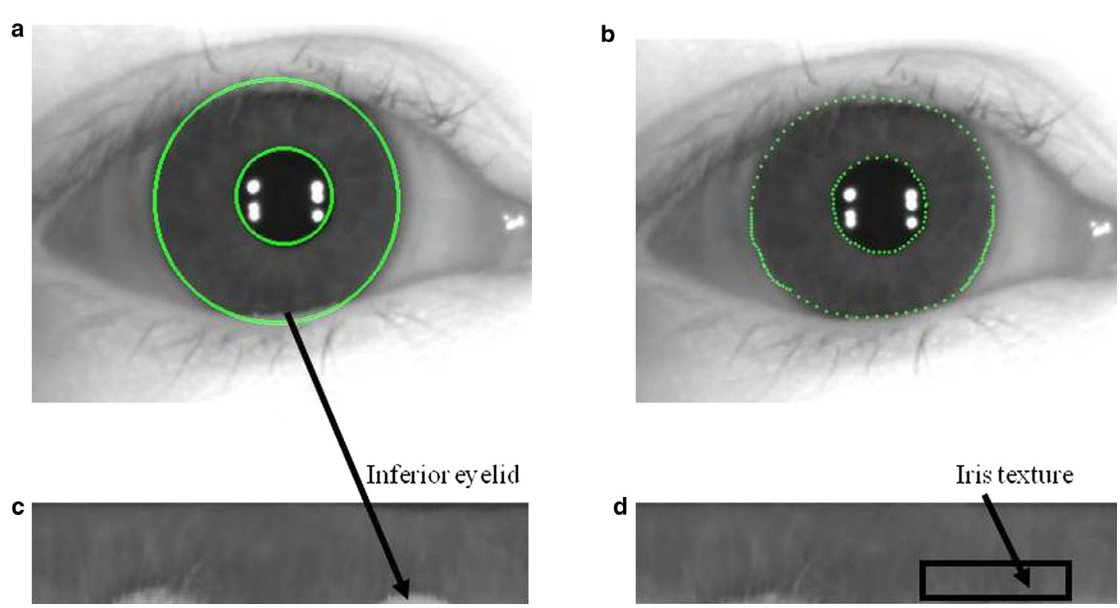

Fig. 8. (a) Border points used for normalization in OSIRISV4.0, (b) border points used for normalization in OSIRISV4.1, (c) normalized image by OSIRISV4.0, (d) normalized image by OSIRISV4.1.

Table 2
Summary of works that have used OSIRISV2 and OSIRISV4.1.

OSIRISV2			OSIRISV4.1		
Team	Topic	Number of papers	Team	Topic	Number of papers
Carlos III University of Madrid	Quality assessemnt [33]	2	Electrical Engineering Department - DEE Federal University of Campina Grande, Brazil	Cryptography [32]	1
Department of Computer Sciences, University of Salzburg, Austria	Iris segmentation [23]	5	The University of Electro-Communications, Tokyo, Japan	Iris segmentation [26]	1
Department of Computer Science and Engineering, University of Notre Dame, USA	Iris recognition system, Bit reliability in an irisCode [24]	4	Norwegian Biometric Laboratory, Gjøvik University College,, Norway	Iris segmentation for Smartphone applications, light field camera...[27]	7
Department of Electronics and Systems Federal University of Pernambuco, Brazil	Cryptography [30]	1	Advanced Technologies Application Center, Havana, Cuba	Iris segmentation [28]	1
Institute of Control and Computation Engineering, Warsaw University of Technology, Poland.	Iris aging [29]	1	Faculty of IT, Monash University, Melbourne, Australia	Cryptography [31]	1
Oak Ridge National Laboratory, USA, and The University of Tennessee Health Science Center: Hamilton Eye Institute.	Iris segmentation [25]	1			

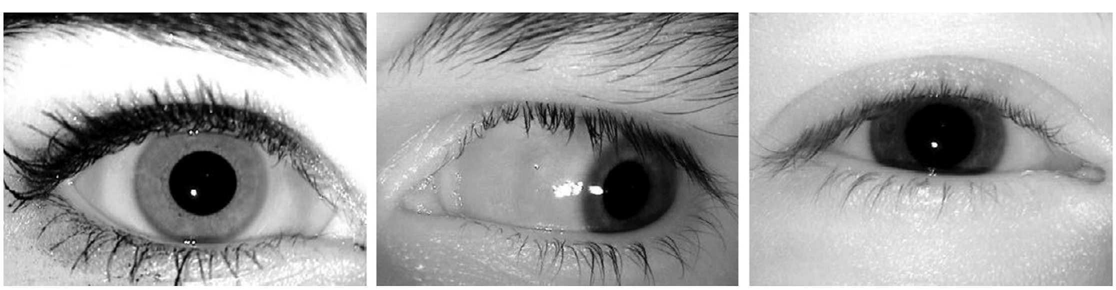

Fig. 9. Examples of images taken from ICE2005 database.

Compared to OSIRISV4, in OSIRISV4.1 the borders used for normalization are closer to real ones in the sclera area and in the lower eyelid part, as illustrated in Fig. 8. Therefore, the matching points considered in the comparison of two irises are better aligned resulting in increased performance. The flowchart of OSIRISV4.1 is resumed in Fig. 4c.

4. Impact of OSIRIS in the research community

OSIRIS Reference System has been cited in several papers since 2009, in different topics such as iris segmentation [23–27], and [28], iris aging [29], cryptography [30], [31], and [32] and quality assessment [33]. To our knowledge, OSIRISV2 and OSIRISV4.1 have been respectively used in 14 and 11 works as reported in Table 1. We note that the use of OSIRISV2 has decreased in favor of OSIRISV4.1, despite the more recent availability online of the latter. This is due to the improved performance of OSIRISV4.1 compared to that of OSIRISV2, as will be presented in Section 5.

Table 2 gives an overview of the teams that have used OSIRIS reference system in their research. We notice that OSIRIS is used by a large community in different areas of research. We give in Table 2, for each team, the number of papers in which OSIRISV2 and OSIRISV4.1 have been used, with the corresponding field of application. We also cite one reference per team.

One of the goals of this paper is generating a unique new reference to OSIRIS system through its last version, this way unifying citations of OSIRISV4.1, which is not yet published, and facilitating the traceability of the software's use.

5. Performance evaluation

For benchmarking purposes, we examine performance of all versions of OSIRIS using publicly available datasets as ICE2005 [9] and CASIA-IrisV4-Thousand [34], described in this Section. Performance assessment results have shown a significant improvement across versions.

1. ICE2005: The ICE2005 dataset is a traditional NIR iris still image set acquired with a dedicated LG2200 camera. The total number of iris images is 2,953 on 132 distinct subjects. There are respectively 1425 right and 1528 left irises from 124 and 120 persons. For some subjects only left or right eyes were acquired, and for most

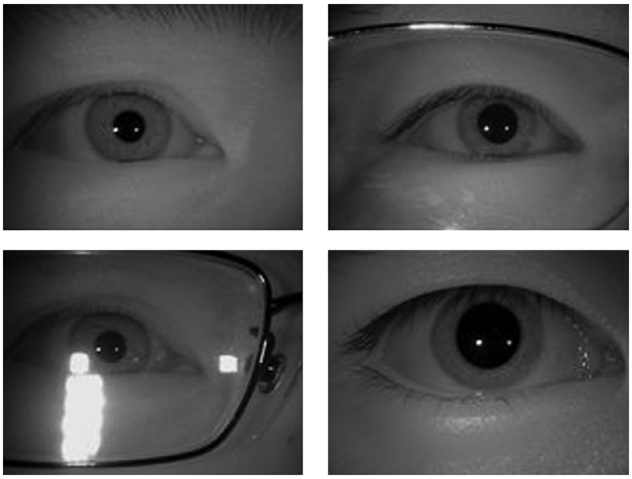

Fig. 10. Examples of images taken from CASIA-IrisV4-Thousand database.

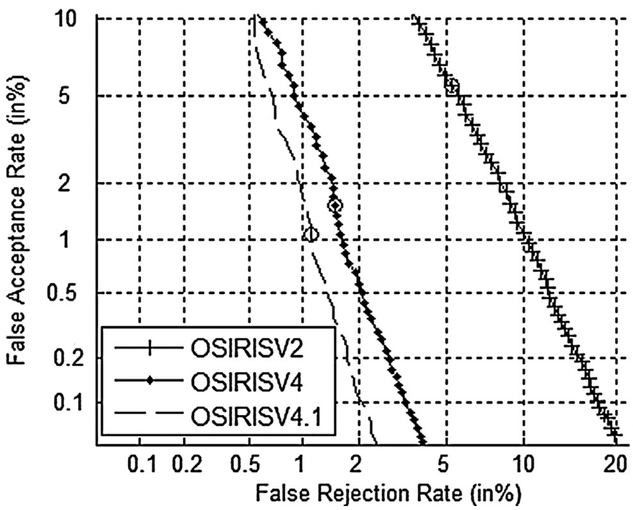

Fig. 11. Comparative evaluation between OSIRISV2, OSIRISV4, and OSIRISV4.1, on ICE2005 database.

of them, both eyes were enrolled. Some images of the database suffer from various kind of noise such as blur, strong occlusions, and presence of artifacts (contact lenses and mascara). Some examples of iris images are given in Fig. 9.

2. CASIA-IrisV4-Thousand: The experiments are carried out on a subset of the challenging CASIA-Iris-Thousand database, introduced more recently in 2012. The complete database includes 20,000 iris images from 2000 eyes of 1000 persons. Thus, each subject has 10 instances of both left and right eye. The images are captured using the dual-eye iris camera using IKEMB-100 produced by IrisKing. In this work, we select all the images of the first 602 subjects (S5000R/L to S5300R/L). The main sources of variations in this database are eyeglasses, strong specular reflections and dilation, which make the iris segmentation particularly difficult. Some examples are illustrated in Fig. 10 to show the difficulty of this database.

We report in Fig. 11 the corresponding DET curves for all OSIRIS versions, i.e. OSIRSV2, OSIRISV4, and OSIRISV4.1 on ICE2005 database. DET curves of OSIRISV4 and OSIRISV4.1 on CASIA-IrisV4-Thousand are shown in Fig. 12. Note that we do not plot OSIRISV2s DET curve on the challenging CASIA-IrisV4-Thousand database, due to its very poor performance relatively to the two last versions (Equal Error Rate of 25.31%).

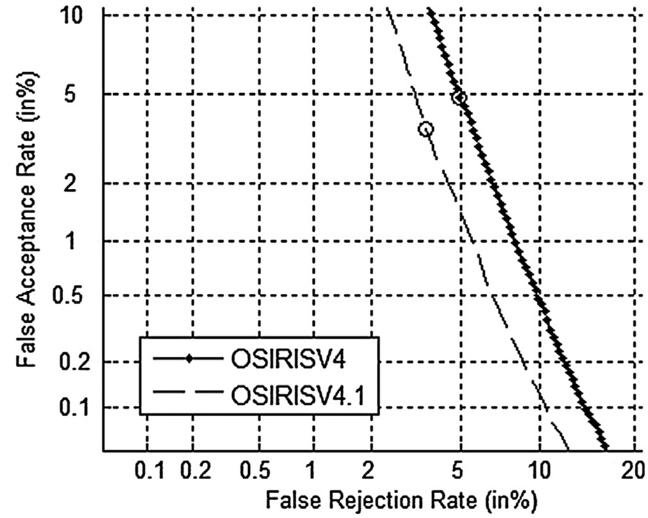

Fig. 12. Performance improvement achieved by the latest version of OSIRIS: OSIRISV4.1, for CASIA-IrisV4-Thousand database.

Table 3
Summary of the matching results of all the OSIRIS versions on ICE2005 database (OSIRISV4.1 online documentation [21]).

	OSIRISV2	OSIRISV4	OSIRISV4.1
EER	0.054	0.015	0.010
FRR @ FAR = 0.001	0.174	0.031	0.019
FRR @ FAR = 0.0001	0.268	0.058	0.034

Table 4
Summary of the matching results of OSIRISV4 and OSIRISV4.1 on CASIA-IrisV4-Thousand database.

	OSIRISV4	OSIRISV4.1
EER	0.048	0.035
FRR @ FAR = 0.001	0.138	0.103
FRR @ FAR = 0.0001	0.215	0.183

The Equal Error Rate (EER) and the FRR (False Reject Rate) at different FAR (False Acceptance Rate) operating points are respectively given in Tables 3 and 4 for ICE2005 and CASIA-IrisV4-Thousand databases. We note an important improvement in performance with the latest OSIRIS versions. In particular, OSIRISV4.1 shows the best results on both databases.

OSIRISV4.1 has also been benchmarked on an unpublished subset of CASIA-IrisV4-Thousand database in the context of the first ICB competition on iris Recognition [35]. Eight participants (institutions and companies) from six countries submitted 13 algorithms in total. With an Equal Error Rate of 3.02%, OSIRISV4.1 has given as the 2nd best system. The best EER was equal to 2.75% and was obtained by Zhuhai YiSheng from Electronics Technology Co, Ltd.

6. Conclusion

It is interesting for the research biometric community to have access to a free iris recognition system, in which each module can be studied and examined independently. To this end, we implemented OSIRIS as a modular, open source software, convenient to study changes in its components and their effects on overall system performance. In addition, the code can be extracted or/and re-used for other issues. Consequently, OSIRIS has been largely used by the biometric community as a relevant benchmarking tool. The different versions of this software have been presented in this paper, including a precise description of the latest version OSIRIS V4.1, unpublished up to now.

The efficiency of this version relies on two important ingredients: on one hand, an implementation of a segmentation algorithm able to determine accurate contours through gradient optimization implemented by the Viterbi algorithm, and on the other hand, a non geometric and non uniform parameterization of the contour which allows a precise localization and normalization of the iris texture.

In addition, we have demonstrated the effectiveness of this last version on two well-known iris databases: ICE2005 and the challenging CASIA-IrisV4-Thousand. As shown by results of the first ICB iris competition, OSIRISV4.1 gives competitive performance relative to other state-of-the-art iris recognition systems. Therefore, OSIRISV4.1 which is publicly available online, can be used with high benefit as an up to date, relevant tool for benchmarking novel iris recognition algorithms.

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