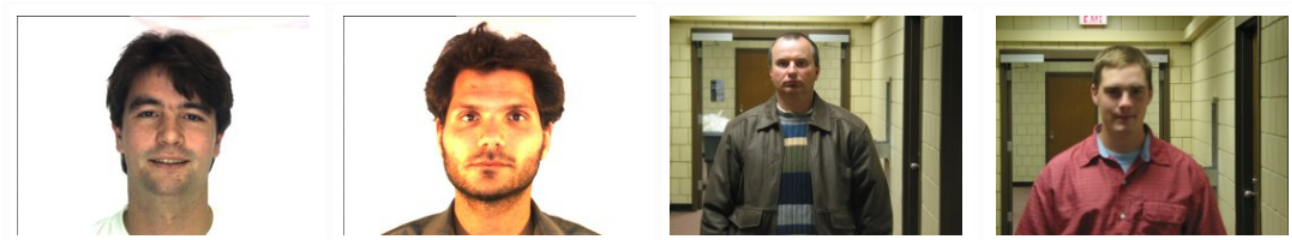
Facial Compliance for Travel Documents

Igor L. P. Andrezza, Erick V. C. L. Borges,
Rajiv A. T. Mota
VSoft Tecnologia
João Pessoa, PB, Brasil
{igor.andrezza, erick.borges, rajiv.mota}@vsoft.com.br

João Janduy B. Primo
Centro de Informática - CI
Universidade Federal de Campina Grande - UFCG
Campina Grande, PB, Brasil
joaojanduy@copin.ufcg.edu.br



(a) (b) (c) (d)

Fig. 1. Issues approached by the proposed methods. (a) Sample of a standard image. (b) Photo with unnatural skin tone. (c) Flash reflection on skin. (d) Shadows across face.

***Abstract*—Biometric characteristics allows to identify an individual based on who they are. This paper focuses on using the face of a subject in electronic identity documents. The International Civil Aviation Organization (ICAO) has endorsed the adoption of the face as the globally interoperable biometric characteristic. Soon afterwards, the International Standard Organization (ISO) proposed the ISO/IEC 19794-5 standard in accordance with ICAO directives. In this paper, a new approach for the evaluation of three ISO/ICAO requirements (unnatural skin tone, shadows across the face and flash reflection on skin) is presented. The results achieved by the proposed methods have overcome almost all the works in the literature. For the "shadows across the face" requirement, the proposed method obtained a result 41% better than the best result in the literature. The proposed method is able to keep the rejection rate equal to zero even when it does not achieve the best equal error rate.**

***Keywords*-Unnatural Skin Tone; Flash Reflection on Skin; Shadows Across Face; International Civil Aviation Organization (ICAO); ISO/IEC 19794-5.**

I. Introduction

The face represents the ideal biometric characteristic in many promising forensic and commercial applications (e.g., access control, video-surveillance, environment intelligence). Among the possible applications, this paper focuses on its choosing in electronic identity documents. In 2002, the International Civil Aviation Organization (ICAO) has endorsed the use of face recognition as the globally interoperable biometric characteristic for machine-assisted identity confirmation with machine readable travel documents [1]. Soon afterward, 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 requirements, photographic properties and digital image attributes of facial images. For instance, a face image should have a natural skin color and a uniform background to be included in an electronic passport. Actually, the number of requirements that need verification is very high, thus making the task of verifying the compliance of a face image to the ISO/ICAO standards quite complex. At present, this activity is performed in most cases by human experts, possibly with the support of an automated system. A complete automation of this task would provide great benefits in terms of ease and rapidity of the document issuing process; unfortunately, the experiments carried out in Ferrara *et al*. [3] and Maltoni *et al*. [4] clearly show that the performance of existing commercial products for automatic ISO/ICAO compliance verification is still unsatisfactory.

This work is framed into a project aimed at developing a Software Development Kit (SDK) to evaluate the compliance of an image to all the ISO/ICAO requirements, checking if the image is appropriate for usage in identification documents. In this paper, innovative approaches to the following three ISO/ICAO requirements are presented:

- *Unnatural Skin Tone*
- *Flash Reflection On Skin*
- *Shadows Across Face*

This paper is organized as follows. Section II reviews the related work; Section III presents the color spaces on which the algorithms are based; Section IV details the proposed methods; Section V presents and discusses the results; finally, Section VI presents the conclusions obtained from this work and lists the future work.

II. Related Work

This section briefly describes some works related to this paper.

A model-free feature based approach for face detection and tracking is presented by Ahlvers *et al*. [5] This approach is based on color space skin cluster, through the skin-like regions detection. In this work three skin clusters based on three different color spaces were presented: RGB skin cluster, YCbCr skin cluster and HSV skin cluster. In general, it is recommended to use one of the luma-independent skin clusters [6] [7].

Kukharev and Nowosielski [8] presented a face detection and recognition system. Skin-color information used in their face detection subsystem. The first step of the face detection subsystem is to identify whether the pixel is skin part of the skin or not. The skin segmentation is accomplished by analyzing the component H of HSV color space and the values of all channels of the YCbCr color system. The usage of two different algorithms for the skin segmentation task produced better results.

Li and Ngan [9] proposed a face segmentation algorithm based on facial salience map (FSM) for head-and-shoulder type video application. The first step of the algorithm is to define the areas with skin-color, that it is done by detecting the presence of a certain range of chrominance values with narrow consistent distribution in the YCbCr color space. The empirical ranges for the chrominance values employed in this work were found by investigating the skin-color distribution of manually segmented images. The data were taken from the California Institute of Technology face databases and CVL Face Database that are provided by the Computer Vision Laboratory [10], which contains 1248 color human faces.

Ferrara *et al*. [11] use the YCbCr skin cluster presented in [5] and define the compliance score for unnatural skin tone simply as the percentage of pixels with a natural skin tone in the bounding box which encloses the face (obtained from a face detection algorithm).

Ferrara *et al*. [12] presented a multi-classifier system based color and texture information for face image segmentation, classifying the regions in one of the following categories: background, face, hair and clothes. The authors also describe a method to evaluate the flash reflection on skin requirement. First, it is necessary to extract the saturation channel of the color space HSV and the red difference chroma channel of the color space YCbCr from the input image. The next step is to compute the difference between the saturation channel and the red difference channel. Then, the AND operator is applied to the difference image and the face region. The compliance score is defined as the percentage of black pixels in the resulting image with respect to the face area (number of white pixels in the face region). The algorithm was tested in a private dataset and provided an EER of 0.77%.

Chang and Tseng [13] proposed an auto-detection and inpainting technique to correct overexposed faces in digital photography. The bright spots are identified based on the statistical analysis of color brightness and filtering and then, they are corrected through inpainting technology.

A method to identify the presence of shadows across face is presented by Ferrara *et al*. [11]. The first step is to extract the Z channel (from the XYZ space color) and then binarize it. The compliance score is calculated as the percentage of nonzero pixels in the binarized Z channel of the face region.

III. Background

This section describes the concepts used to develop the proposed methods.

A. YCbCr color space

The orthogonal color spaces reduce the redundancy present in RGB color channels and represent the color with statistically independent components (as independent as possible) [14]. As the luminance and chrominance components are explicitly separated, these spaces are an advantageous choice for skin detection. In the YCbCr space, the Y value represents the luminance (or brightness) component, computed as a weighted sum of RGB values, the Cr and Cb values, also known as the color difference signals, represent the chrominance component of the image, they are computed by subtracting the luminance component from B and R values. The YCbCr space is one of the most popular choices for skin detection.

B. CIE XYZ color space

One of the first mathematically defined color spaces is the CIE XYZ color space (also known as CIE 1931 color space), created by the International Commission on Illumination in 1931. The CIE system is based on the description of color as a luminance component Y and two additional components X and Z. The spectral weighting curves of X and Z have been standardized by the CIE based on statistics from experiments involving human observers. The magnitudes of the XYZ components are proportional to physical energy, but their spectral composition corresponds to the color matching characteristics of human vision. The CIE model capitalizes on this fact by defining Y as luminance. Z is quasi-equal to blue stimulation, or the S cone response, and X is a mix (a linear combination) of cone response curves chosen to be nonnegative. Defining Y as luminance has the useful result that for any given Y value, the XZ plane will contain all possible chromaticities at that luminance [15] [16]. The conversion from the RGB color system to the XYZ color space is accomplished by the Equation 1.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

C. The Gray World assumption

One of the simplest and the most often used assumptions about the color constancy is the so-called Gray World Theory (GWT) proposed by Buchsbaum [17]: the majority of all visual scenes in the world can be integrated to the gray, i.e.

$R_{avg} = G_{avg} = B_{avg}$. The most direct solution for automatic correction of the white is to calculate the mean values for each color channel of the captured image and to use them to calculate the ratios between them [18]. The greater channel's average is most often used for a base:

$$
\begin{aligned}
Max_{avg} &= \max(R_{avg}, G_{avg}, B_{avg}) \\
corrR &= \frac{R_{avg}}{Max_{avg}} \\
corrG &= \frac{G_{avg}}{Max_{avg}} \\
corrB &= \frac{B_{avg}}{Max_{avg}}
\end{aligned} \tag{2}
$$

The obtained coefficients are used to correct the color values of the pixels in the image.

D. BioLab-ICAO framework

The BioLab-ICAO framework was developed aiming to provide a common benchmark for the evaluation of ICAO compliance verification algorithms to the scientific community through the website [19]. It consists of: 1) a set of requirements, directly derived from the ISO/ICAO standard; 2) a large database of face images and related ground truth data, produced by human experts with a manual labeling process; 3) a testing protocol for objective performance evaluation and comparison; 4) a set of baseline algorithms internally designed to evaluate the compliance to each defined requirement.

Evaluating automatic systems aimed to verify the compliance of face images to the ISO/ICAO standard requires a large database of images representing the many different possible defects defined by the ICAO requirements. To do so, it was used public databases. The database contains 1741 images from the AR database [20], 1935 images from the FRGC database [21], 291 images from the PUT database [22], 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 and needed for an objective performance evaluation [12].

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. The value 100 indicates that the image is compliant with that requirement and 0 means it is noncompliant. Sometimes an algorithm may fail in processing an image or in evaluating a specific characteristic of the image, therefore, a rejection occurs. If 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 kinds 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.

The BioLab-ICAO framework is available online[19] to evaluate any algorithm which aims to analyze the compliance of an image to the ICAO requirements. To do so, it is necessary to submit one executable file, in the form of Win32 a console application, to the online framework. The executable will take the input from command-line arguments and will append the output to a text file. For each ICAO requirement, the framework will calculate accuracy indicators, including the EER.

IV. Methods

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

A. Skin Segmentation

The skin region of the face image is necessary to evaluate some of the ISO/ICAO requirements. Therefore, an adapted skin segmentation method was developed.

The skin segmentation method demands the usage of color information in a fast, low-level region segmentation process to classify each pixel into skin and non-skin by analyzing the YCrCb color space. The first step is to apply the gray world filter to the input color image in order to solve the color constancy problem.

The resulting image is then transformed to the YCrCB color space. Denoting R_{cr} and R_{cb} as the ranges of Cr and Cb, respectively, to define the skin-color reference map. The ranges used in this work were proposed by Li and Ngan [9] and proved to be robust against different types of skin color. The segmentation requires only the chrominance component of the image because it uses only the color information.

Considering an input image of $M \times N$ pixels, the output of the skin segmentation process is described by the Equation 3.

$$
Skin(x,y) = \begin{cases} 1, & \text{if}[\text{Cr}(x,y) \in R_{\text{Cr}}] \cap [\text{Cb}(x,y) \in R_{\text{Cb}}] \\ 0, & \text{otherwise} \end{cases} \tag{3}
$$

where $x = 0, ..., M$ and $y = 0, ..., N$. The pixel at the position (x, y) is classified as skin if both the Cr and Cb values are into the range defined by R_{Cr} and R_{Cb}. Otherwise, the pixel is classified as non-skin. Fig. 2 illustrates the skin segmentation process on people with different skin tones; the white pixels represent the pixels defined as skin.

B. Unnatural Skin Tone

The first ISO/ICAO requirement addressed in this work has the goal of analyzing the skin tone of the face present in the input image and decide if the face image has an unnatural skin tone. An unnatural skin tone may be caused by the usage of an inappropriate lighting source.

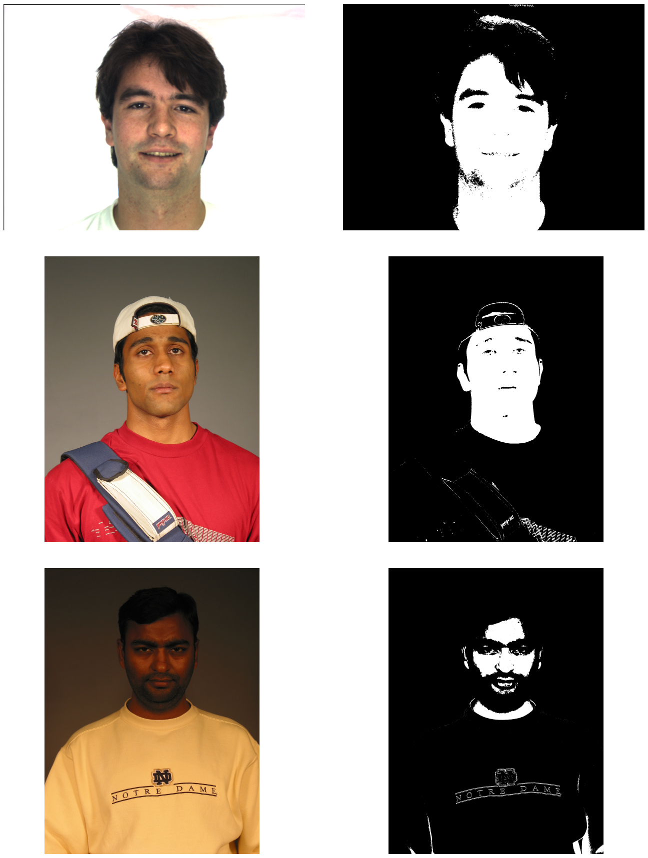


Fig. 2. Skin detection.

The strategy used to calculate the requirement was to identify how much of the skin has a natural tone. The computation of this strategy was defined as the rate of natural skin over the skin region on the face region previously detected.

A modified version of the method proposed by Ahlvers *et al*. was used for the purpose of detecting the natural skin region [5]. Two modifications were made in Alvhers's method in order to identify the natural skin tone region more precisely. The first modification was to apply the histogram expansion filter in the input image and the second one was to define a more restrictive range for the Y channel - the range 70 to 180 was used instead of the values greater than 80 because it allows to discard regions under incorrect illumination.

(a) Face region image (b) Skin (c) Natural Skin

Fig. 3. Images of the process in a image with unnatural skin tone.

Aiming to analyze only the region previously segmented as skin, an AND operation is performed between the resulting image of the skin segmentation and the natural skin tone detector.

The computation of the score for this ISO/ICAO constraint is defined by the Equation 4.

$$score = \frac{\sum_{j=1}^{h}\sum_{i=1}^{w}(Nat \wedge Skin)(i,j)}{\sum_{j=1}^{h}\sum_{i=1}^{w}Skin(i,j)} \tag{4}$$

Where:

- h is the height of the face region;
- w is the width of the face region;
- *Skin* is the result of the skin detection on the face image;
- *Nat* is the result of the natural skin detection on the face image.

It is important to notice that the higher is the obtained score value the more compliant is the image with the requirement.

Fig. 3 and Fig. 4 show different resulting images obtained from the skin segmentation and natural skin tone detector. While Fig. 4 is in compliance with the requirement, Fig. 3 is not.

(a) Face region image (b) Skin (c) Natural Skin

Fig. 4. Images of the process in a image with natural skin tone.

C. Flash reflection on Skin

The second ISO/ICAO requirement addressed in this work has the goal of verifying the presence of flash reflection on the skin of the face image. An image compliant with this requirement does not present flash reflection on the skin.

A method based on the work of Chang and Tseng [13], which detects bright spots, was developed to detect the presence of flash reflection on the skin. The method works as follows: the values in the Y channel of the YCbCr color system are used to detect gray-scale brightness in the image with the purpose of establishing a threshold value, defined as $alpha$. The value of $alpha$ is defined by the Equation 5.

$$\alpha = 0.8 \cdot (\max(Y) - \min(Y)) \tag{5}$$

If the brightness of a pixel p is less than α, it is not a target bright spot. However, if it is greater than α, it is necessary to confirm whether it is labeled as a skin pixel by the skin segmentation algorithm; and if it is, the pixel p is considered a target bright spot.

After detecting the bright spots, the score for the flash reflection on skin is obtained by the ratio between the number of pixels marked as bright spot and the number of pixels of the image. This score is calculated by the following Equations 6 and 7.

$$score = \frac{\sum_{j=1}^{h}\sum_{i=1}^{w} SpotArea(i,j)}{w \cdot h} \quad (6)$$

$$SpotArea(i,j) = \begin{cases} 1, & \text{if pixel}(i,j) \text{ is a bright spot} \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

Where:

- *h* is the height of the face image;
- *w* is the width of the face image;
- *SpotArea* is the image resulted from bright spots detection algorithm.

The results of the detection of bright spots on facial images are shown in the Fig. 5. The white regions represent the flash reflections areas on the face.

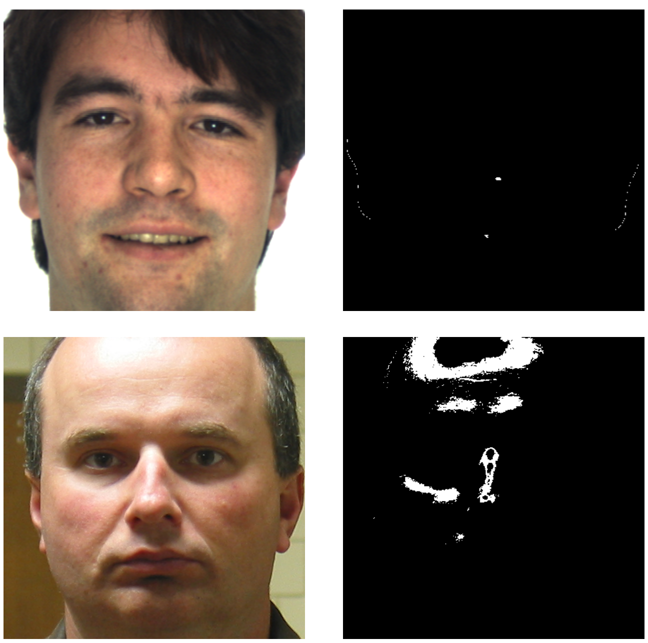


Fig. 5. Results from the bright spots detection.

It is important to realize that the bigger is the flash region detected the higher is the result of the Equation 6. Therefore, it is necessary to use the complementary value of it to be evaluated by the BioLab-ICAO framework.

D. Shadows across face

The third and last ISO/ICAO requirement addressed in this work has the goal of verifying the presence of shadows across the face image.

It is known that the Z channel from the XYZ color space can be used to detect shadows on a face image [12]. Based on this information, the developed method works as follows: given an input colored image, a RGB to XYZ conversion is applied on its face region. Then, the Z channel of the resulting image is binarized using a thresholding filter. The result of the binarization is called Z_{bin}. The shadow detection is easily noted in Zbin (see Fig. 6).

The score of this requirement is obtained as the quantity of skin pixels marked as non-shadow-pixel. This computation is defined in the Equation 8.

$$score = \frac{\sum_{j=1}^{h}\sum_{i=1}^{w} (Z_{bin} \wedge Skin)(i,j)}{\sum_{j=1}^{h}\sum_{i=1}^{w} Skin(i,j)} \quad (8)$$

where:

- *h* is height of the image;
- *w* is the width of the image;
- *Skin* is the result of the skin detection on the face image.

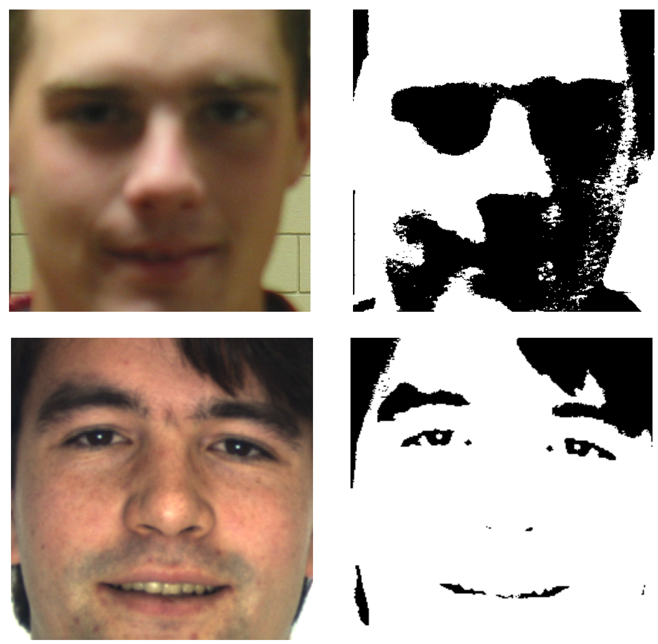


Fig. 6. Results of the binarization of the Z channel from the XYZ color system.

The resulting score of the Equation 8 indicates the compliance degree of the facial image to this requirement. The lower is the score, the lower the presence of shadows on the face.

V. Experiments and Results

The proposed methods were tested by using the BioLab-ICAO framework [4] to evaluate their performance. Two commercial SDKs (referred here as SDK1 and SDK2), whose names cannot be disclosed, and the BioLabSDK were evaluated on the same framework and have their results presented

TABLE I
EER AND REJECTION RATE OF THE FIVE SDKS EVALUATED

Characteristic	Unnatural Skin Tone		Flash Reflection on Skin		Shadows Across Face	
	EER	**Rej.**	**EER**	**Rej.**	**EER**	**Rej.**
SDK1	18,7%	4,8%	5,0%	2,7%	36,4%	8,1%
SDK2	50,0%	0,8%	50,0%	7,5%	-	-
BioLabSDK	4,0%	0,2%	0,6%	0,0%	13,1%	0,4%
BioTest	5,1%	1,7%	1,2%	0,4%	15,9%	19,8%
Proposed Method	3,7%	0,0%	1,3%	0,0%	7,7%	2,5%

by Ferrara *et al*. [11]. The algorithm BioTest, developed by Biometrika Srl, has been also evaluated [23] by BioLab-ICAO framework.

Some of the works cited in Section II did not have their results compared to the proposed methods because they have a different scope rather than image validation for usage in official documents. This characteristic prevents the comparative with those works.

Table I presents the ERR obtained by the works cited above and the proposed methods in this work. The column 'Reject' refers to the images not processed by an SDK. The information '-' means the SDK does not support the test for this characteristic.

The results obtained by the proposed method for verifying the unnatural skin tone compliance have overcome the results obtained by the other methods and it is the only one to present a rejection rate equal to zero.

The EER obtained by the proposed method for calculating the compliance for the flash reflection on skin was better than the commercial SDks, although it presented a worse result when compared to the other ones. Nevertheless, the rejection rate was equals to zero, a result that the BioTest SDK was not able to achieve.

Evaluating the shadows across face compliance is known to be a hard task [11] to an automatic system solve. None of the methods found in the literature was capable of achieving a result which the EER is under 10%. In this context, the proposed method was able to overcome all the other SDKs, achieve an EER equal to 7,7% and to have a low rejection rate of 2,5%.

VI. CONCLUSIONS

A facial image is required to be compliant with a set of requirements defined by the ISO/IEC 19794-5, in accordance with ICAO directives, to be included on official documents. The number of requirements to verify is very high, so, the development of an automatic system to determine if a facial image is in compliance with the ISO/ICAO requirements is needed.

This work presents novel methods to calculate the compliance of an image to three ICAO requirements, using a skin segmentation algorithm as a pre-processing step in all methods. The proposed method for verifying the presence of unnatural skin tone has obtained a better result than any other method presented in the literature and did it with a rejection rate equal to zero, making it the only method capable of having such result.

The analysis of the proposed method for verifying the presence of flash reflection on skin shows that the proposed method is as accurate as the best methods found in the literature. An important goal reached by this method is to produce a good performance with a rejection rate equal to zero, a goal achieved just by BioLabSDK.

The last proposed method aims to detect the presence of shadows over the face. This method has obtained an EER 41% lower than the best result found in the literature, an excellent result for such difficult task. Future work will concentrate in researching to reach a rejection near or equal to zero keeping the EER as accurate as it is presented in this work.

As a future work, it would be interesting to analyze the correlation between the impact of the skin segmentation on the performance of the proposed methods and to have an experiment comparing the running time experiment between the analyzed methods.

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