International Journal of Control and Automation
Vol. 11, No. 5 (2018), pp.59-72
http//dx.doi.org/10.14257/ijca.2018.11.5.06

Eye Detection based on Viola & Jones Detector, Skin Color, and Eye Template

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Abstract

In this paper, we propose a new method of eye detection based on Viola & Jones detector, skin color and eye template. Our method is processed into three steps: In the first step, faces are detected by using the Viola & Jones detector. In the second step, face images are segmented into skin regions and non-skin regions with a threshold calculated by a combination of rules proposed on elements of the three color spaces RGB, HSV and YCbCr. The third step is the matching of an eye template with non-skin regions. Our method is tested on the FEI database available online, as well as a set of personal images and other from the Internet. The obtained results are satisfactory in terms of the quality of detection and rapidity.

Keywords: *eye detection, face detection, skin color, Viola-Jones detector, eye template*

1. Introduction

Eyes detection is a very interesting field of research that verifies the presence of eyes and locates their positions in an image. Similarly, it is often the first step in such applications such as face recognition [1,2], video surveillance [3,4], facial expression recognition [5,6], age estimation [7], gaze tracking systems [8,9], and driver fatigue monitoring systems [10-13].

However, eyes detection is a difficult task because of the computation time, the lighting conditions and the presence or absence of structural components such as glasses. To overcome these problems, various techniques have been developed in recent years and can be divided into four categories [14,15]: Template-matching methods, feature-based methods, appearance-based methods, and hybrid methods. In template-matching methods [16,17], an eye template is constructed and then compared with the different regions of the image to determine those that are the eyes. These methods are easy and quick, but they cannot be treated with eye variations in the scale, expression, rotation and lighting. The feature-based methods [18-20] explore the characteristics of the eye such as shape, intensity or gradient information. Although these methods are generally effective, they lack precision in the images with low illumination. In appearance-based methods [21-26], eyes are detected on the basis of their appearance photometric. These methods treat the detection of eye as a classification problem (eye/non-eye). The classification is performed by using a set

Received (November 27, 2017), Review Result (March 22, 2018), Accepted (April 1, 2018)

ISSN: 2005-4297 IJCA

of learning images and by using learning algorithms such as Neural Networks, AdaBoost algorithm, and Support Vector Machine (SVM). These algorithms require a large number of training data to enumerate all the possible eyes appearances. Hybrid methods [27-34] combine several methods to exploit their advantages and to avoid their disadvantages.

In this article, we present an efficient eye detection method. It is based on the Viola-Jones method and the skin color. Our technique involves three steps: in the first one, faces are detected using the Viola & Jones detector. In the second step, face images are segmented into skin regions and non-skin regions with a threshold calculated by a combination of rules proposed on elements of the three color spaces RGB, HSV and YCbCr. In the third step, the eyes are detected by matching of eye template with non-skin regions.

The different steps of our eyes detection method are presented in Figure 1 below.

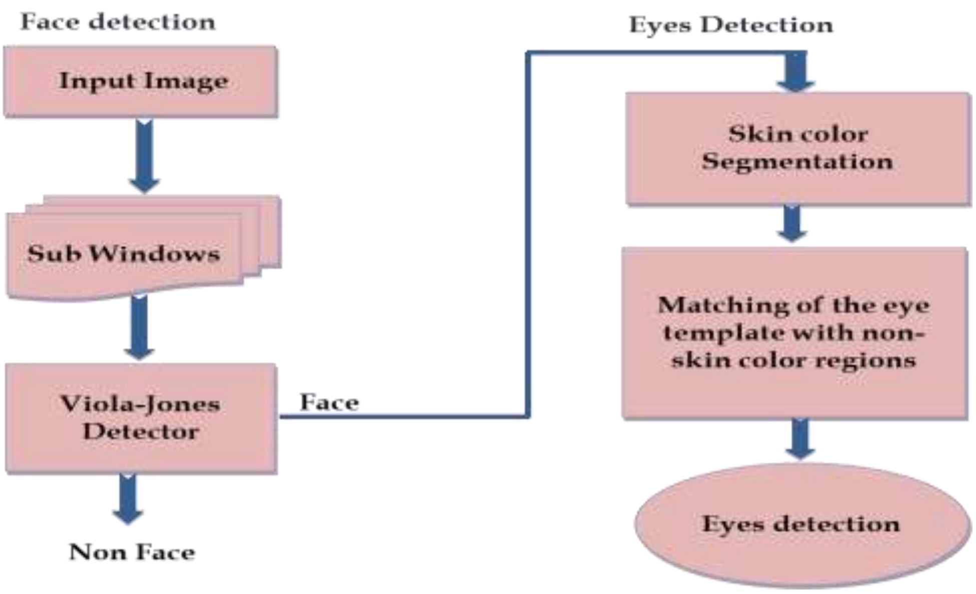


Figure 1. Diagram of Eyes Detection by our Method

The rest of this paper is organized as follows. In the second part, we provide a brief overview of the related word of the eyes detection. In the third and the fourth part, we dwell on our approach and its experimental results. The last part is devoted to the conclusion.

2. Related Work

In recent decades, several eye detection methods are proposed and can be classified into four categories: Template-matching methods, feature-based methods, appearance-based methods, and hybrid methods.

Template-matching methods [16,17]: Among the eye detection methods based on template matching, there is the method proposed by F. Rehab *et al.*, [17] uses a deformable template (the template size and the rotation angle are adjusted to find the search area that best fits the reference template) and a matching algorithm based on the normalized cross-correlation coefficient (NCC) and particle swarm optimization (PSO).

Feature-based methods [18-20]: The method of eye detection presented by Jiatao Song *et al.*, [18] starts with: Extracting the edge binary images from the grayscale image based on a multi-resolution wavelet transformation, extracting regions and eye segments from the binary image, and the location of the eye using light points and intensity information. Lilipta Kumar Bhatta, *et al.*, [19] propose an approach to extract facial features (the eyes, the nose, and the mouth) which takes place in three steps. First, the faces are detected by the Sobel edge detector, and the intensity values of the edges. Then, in the detected faces, the skin regions are extracted in the YCbCr space. Then, the left eye is located in the left part of the skin color image considering that the point with minimum intensity value is as position of the left eye. The right eye is automatically on the same distance from the center due to the symmetry. Muhammad Affan Zia *et al.*, [20] introduce an eye detection approach that takes place in two steps: the first step is to detect the faces in the image by segmenting the skin color in the Lab color space. The next step is to locate the eyes in the facial area by using the circular Hough transformation.

Appearance-based methods [21-26]: Many appearance-based approaches are proposed. For example, Riti Sharma et al. [22] develop an eye detection method that uses the histogram of oriented gradients (HOG) for reducing the size of the image and the SVM for classification. Vijayalaxmi *et al.*, [23] perform the detection of eyes using a neural network and a Gabor filter. The proposed algorithm is divided into two phases: training and detection. In the training phase a set of images of the eyes and non-eyes are used to form the neural network, and in the detection phase, the eyes are detected using the formed network. Peng Wang *et al.*, [25] present an eye detection method based on the AdaBoost algorithm, new rectangular features and geometric features. This article uses the rectangular features proposed by Viola-Jones [35] and adds other features to build a cascade classifier for eye detection. Then the symmetry characteristic of both eyes, and some geometric features are adopted to correct the detection errors obtained by the cascade classifier (the eyebrows, the mouth, the eyes big or small).

Hybrid methods [27-34] that combine between several techniques to exploit their advantages and avoid their disadvantages. More articles are cited: S. El Kaddouhi *et al.*, [28], propose a new method for detecting faces and eyes. It is based on the skin color, face shape and corners points of Harris. In this method, faces are detected by the segmentation of the skin areas and by using the shape operations (surface, ratio, eccentricity). Then, the eyes are located by matching of an eye template with a small area determined by clustering of neighboring corners points. Mingxin YU *et al.*, [29] present an eye detection technique based on the grayscale variance filter and the support vector machine. The variance filter is used to eliminate most images from non-eye regions to keep fewer eye candidate regions. Then the precise location of the regions of both eyes is determined by the SVM classifier. M. Hassaballah, *et al.*, [31] suggest an eye detection method based on gray intensity variance and independent component analysis. First, the face area is located by the face detector boosted cascade. Then the top half of the face is divided into a large number of overlapping windows and applying a variance filter to select between these windows those candidate eyes. Then all the selected windows are checked using the independent component analysis to select only two windows that are the windows of the right and left eyes. The method of detection and localization of the eyes centers presented by Zhaocui Han, *et al.*, [32] use the method of Viola and Jones to detect the faces in an acquired image. Then extract the area combining the eye and the neighboring eyebrow using the Haar features. Then locate the eyes by integrating the gradient distribution features, and curvelet features, and using the principal component analysis.

3. Our Method

Our suggested method for eye detection contains three algorithms. The first algorithm involves using a simple and effective method for face detection which is based on the Viola & Jones detector. In the second step, face images are segmented into skin regions and non-skin regions with a threshold calculated by a combination of rules proposed on elements of the three-color spaces RGB, HSV and YCbCr. In the third step, the eyes are detected by the matching of an eye template with the non-skin regions.

3.1. Face Detection by Viola & Jones Detector

In the proposed method, the Viola-Jones detector [35] are chosen as a face detection algorithm, because of its high detection rate, and its ability to run in real time. This detector is comprised of three main concepts: Employing rectangular Haar-like features (see Figure 2 (a)) and a learning method based on Adaboost, (see Figure 2 (b)) and the attention cascade structure (see Figure 2 (c)).

In the Viola-Jones method there are two essential phases:

- **The Learning Phase:**

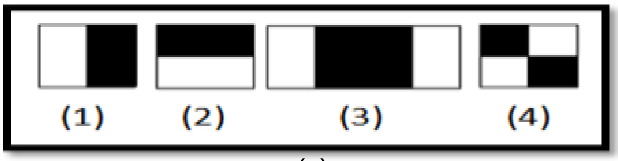
The learning is done on a very large set of positive (face) and negative (non-face) images. Many thousands of examples are usually needed. This learning includes:

- Calculation of Haar-like features on the positive and negative examples;
- Construction of weak classifiers
- Formation of the cascade: In each stage of the cascade, a strong classifier is formed by the combination of several weak classifiers.

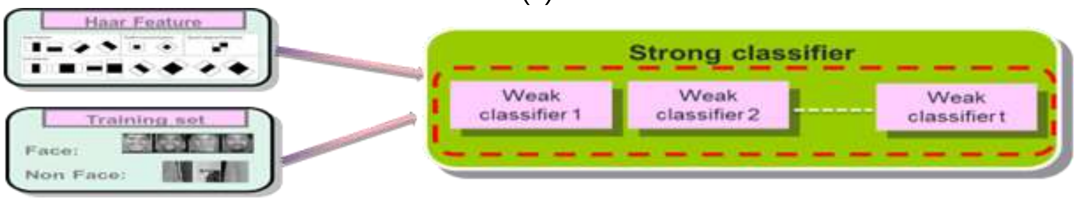
- **The Detection Phase:**

The detection is applied to a test image, in which it is desired to detect the face. There are two steps:

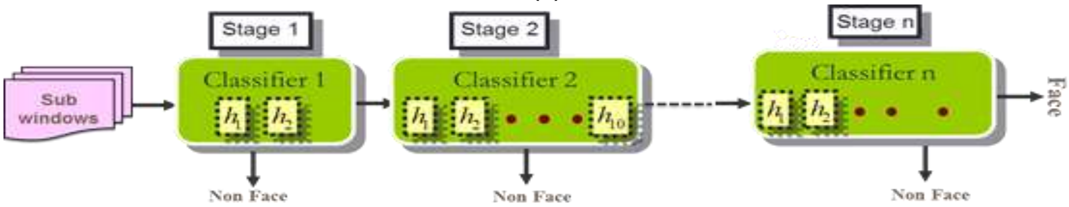
1. scan the image with an initial window of size 24 × 24 pixels (then increase by a factor of 1.25), and application of the cascade to each sub-window, starting with the first stage of cascade:
   - The calculation of the Haar-like features on the sub-window;
   - The calculation of the response of the strong classifier of the current stage,
   - If the answer is positive, passed at the following stage, else passed at the next sub window.
   - Finally, the sub window is declared positive if all stages responds positively;
2. Merge overlapping multiple detections to return only one result.



(a)



(b)



(c)

Figure 2. Components of the Viol-Jones Detector. (a): Examples of Haar like Features. (b): Training of Classifiers by AdaBoost Algorithm. (c): Cascade of Classifiers

Figure 3 illustrates some results of face detection in different situations.

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

Figure 3. Face Detection Performed by our Method: Frontal Face (a), Frontal Face with Glasses (b), Profile Face (c), Image with Low Lighting (d), Face with Smile (e)

3.2. Determination of Non-Skin Regions

Generally, the human face contains skin regions and non-skin regions (eyes, mouth, beard, eyebrows). Thus, the detection of the non-skin regions in the faces make it possible to determine regions with a high probability of being eyes. Otherwise, to determine the non-skin areas, we follow the following steps:

3.2.1. Choice of Color Space

Several studies have shown that the variability of skin color was more than the difference in intensity rather than chrominance. However, the most suitable color spaces for segmenting skin regions are those separating luminance from chrominance [36]. Among these spaces we used rgb normalized, HSV and YCbCr.

3.2.2. Rules Defining the Skin Regions

Several rules are used to determine regions with skin color, but the rules that give the best results are those used in [28] (see Table 1):

Table 1. Rules Defining the Skin Regions

Space	Rules	
Normalized rgb	A	$0.45 \leq r \leq 0.7$
	B	$0.23 \leq g \leq 0.55$
YCbCr	C	$77 \leq Cr \leq 127$
	D	$133 \leq Cb \leq 173$
HSV	E	$0 \leq H \leq 0.2$
	F	$0.2 \leq S \leq 0.7$

3.2.3. Face Image Segmentation

The segmentation of images into skin and non-skin regions is done by using previously defined rules. It is performed using a threshold calculated by the combination of the rules proposed in Table 1. These rules are combined as follows:

$$\big((A)AND(B)\big)OR\big((C)AND(D)\big)OR\big((E)AND(F)\big) \quad (1)$$

Figure 4 shows segmentation of images into skin and non-skin regions.

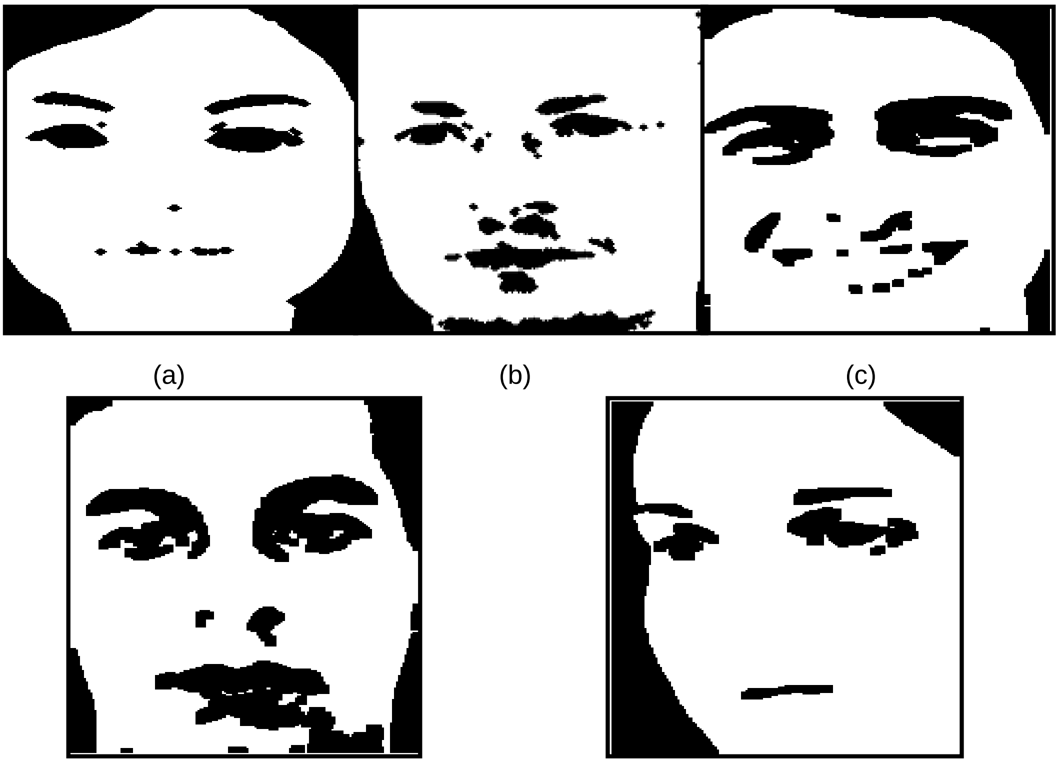


Figure 4. Segmentation of Face Images into Skin and Non-Skin Regions: Frontal Face (a), Frontal Face with Glasses (b), Face with Smile (c), Image with Low Lighting (d), Profile Face (e)

3.2.4. Determination of Non-Skin Regions

In the image obtained after the segmentation, we see that there are two types of regions: white regions that represent the areas of the skin, and black regions that represent the non-skin areas. Each of non-skin areas is likely to be an eye. Thus, the location of these regions can determine areas likely to be eyes as shown in Figure 5 below.

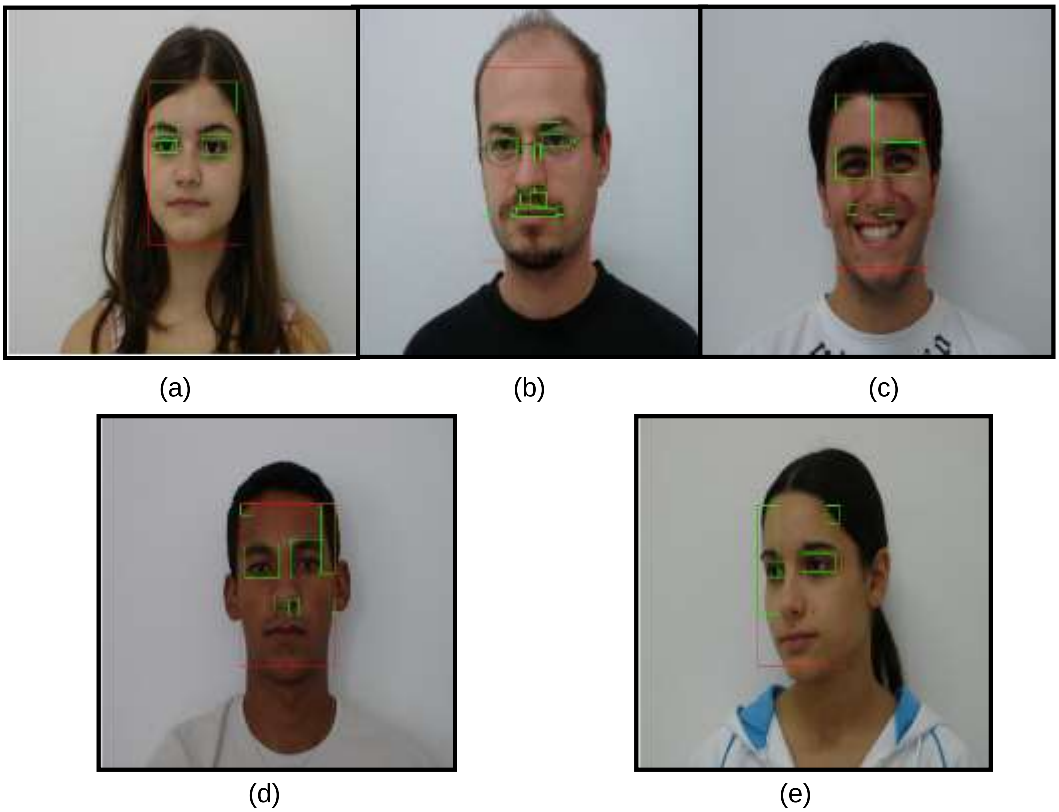


Figure 5. Determination of Non-Skin Regions: Frontal Face (a), Frontal Face with Glasses (b), Face with Smile (c), Image with Low Lighting (d), Profile Face (e)

3.3. Eye Detection by Template Matching Method

After getting the non-skin regions, an eye template (**T**) is created by the average of a set of eyes images of several people taken from the FEI database. Then the correlation between this template and the different non-skin regions is calculated by using the normalized cross-correlation function (**NCC**) defined by the formula 2 [17].

$$NCC(x,y) = \frac{\sum_{x,y} \delta_{I(x,y)}\, \delta_{T(x-u,y-v)}}{\left\{\sum_{x,y} {\delta_{I(x,y)}}^2 \sum_{x,y} {\delta_{T(x-u,y-v)}}^2\right\}^{0.5}} \qquad (2)$$

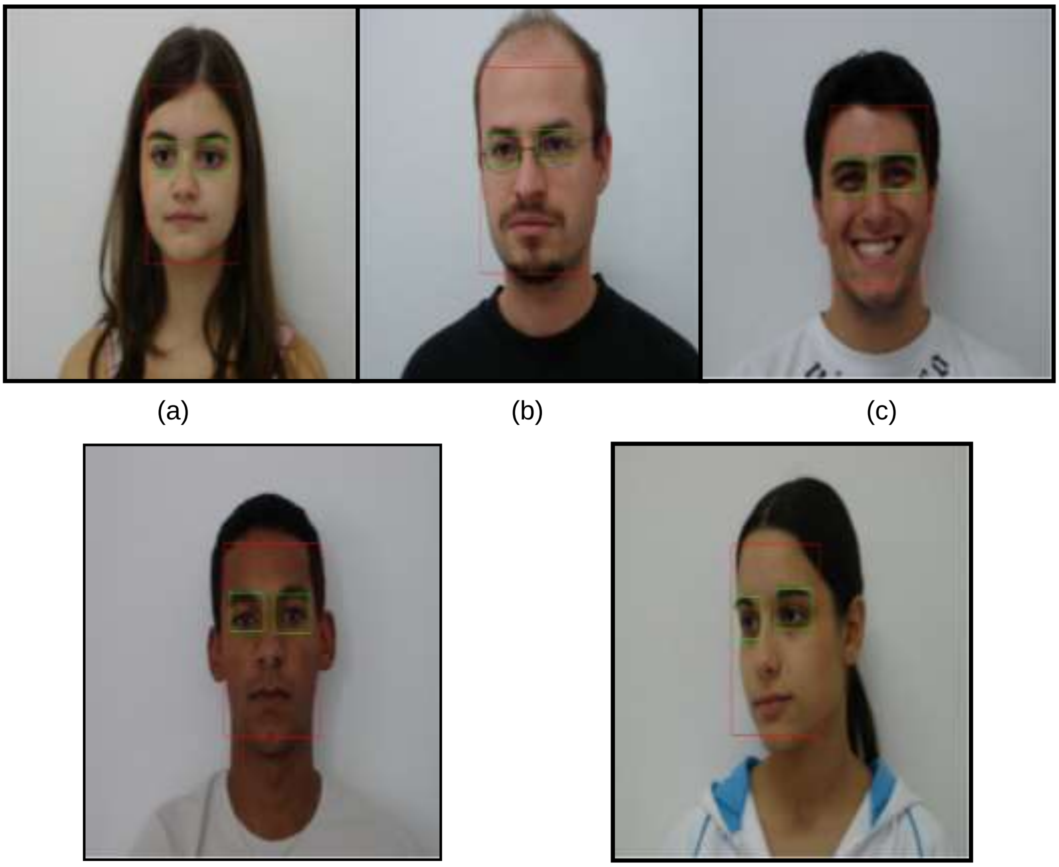
Where:
$u \in \{1,2,3,\ldots,p\}$,
$v \in \{1,2,3,\ldots,q\}$
$x \in \{1,2,3,\ldots,m-p+1\}$,
$y \in \{1,2,3,\ldots,q-n+1\}$
$\delta_{I(x,y)} = I(x,y) - \overline{I_{u,v}}$
$\delta_{T(x-u,y-v)} = T(x-u,y-v) - \overline{T}$

$$\overline{I_{u,v}} = \frac{1}{pq}\sum_{uv} I(x,y)$$

$$\overline{T} = \frac{1}{pq}\sum_{uv} T(x-u, y-v)$$

I is the input image
T is a template
m and n are the sizes of image.
p and q are the sizes of template.

Figure 6 shows the detection of the eyes by our method. The red rectangles represent the detected face, and the green rectangles represent the detected eyes.



(a) (b) (c)

(d) (e)

Figure 6. Face and Eye Detection by our Method: Frontal Face (a), Frontal Face with Glasses (b), Face with Smile (c), Image with Low Lighting (d), Profile Face (e)

We observe that the proposed approach allows to detect the eyes in the color images for the frontal faces (a), the faces with glasses (b), the faces with smile (c), image with low lighting (d), and the profiles faces (e).

4. Experimental Results

To evaluate the performance of our method and compare it with the other methods of eye detection, we used the FEI database [37], a set of additional personal pictures and other issues of Internet. The evaluation is based on two indicators: the correct detection rate (the number of correctly detected eyes over the total number of eyes), and the false detection rate (the number of false detected eyes over the number of detections).

4.1. Simulation (Dataset)

We tested our method on the FEI database [37] available online. It contains a set of images of 200 people taken in 14 different situations (lighting, pose ...). We tested our method in 2800 images; each image contains a single face. This test gives very important results (Table 2). Indeed, for all the images, we obtained a correct detection rate exceeds 96% and a false detection rate approximately 2%.

Table 2. Eye Detection Results Obtained using our Approach

Characteristics of the database FEI [37]			Eye detection with our method			
Images	Number of images	Number of eyes	Number of correct detection		Number of false detection	
Frontal	1400	2800	2761	98,60%	19	0,68%
Profile	800	1171	1109	94,70%	81	6,80%
Dark lighting	400	762	694	91,07%	13	1,83%
facial expression (smile)	200	400	392	98,00%	5	1,25%
Occultation (glasses)	66	115	109	94,78%	8	6,83%
Total	**2800**	**5133**	**4956**	**96,55%**	**118**	**2,32%**

For frontal faces under standard conditions of lighting, and in the absence of occlusions (glasses), our method achieved a correct detection rate exceeding 98% and a false detection rate less than 1%. Our technique is able to detect the eyes in the images with a weak variation of lighting. But it fails when there is a strong variation of lighting, which justifies the decrease of the rate of true detection in the case of the dark images. For profile faces and in the presence of glasses, our approach achieved a satisfactory result. We obtained a correct detection rate more than 94%, and a false detection rate less than 6%. The presence of the facial expressions does not affect the quality of our approach, because we obtained a correct detection rate higher than 97%, and a low false detection rate.

To illustrate the detection of the eyes in the presence of the various factors that disturb the detection process, we present in Figure 7 some example of results obtained. We see that our method can detect eyes with precision, even for profile faces (a1 and a2) faces with smile (b1 and b2), face with glasses (c1 and c2), and dark images (d1 and d2).

(a1) (a2) (b1) (b2)

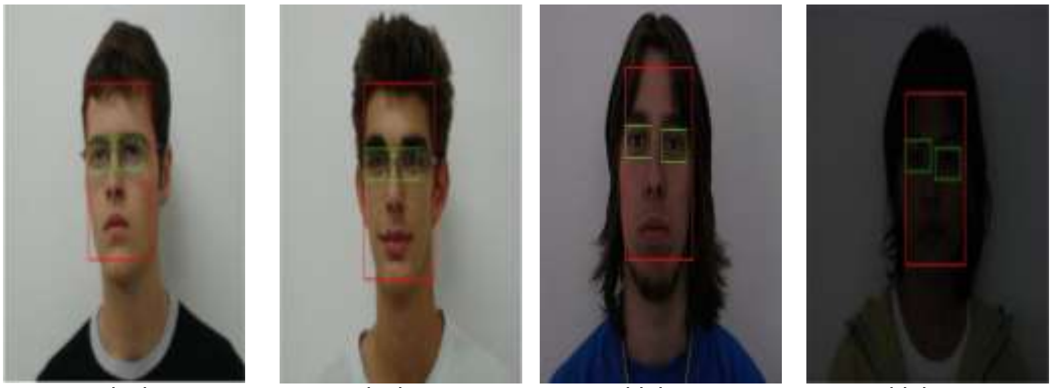

(c1) (c2) (d1) (d2)

Figure 7. Eye Detection in the Presence of Various Constraints : a1 and a2 : Profile Face. b1 and b2 : Face with Smile. c1 and c2 : Face with Glassses. d1 and d2 Dark Images

4.2. Comparison

To confirm and demonstrate the quality of our approach, we compared our results with those of three other eye detection methods recently published in the field and using the same database (FEI). The results obtained are shown in Table 3.

Table 3. Results of Eyes Detection Obtained with our Method and Compared to Those in the Literature

	correct detection rate
Our method	**96,55%**
L.K.Bhatta et al. [19]	96,5%
S.E.Kaddouhi et al. [28]	95,86%
Mingxin YU et al. [29]	95,2%

Table 3 shows the correct detection rate obtained with our method compared with that obtained with the other. We see that our method gives satisfactory results compared to other approaches. It gives a better rate than all other methods.

4.3. Real Data

To show the quality of our algorithm in the case of complex images, we tested our method on 50 images containing 336 eyes. These images are complex with body parts, several people and backgrounds can disrupt the process of detection. We obtained very important results (Table 4). We have detected 310 eyes and 31 false detections. We achieved a correct detection rate greater than 92%, compared to the false detection rate remains low (9.09%).

Table 4. Eye Detection Results Obtained

Number total of eyes	Number of eyes detected		Number of false eyes	
336	310	92.26%	31	9.09%

To show the quality of our method, we have shown in Table 5, the results of the four selected images from 50 images used to test our method and that are characterized by complex background and contains face the profile.

Table 5. Steps of Detection by our Method on Complex Images

Input Image	Face Detection	Face and Eye Detection
		
		
		
		

5. Conclusion

In this paper, we presented an eye detection method based on the Viola-Jones detector, the skin color and the application of an eye template. Under all conditions of pose, expression or the presence of occultation, our method provides perfect eye detection. The results obtained show that this technique has many advantages in terms of the quality and the speed of the detection.

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