Analysis of the Eyes on Face Images for Compliance with ISO/ICAO Requirements

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***Abstract*—The face has been used in identity documents and represents the ideal biometric characteristic in many applications. The International Civil Aviation Organization endorsed the use of face as the globally interoperable biometric characteristic. Successively, the International Standard Organization proposed the ISO/IEC 19794-5 standard for face usage in travel documents. The purpose of this work is to evaluate the quality of face images for identification documents and check if the face images satisfy the requirements defined by the ISO/IEC 19794-5. This work presents approaches for the evaluation of the following ISO/ICAO requirements: eyes state, red eyes and looking away. In addition, an approach to estimate the location of the center of the eyes is proposed. The proposed methods to check ISO/ICAO requirements were evaluated using the BioLab-ICAO Framework. The results achieved by the proposed methods were satisfactory, overcoming almost all the works in the literature for this purpose.**

***Keywords*-ICAO requirements; Eye detection; Validate faces.**

I. Introduction

The face represents the ideal biometric characteristic in many promising forensic and commercial applications (e.g., access control, video-surveillance, ambient intelligence). Compared to other biometric characteristics, the face is less intrusive. Also, acquiring a face does not require expensive devices or the cooperation of the subject.

The International Civil Aviation Organization (ICAO) endorsed the use of the face as the globally interoperable biometric characteristic for machine-assisted identity confirmation with machine readable travel documents [1]. However, face images may have some undesirable features such as illumination and pose variation, background and different facial. Aiming to solve those issues, in accordance with ICAO directives, the International Standard Organization (ISO) proposed the ISO/ IEC 19794-5 standard [2], which specifies record format for encoding, recording and transmitting the facial image information, and defines scene constraints, photographic properties and digital image attributes of facial images. For instance, a face image must have a natural skin color and a uniform background to be included in an electronic passport.

The eyes are very important to the face analysis. Their state, movement, and features can provide useful information for several purposes, for example, facial expression recognition.

This work is part of a project that aims to develop a software development kit (SDK) that will allow the evaluation of the compliance of a given image in relation to ISO/ICAO constraints, thus checking if the image is appropriate for usage in identification documents. In this work approaches are presented to verify the compliance of images to the following ISO/ICAO requirements:

- *Eyes Closed*
- *Red Eyes*
- *Looking Away*

In addition, this work also proposes a method to locate the eye center and then detect the iris by using edge detection techniques and Hough Circle Transform. The accuracy of the proposed method responsible for the eye center detection was tested by the BioLab-ICAO framework [3].

The manuscript is organized as follows. In Section II the related works are reviewed and discussed; Section III presents the BioLab ICAO Benchmark used in this work; in Section IV the proposed methods are described in detail, and in Section V the experiments and results are shown and a discussion about them is made. Finally in Section VI are presented the final conclusions obtained from this work and the future works are introduced.

II. Related Work

This section describes works that are related to this research.

A. Eye Detection

Eye detection methods are divided into two categories: active and passive. Active detectors require a sequel of images to perform the detection, whereas passive detectors need one image only. Usually, the passive approach is categorized in Template-based, Feature-based e Appearance-based [4].

In the Template-based approach, a generic eye model, the template, is defined and used to seek on the image a region that matches with this pattern. In the Appearance-based methods, the detection is based on their photometric appearance. This approach uses a set of images. Each image represents different features of the eyes to be used for the training of the classifier. Features such as color, texture and shape of the eyes are considered in the eye detection process. The features are used to remove false candidates. [4].

There are several Feature-based approaches proposed in the literature. They usually follow a common process: (a) defining the probable eyes candidates, (b) removing the false positive and (c) determining the eye center. To remove false positives, most of the methods in the literature use thresholding filters, with the skin as the foreground, combined with rules based on previous knowledge. Some of these rules are based on eyes position, edge detection, anthropometric relations, skin regions [5] [6] [7]. Other algorithms use edge detection [8] [9] and morphologic math [10] [11]. The main disadvantage of Feature-based approaches is to find a satisfying criterion to identify skin regions, eyebrow and being robust to face pose, ethnic variations and illumination variation [12].

B. Eye State

The eye state may be classified as opened or closed. This information has been used for several purposes, especially in surveillance systems for drivers and fatigue estimation.

Several methods to detect eye state can be found in the literature. Wang *et al*. [13] claim that the presence of iris can provide an important information to distinguish the eye state. Using the edge information of an eye and then applying the Hough Transform to detect iris, the authors define that, if the iris is found, the eye is opened, otherwise the eye is closed. Besides using the edge information, Liu *et al*. [14] use the color information. Starting from the knowledge that sclera has a saturation value smaller than the other parts of the eye, the authors use the HSI color system, to determine whether the eye is opened. After establishing the eye state through the color information, the authors use the red channel of the RGB color system and the canny filter to generate an edge map; they use it because they affirm the red channel has more high contrast with the white of the eye and the skin than other ones. Then, the Hough Transform is used in the resulting image to find potential irises. In the work, it is said that one advantage of this approach is the possibility to detect if an eye is closed, in almost all cases, before using the edge information.

The image of an open human eye has three different regions, pupil/iris in the middle and two white parts in the left and right sides. However, in the image of a closed eye, these areas cannot be discriminated. Based on this observation and on the known fact that the iris grayscale values are smaller than the sclera ones, Vijayalaxmi and Rani [15] use mean value and standard deviation of the region to define eye state. The mean and standard deviation of the open state are found and concluded that the mean is always greater than 0.2 and the standard deviation is always less than 0.02. If the mean is less than 0.2 and the standard deviation is greater than 0.02, then the state of the eye is concluded as closed.

C. Red eyes

A common problem in face images is the red eyes effect on the retina. This problem is caused by the red reflection of the blood vessels in the retina when a strong and sudden light strikes the eye. Most of the works in the literature approach this issue aiming to remove it from the images and are based on a previous handmade or automatic eye detection. Approaches that do not use a previous information about the face or eyes are usually based on color information, contrast, geometry, etc.

Gaubatz and Ulichney [16] divide the red eye process into three stages. In the first stage, the search space is reduced by detecting the face with Viola-Jones [17] and through the usage of geometric information to presume the eye region. After detecting the face region, the authors use metrics to classify the pixels as red-eye-pixel or not. The used metrics are variations of the color system YUV, redness calculus and a variation of it. Finally, they search for glint caused by a camera flash.

Zhang *et al*. [18] look for candidate regions through some metrics. They define some values in the RGB color system and if the pixel has one of those values, it is marked as a red pixel. Another metric used is to define a template to find highlight pixels around the pixels marked as red ones and later on cluster them with a region growing algorithm. After that, techniques such as neighbor analysis, size restriction and the surrounding of non-skin pixels are used to remove incorrect regions.

An overview of the literature of the main approaches used to detect red eyes has been made by Gasparini and Schettini [19]. According to their work, initially, a reduce in the search space is made, followed by a non-standard color transformation that usually produce a grayscale image defined as the redness map. There are several approaches to obtain the redness map, and a summary of them is presented in the work.Most of the cited authors use RGB and YCbCr color system.

D. Eye gaze Direction

The combination of eye gaze direction classification and head direction detection provides various control signals that can be used in many applications such as assistive technology.

Eye gaze direction usually can be estimated by detecting the pupil center, eye corners, the distance between pupil center and eye center, the distance of the vertical and horizontal sclera and etc. However, when the person is looking downward, the pupil is hidden and it becomes difficult to detect.

Choi and Kim [20] use the pupil center detection based on the CDF (Cumulative Distribution Function) and calculate the distance of vertical and horizontal sclera with the detected pupil at the center.

AI-Rahayfeh and Faezipour [21] use Viola-Jones method to detect face and Circular Hough Transform to locate the center of the iris. The iris coordinates are used to crop the sub-images from the original image and then, it is performed a transformation on them to the HSI color system. Depending on the eye gaze direction, one of the two regions, the left or the right, will contain the white area of the eye while the other will contain skin area. To determine whether the gaze direction is left or right, SVM classifier is used.

Yilmaz and Kose [22] using Adaboost and Haar-like features to detect face region, eye region is detected using

Support Vector Machines (SVM) and grayscale image features. Gaze directions are classified and recognized using SVM and grayscale image features.

III. BIOLAB-ICAO BENCHMARK

It is a framework developed to provide to the scientific community a common benchmark for the evaluation of algorithms for ICAO compliance verification. A large ground-truth database, a precise testing protocol for objective performance evaluation and baseline for all ISO/ICAO requirements are made publicly available through the its [23], thus facilitating further studies on this topic.

Images from public databases plus especially additional acquired images were used to create the database used by the BioLab-ICAO benchmark. The database contains 1741 images from AR database [24], 1935 images from the FRGC database [25], 291 images from the PUT database [26], 804 images artificially generated by applying ink-marked/creased, pixelation and washed-out effects to compliant images from the AR database and 817 newly acquired images. The database is supplied with ground-truth data produced by human experts with a manual labeling process needed for an objective performance evaluation [27].

The adopted testing protocol requires the SDK to yield as an output in the range [0 ... 100] for each requirement, which represents the compliance degree of the image to the requirement. Tha value 100 indicates that the image is compliant with that requirement and 0 means it is noncompliant. Sometimes an SDK may fail in processing an image or to evaluate a specific characteristic of the image, therefore, a rejection occurs. The equal error rate (EER) is calculated from the distribution of the degrees of compliance and used to evaluate the performance for each characteristic.

IV. PROPOSED METHODS

This section describes the algorithms implemented to evaluate the ICAO requirements.

A. Eye and Iris Center Location

An appearance-based method is used to find eye center. First, the algorithm proposed by Kazemi and Sullivan [28] is used to estimate the position of facial landmarks, including the eyes corners. The method is trained by using a set of images which have the points marked manually.

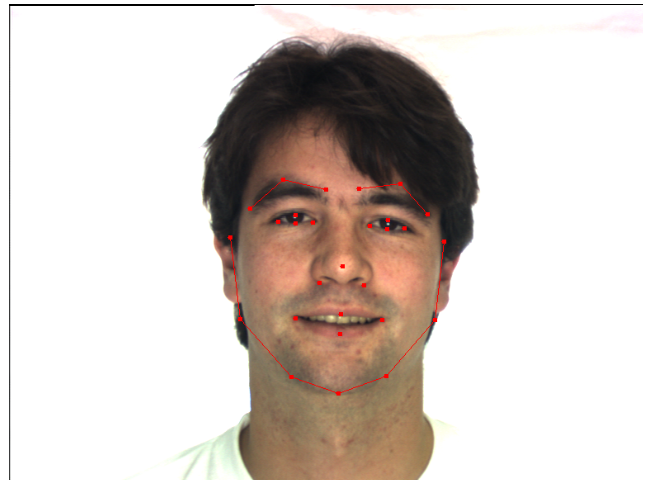


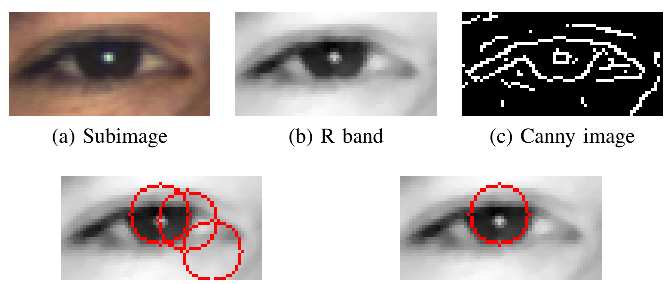
Fig. 1. Facial Landmarks

Once the facial landmarks are obtained (see Fig. 1), the eyes centers are calculated through the coordinates of the eyes corners. The middle point between corners is the eye center.

The eyes corners are used to estimate the iris center position. So, the eyes region is defined by using the eyes corners and a subimage is generated by cropping the image in the eyes region. The resulting image is normalized to a default size, thus setting all the iris radius to the same length (Fig. 2 (a)).

The resulting image is converted into gray. Then, a Canny edge detector is used to detect the iris. The iris will be successfully detected if it is strikingly contrasting with the sclera and the skin. Therefore, only the R channel from the RGB image is used [29]. Intending to improve the lighting conditions, the Log filter is applied to the image and later, a median filter also performed to reduce noise.

Assuming the darkest regions of the resulting image is in the iris, a global histogram operation is made in order to increase the contrast on the image (Fig. 2 (b)). The Canny filter is applied to the image (Fig. 2 (c)). and then, the Hough Circles Transform is used to find circles which correspond to an iris (Fig. 2 (d)). This is made easier by the previous normalization and the upper limit of circles that the algorithm must find. Choosing which one is the best option among the candidates circles to be used as the iris is made by selecting the one that has the highest quantity of dark pixels into it (Fig. 2 (e)). The iris detection full process is illustrated in the Fig. 2.



(a) Subimage (b) R band (c) Canny image

(d) Candidate Circles (e) Iris Detected

Fig. 2. Iris Detection Steps

B. Eyes State Detection

The eye can be classified as opened or closed. The proposed eyes state detection solution consists of merging two measures, the first measure (named as M_1), uses the information about the width and height of the eye, and the second measure, (named as M_2) is related to the presence of the sclera.

To compute M_1, the left eye region and the right eye region are detected by using previous knowledge about the face geometry. Each region is analyzed separately. The region is cropped from the image and is transformed into grayscale by using just the red channel of the RGB color system. A global binarization filter is applied to the gray image and the black pixels (eyelashes and iris) are clustered into continuous regions, discarding the small regions. The value of M_1 is then given by the Equation 1 and Equation 2.

$$M_1 = \min(r_i) | i = 1, 2, ..., N \tag{1}$$

$$r_i = \frac{(ah_i) + b(100 - (w_i - h_i))}{(ab)} \tag{2}$$

where:

- a and b are constants;
- h_i is the ratio of the height of the region i and the eye region height;
- w_i is the ratio of the width of the region i and the eye region width;
- N is the number os regions analyzed

The smaller the value of M_1, the more closed the eye is. The Fig. 3 demonstrates how this approach works in two different eye images.

(a) Closed image (b) Closed image Red (c) Closed threshold

(d) Open image (e) Open image Red (f) Open threshold

Fig. 3. Eyes closed x Eyes Oppenned

To compute M_2, the eye image is binarized aiming to segment the white regions which may be the sclera. If the sclera is detected, it means the eye is opened. M_2 is calculated by the quotient of the number of white pixels in the resulting image by the total number of pixels of the image.

Fig. 4 shows the process to calculate M_2.

(a) Eye image (b) Sclera image

Fig. 4. Eye sclera image

Finally, the score is calculated merging M_1 and M_2. The merging is given by the Equation 3.

$$score = M_1 - \alpha M_2 \tag{3}$$

where α is a constant value. The smaller the score is the more closed the eye is.

C. Red Eyes Detection

The proposed red eye detection method uses color information. Every single pixel is examined in the HSV and RGB color systems and marked as non-skin or red. Then, a score is defined by analysing the resulting data.

The pixels in the eye region of the input image are classified into skin or non-skin. This skin segmentation process is made by searching a skin-color region that can be identified by the presence of a certain set of chrominance (i.e., Cr and Cb) values narrowly and consistently distributed in the YCrCb color space. The ranges to Cb and Cr were proposed by Ngam *et al*[29]. The result of this process is a binary image, named as NS, which the white pixels represent the non-skin pixels.

The red pixels present into the eye region of the input image are detected by using two different methods. The first method analyzes the values of the HSV color system and the second one analyzes the values of the RGB color system. A pixel, in the first method, is marked as a red pixel if the following criteria are satisfied:

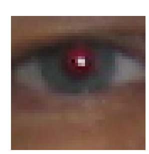
$$\begin{cases} (0 < H < 0.03 \cup 0.95 < H < 1) \\ S > 0.57 \\ V > 0.3 \end{cases} \tag{4}$$

where H, S and V denote, hue, saturation and value components, respectively. The result of the process is a binary image, named as Rhsv, which the red pixels are represented as the white pixels.

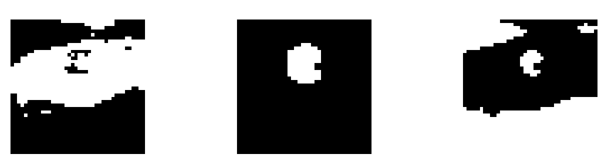
In the second approach to detect the red pixels, the Equation 5, presented by Held[30], is used to generate a redness map.

$$rednessRGB(x, y) = R - \min\{G, B\} \tag{5}$$

where R, G, and B denote red, green, and blue components, respectively. A bitwise operation is performed in the resulting redness map to mark which pixels are considered red, relting in a binary image (Rrgb). The process checks whether a pixel is greater the a threshold value, and then considered as red, or not. The foreground, white pixels, of Rrgb are the red pixels detected by this approach. The Fig. 5 shows the resulting NS, Rhsv and Rrgb generated from the input image.



(a) Input image



(b) NS (c) Rhsv (d) Rrgb

Fig. 5. Red eyes stages

The final result requires the computation os two different scores which will be merged later. The first score (s_1) is the quotient of white pixels by the total of pixels from the result of an AND operation performed between NS and Rhsv. Aiming to calculate the second score (s_2), it is made a bitwise AND operation between NS, Rhsv and Rrgb. Then, s_2 is calculated as the quotient of white pixels by the total number of pixels of the image.

Finally, the score which determines the compliance of the image to the requirement is defined by s_1 plus an additional value, if s_2 is greater than a threshold value, or simply as s_1 otherwise.

$$score = \begin{cases} s_1 + \alpha, & s_2 > t \\ s_1, & \text{otherwise} \end{cases} \tag{6}$$

The resulting images obtained in order to calculate s_1 and s_2 are shown in the Fig. 6.

(a) NS ∧ Rhsv

(b) NS ∧ Rhsv ∧ Rrgb

Fig. 6. Result to red eyes Detection

D. Looking Away Detection

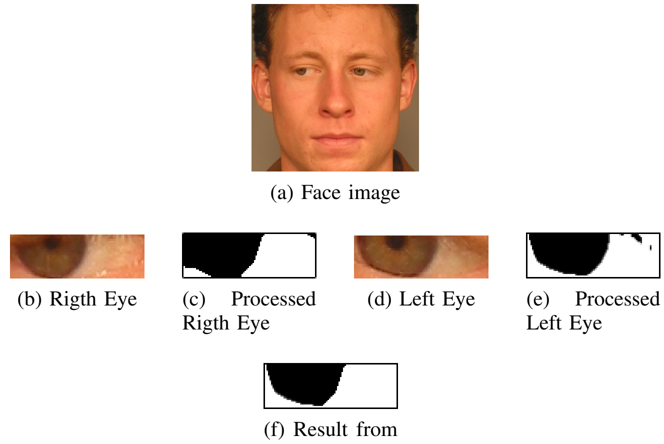
The proposed method to verify the looking away ISO/ICAO requirement assumes that if the subject is looking ahead then the pupil is in the center of the eye.

The proposed method uses the eye corner to define a bounding box centered in the eye center. Only the green channel of the RGB system is used and the region defined by the box is cropped from the image. Then, filters to correct the illumination and reduce noise are applied to the cropped image. The resulting images from both eyes are transformed to have the same size. Assuming that the eyes are symmetric, an OR operation is applied between left eye image and right eye image.

The resulting image is horizontally divided into two sub-images, Left and Right. Therefore, if the pupil is centered, Right and Left should have the same amount of white pixels. The score is calculated by the Equation 7.

$$score = \frac{\min(SumL, SumR)}{\max(SumL, SumR)} \tag{7}$$

where $SumL$ is the sum of white pixels in Left and $SumR$ is the sum of white pixels in Right. The Fig. 7 and Fig. 8 show the process in a image with the subject looking ahead and in a image with the subject looking away.



(a) Face image

(b) Rigth Eye

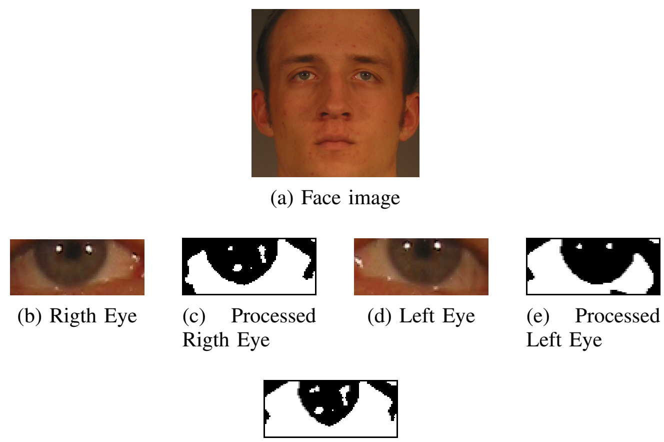
(c) Processed Rigth Eye

(d) Left Eye

(e) Processed Left Eye

(f) Result from OR Operation

Fig. 7. Looking away



(a) Face image

(b) Rigth Eye

(c) Processed Rigth Eye

(d) Left Eye

(e) Processed Left Eye

(f) Result from OR Operation

Fig. 8. Not looking away

V. Experiments and Results

When the image is processed, the degree of compliance is compared with a predefined threshold to decide if the image should be accepted or rejected. Two types of error can be made by the software for compliance verification:

1) *False Acceptance*: declaring compliant with respect to a given characteristic an image that is noncompliant;
2) *False Rejection*: declaring noncompliant an image that is compliant.

Starting from the distribution of the degrees of compliance, the equal error rate (EER) is calculated and used to evaluate the performance for each characteristic. The EER is defined as the error rate measured when false acceptance rate equals false rejection rate.

Some of the works cited in Section II did not have their results compared to the proposed methods results because they have a different scope of ours, which is the image validation for the usage in official documents.

The proposed methods were tested by using the BioLab-ICAO framework [3] to evaluate their performance. The results obtained by the proposed method were compared with two commercial SDKs (referred here as SDK1 and SDK2), whose name cannot be disclosed, and with the BioLabSDK (which was evaluated on through the same framework and have presented their results by Ferrara *et al.* [31]).The algorithm BioTest[32], developed by Biometrika srl, has been also compared.

Aiming to evaluate the accuracy of eye localization, the relative error measure based on the distances between the expected and the estimated eye positions introduced in [33] is calculated as:

$$d_{eye} = \frac{max(\left\|C_l - \hat{C_l}\right\|, \left\|C_r - \hat{C_r}\right\|)}{\|C_l - C_r\|} \quad (8)$$

where $C_{l/r}$ and $\hat{C_{l/r}}$ are the ground truth and the positions returned by the algorithm, respectively. This measure is scale independent and therefore it permits to compare data sets characterized by different resolution.

Table I presents the results of eye location accuracy. The column 'Reject' refers to the images not processed by an SDK. The result for SDK2 is not reported since it does not return the eye .position

TABLE I
EYE LOCATION ACCURACY

Algorithm	**Rejected**	$d_{eye} \in \lceil 0; 0.1 \lceil$	$d_{eye} \in \lceil 0.1; 0.2 \lceil$	$d_{eye} \geq 0.2$
BioTest	14,22%	77,08%	5,08%	3,62%
BioLabSDK	4,9%	83%	6,1%	6%
SDK1	6,3%	87,8%	1,3%	4,6%
Proposed Method	5,57%	88,73%	3,81%	1,89%

The results shown in in Table 1 demonstrate the proposed method is more accurate than the other evaluated SDKs. That is an impressive result, especially considering the characteristics of the BioLab-ICAO database (e.g., presence of hair across eyes, presence of glasses or frames too heavy) which makes this task even harder.

In Table II, the results obtained by the five SDKs on ICAO requirements tests (Eyes Closed, Red Eyes and Looking Away) are reported, by providing EER and rejection rate for each characteristic. In Table II, the information '-' means the SDK does not support the test for this characteristic.

The results obtained by the proposed approaches reach a good performance in the BioLab-ICAO Benchmark. The EER achieved by the methods which evaluate the compliance with red eyes and looking away requirements demonstrate their superiority over the other ones. The mark obtained by the algorithm which determines whether the eyes are closed or not has not overcome the results of only one method presented in the literature, SDK1.

TABLE II
EER AND REJECTION RATE OF THE FIVE SDKS EVALUATED

Characteristic	**Eyes Closed**		**Red Eyes**		**Looking Away**	
	EER	**Rej.**	**EER**	**Rej.**	**EER**	**Rej.**
SDK1	2.9%	3.1%	5.2%	4.5%	27,5%	7.1%
SDK2	-	-	34.2%	0.0%	-	-
BioLabSDK	4.6%	0.0%	7.4%	0.0%	20.6%	0.0%
BioTest	6.7%	7.1%	10.3%	8.4%	24.2%	3.1%
Proposed Method	3.8%	5.0%	4.0%	3.7%	16.9%	1.2%

VI. CONCLUSIONS

The development of an automatic system to determine if a facial image is in compliance with the ISO/ICAO norms has become a necessity. This work focused on the requirements related to the analysis of the eyes.

The proposed method for eye detection presented a satisfactory accuracy, presenting a low error in most of the cases. Furthermore, an analysis of the rejected images was made and it was identified that the mistakes occurred due the failure in the face detection or in the occlusion detection (sunglasses, hair across eyes etc.).

The detection of looking away is a hard task to be made by an automatic system. The poor results are related to the impossibility of correctly detecting the face region (e.g., for excessive head rotation or eyes not clearly visible) [31]. The introduced novel approach obtained better results than other methods presented in the literature, although presenting a relatively high EER. Some improvements may be considered in order to achieve a better result, like the usage of the position of the iris center and the eye corners.

The method introduced in this work to determine whether a facial image present red eyes or not obtained a result better than any other method in the literature. The main difficulties in to develop a solution to this problem were to establish whether the red pixel was skin or eye pixel and to deal with the different red tones on the eye generated by this effect.

The analysis of the results obtained through the BioLab-ICAO framework related to the eyes closed requirement shows the proposed method achieved results better than the most methods. The major obstacles to developing a solution to this problem were to deal with the light eyes and the similarity between eyebrows and eyelashes in a closed eye.

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