Real-Time Video-Based Eye Blink Detection

Gheis Mohammadi, Abdolhossein Sarrafzadeh, Jamshid Shanbehzadeh

Abstract— **Eye is an important part of the human body and, it plays a fundamental role in vision based human-computer (HCI) interaction technology. Eye blinking is a major feature in HCI and, its application in such systems has been increasingly grown. This paper presents an adaptive blink detection algorithm. The advantages of this algorithm are simplicity, accuracy, very low computational cost and robustness against lighting conditions. This algorithm is based on very simple image processing techniques. The first step of blink detection method is eye detection. To accomplish this, we suppose that a fairly large face image is available. Each frame of the input video is processed and the location of eye is found. The next step calculates a value to determine the state of eye and then by analyzing it, eye blink is detected. The accuracy of our method is tested by providing a data set of several people and comparing the results to some existing methods. The experimental results show that the proposed method has 94.45% detection accuracy with overall accuracy of 99.84%. The average blink detection time for a sample is less than 0.1ms which is suitable for real-time applications.**

Keywords— **Blink detection, Real time eye analysis, Video based detection method, Simple image processing technique, Low resolution web camera**

I. INTRODUCTION

Eye blink detection (EBD) is one of the important problems in computer vision. Some of its applications are physiological or psychological conditions of human disease [1] and, fatigue analysis [2] [3] , cognitive effort [4] , lie detection because of anxiety [5] and analysis of gender, age, kind of activity, ambient characteristics, and time [6] [7] [8] [9] [10] [11] [12] [13] [14] [15]. For most blink-based applications (such as mouse simulation and drowsiness detection on the basis of the blink) to be successful, eye-blink detection should be robust and non-intrusive.

Several EBD methods have been proposed in recent years. The existing methods can be roughly classified into two categories: contour template based and appearance based methods. The first class of methods can usually extract eye contours accurately. However, different templates should be involved for the closed and open eyes separately. These methods are also sensitive to illumination changes. In appearance based methods, image patches of open-eyes and closed-eyes are collected as positive and negative samples for a classifier to learn, but it is complicated to extract eye contours accurately.

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This paper presents a method that uses a regular common low resolution webcam. It requires no offline training and there is no dependence on locating specific eye features. Instead, it is based on general appearance of eye. This method is very fast, has a low computational cost and can detect blink in variable lighting conditions.

The organization of the rest of this paper is as follows. Section 2 talks about related work. Section 3 presents the proposed algorithm. Section 4 presents the experimental results and the conclusion comes in Section 5.

II. RELATED WORKS

Although blink detection using head-mounted hardware are more accurate than remote eye-blink detection from video images, remote detection has several advantages such as ease of use, non-invasiveness and much lower cost. We need a system that can remotely detect blinks under varying light condition without additional hardware like infrared lamps. This system must be capable of operating using low resolution cameras under typical indoor environments. There are several eye tracking systems that can track eyes under these conditions but most of those are unsuitable for detecting eye blinks. Some of these methods are as follows.

Morris et al. [16] introduced a real time blink detection algorithm based on the calculation of variance map and analysis of eye corners. The precision of this method is about 95% TP, but its limitation is its high sensitivity to head movement and, the performance of the blink detection was greatly degraded by the face movements.

Sirohey et al. [17] proposed an EBD algorithm by localizing eye features and analyzing their movements. It uses normal flow to estimate the motion information. They simulated head motion by using an affine model. It used head motion to separate eye and head movements. This algorithm can track iris and eyelid movements with more than 90% accuracy, but suitable for off-line applications. In a later paper [18] they used a deterministic finite state machine (DFSM) with three states to detect eye blinks.

Chau and Betke [19] proposed an EBD algorithm with overall precision more than 95%. Their method used correlation with an open eye template and operated in real-time. It can be automatically adapted with large head movements. The drawback of this method is that it detects open and closed states of eye but, it is incapable of distinguishing between these states.

Pan et al. [20] described a real time method to detect the degree of eye closure. It used a boosted classifier and models changing of eye states by Hidden Markov Model (HMM). It worked well with common low resolution webcams and provided more than 96% accuracy. This method suffers from non-standard eye motion (such as partial blinks) because it employs examples of typical eye motion in training.

Orozco et al. [21] described a system that used two appearance-based trackers, one for iris tracking and other to

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detect eyelids and blinking. This system is based on a simple appearance model and can operate in real time using low resolution camera images. Although, the accuracy of this method in iris tracking and detecting eyelids is reasonable, its performance in EBD is unacceptable.

In most of the described methods, their overall performance is greatly variable with respect to the accuracy of feature localization because they detect blinks by localizing eye parts. If we use low quality webcam images as input, achieving good accuracy is difficult. Additionally, real-time limitation prevents us from using sophisticated eye localization techniques.

III. PROPOSED METHOD

This section presents an adaptive EBD algorithm that can detect blinks accurately using low resolution webcams with very low computational cost under variable lighting conditions. The first step in analyzing the blinking of the user is to locate the eyes. To accomplish this, we suppose that a large face image is available. Each frame of the input video is processed and the location of eye is found. Fig. 1 shows the block diagram of the method. The first block captures an RGB color image and the second block detects or tracks the face region of the input image. The third block localizes the eye regions in the predetermined region of the detected face area. Step 4 calculates a value to determine the state of the eye and then by analyzing it, we can detect eye blinks.

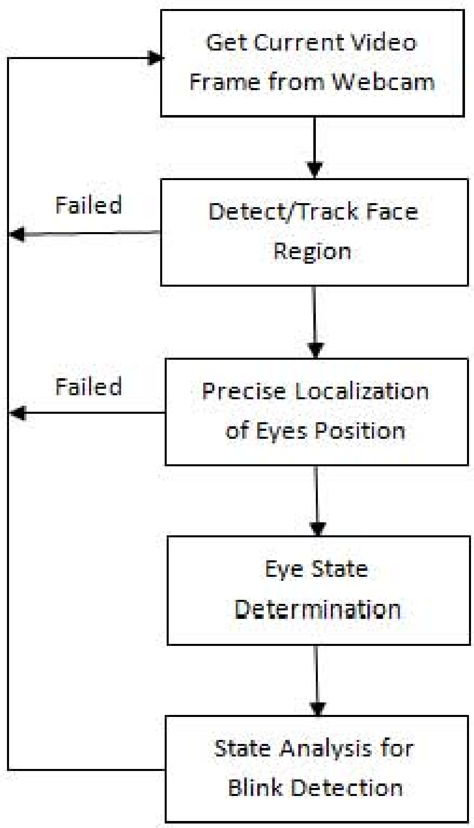

Fig. 1.Block diagram of the proposed method

A. *Detecting face and eye regions*

In our method, we suppose that eye image is localized in the current frame. Our method detects blink in real time. In our experiments, we use the AdaBoost algorithm [22] to detect face and eye regions. Each frame of the input video is processed by 3 different AdaBoost classifiers to detect the location of user's face and the left and right eyes. We use a set of simple geometrical constraints to verify the detected regions. Sometimes the user turns his/her face without placing it in the frontal position. In this case, the classifier fails to detect the location of the face. In such situations, we can use the Camshift algorithm [23] in face tracking.

B. *Blink detection*

The first step in EBD is to determine the eye state. To accomplish this, we use a value, 'τ', which can help us to determine the main states of the eye, open or close, and all the intermediate states such as partial blinks, squints, etc. 'τ' is calculated by using the following steps:

1. Take an eye image.
2. Extract its red channel (Instead of grey scale).
3. Apply a smoothing median filter.
4. Compute the cumulative histogram 'H' of the filtered image. The cumulative histogram can be found by integrating the histogram of each of the ROI by using (1):
   $H(L) = \sum_{r=0}^{L} h(r)$ (1)
   Where $h(r)$ is the histogram representing the probability of occurrence of intensity level 'r' and $0<r<255$.
5. $\tau = \tau_{max}$ that $H(\tau_{max}) \leq 0.03$
6. $$\begin{cases} \nabla\tau = \tau(n) - \tau(n-1) \\ \nabla\tau_{mag} = |\nabla\tau| \\ \nabla\tau_{sign} = Sgn(\nabla\tau) \end{cases} \quad (2)$$

Where 'n' is video frame number and 'Sgn' is Sign function. $\nabla\tau_{mag}$ and $\nabla\tau_{sign}$ are respectively magnitude and direction of 'τ' variation respect to the previous video frame. Figure 2 shows an example of 'τ' and '$\nabla\tau$' graphs for a participant left eye that includes slow blinks. The final graph is produced by multiplying the left and right eye ('τ' and 'τ_{LR}'). In the graphs of '$\nabla\tau$' and '$\nabla\tau_{LR}$', we can see that there are some peak values. These peak values appear in the frames in which the subject changes his/her left eye state. Therefore, we can use '$\nabla\tau$' to classify the state of the eye.

We produce a deterministic finite state machine (DFSM) to determine blink parameters. Our DFSM has four states: Open, Closing, Closed and Opening. This machine enables the detection of blink and allows most of the variations in the eye movement, like holding eyes closed or opened for a period of time. Transitions between states are based on two parameters: $\nabla\tau_{mag}$ and $\nabla\tau_{sign}$. Figure 3 shows the structure of the DFSM. To move from a steady state, $\nabla\tau_{mag}$ must exceed a certain State-Change threshold T_{SC}.

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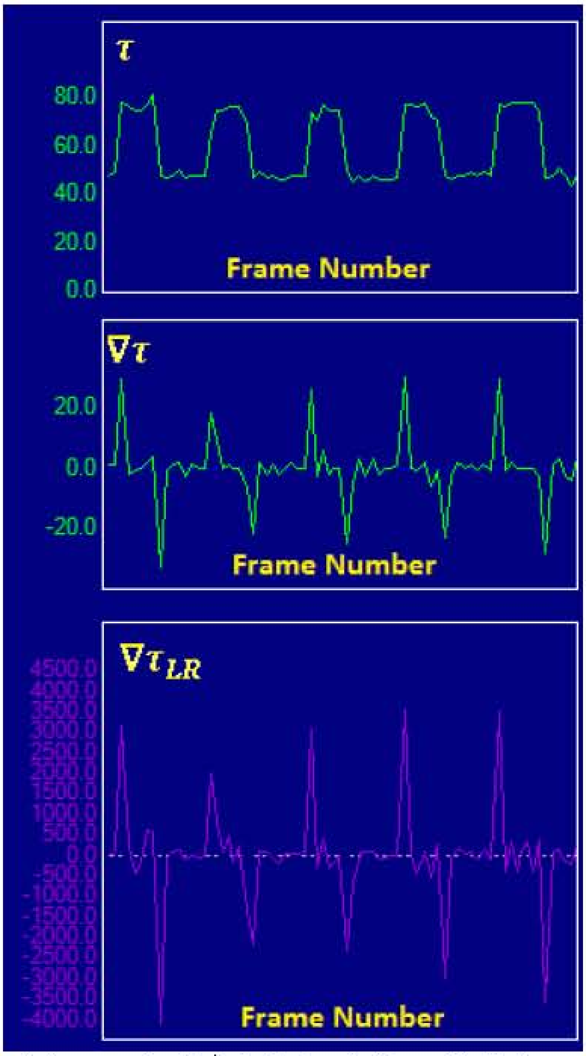

Fig. 2. An example of 'τ' and '∇τ' graphs for a subject left eye

Although such DFSM can detect eye states, these states are often unreliable because of noise. In some cases, the DFSM can make incorrect transitions between states. To estimate those states, an additional pre-processing step is added that analyses the state transitions and removes spurious "blinks". We can also use this pre-processing step to estimate other types of eye movement besides blinking.

Figure 4 shows the diagram of DFSM and estimated T_{SC} value for a simple video sequence with one slow blink.

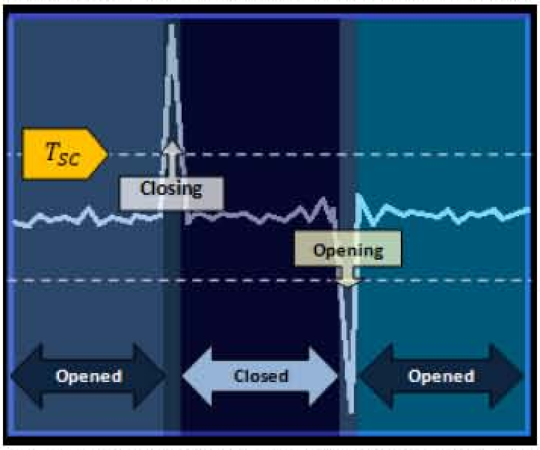

Fig. 4. An example of '∇τ' with marked threshold and DFSM states

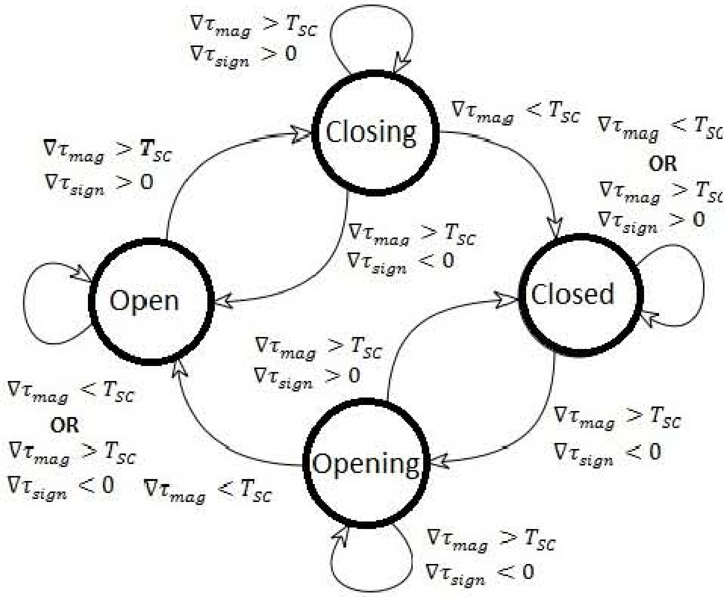

Fig. 3. Structure of our discrete finite state machine for identification of eye-blinks

IV EXPERIMENTAL RESULTS

The hardware setup we used in our approach was a webcam connected to a laptop. We use inexpensive hardware to evaluate that the prototype system can work with low cost components and is therefore affordable and could function well with any other systems.

Experimental results were obtained using Microsoft LifeCam VX-700 with resolution of 800 * 600, and a Dell Inspiron 6400 2.0GHz Centrino Dual Core with 2GB RAM laptop. The proposed approach was implemented in Microsoft Visual C#.net using "EMGU.CV"library for image processing. While preliminary tests have shown that the proposed approach works well in the any environment, all results reported here have been obtained indoor without lighting control.

Table 1 shows the average execution time of each part for a single frame using our unoptimized C#.net program. Table 1 shows that about 99% of the total execution time is spent for face and eye localization. The EBD is very fast and its execution time is less than 0.1 ms.

TABLE I
AVERAGE EXECUTION TIME OF EACH PART OF OUR METHOD FOR A SINGLE FRAME

Algorithm Parts	Time(ms)
Face detection (Using Haar Cascade Classifier)	27.91
Face tracking (Using Camshift)	14.47
Left eye detection (Using Haar Cascade Classifier)	30.20
Left Eye tracking (Using Haar Cascade Classifier and some simple geometrical constraints)	16.83
'τ' Calculation	0.073
Eye State Analysis	< 0.001
total average execution (Face & Eye Tracking + Blink Detection)	30.3

Another experiment was performed with a total of 17 participants (14 males and 3 females). Test subjects had various ages and some were individuals wearing glasses. The participants were sitting approximately 70 cm away from the camera. Our application captures 5000 frames from every subject and processes these frames in real time. Table 2 shows the results.

The detection accuracy and the overall detection accuracy is calculated using (3) and (4), respectively.

$$Detection\ Accuracy = \frac{TP}{TP+FN} * 100\% \qquad (3)$$

$$Overall\ Accuracy = \frac{TP+TN}{TP+FP+FN+TN} * 100\% \qquad (4)$$

The experimental results show that the proposed method has 94.45% detection accuracy with overall accuracy of 99.84%. From the experiments, two situations occasionally decrease accuracy of our EBD algorithm. The first one is the result of swift movement of user's head (Fig 5.a). In this situation, our algorithm is unable to correctly determine eye blink states. This is because eye images are blurry such that skin colors blend with the colors of the eye areas. The second situation is when the user bows his/her head or changes the eye focus to the lower area (with respect to the camera position) so eyelids are captured partially closed (Fig 5.b).

The performance of the present method is compared with some recent methods and results are presented in Table 3. Table 3 shows that the accuracy of our method is higher than other methods and the proposed method is much faster.

V. Conclusions

This paper presented a simple real time EBD algorithm that detected blinks accurately with very low computational cost in real time. The proposed method consists of these steps: The first step is detecting or tracking the face region in captured frame. The second step is localizing the eye regions in the predetermined region of the detected face area. In next Step, we calculate a value to determine the eye state and then by analyzing it, eye blinks are detected. The proposed approach improved both detection time and accuracy in comparison with most blink detection methods.

(a) (b)

Fig. 5. Some detection failed situations (a) eye images are blurry such that skin colors blend with the colors of the eye areas (b) user bows his head and changes the eye focus to the lower area

TABLE II
BLINK DETECTION ACCURACY OF OUR METHOD

Subject ID	Blinks: Total Blinks	Blinks: Detected as Blink (TP)	Blinks: Detected as Not Blink (FN)	Not Blink: Detected as Blink (FP)	Not Blink: Detected as Not Blink (TN)	Detection Accuracy	Overall Accuracy
1	88	85	3	6	4906	96.59%	99.82%
2	92	86	6	2	4906	93.47%	99.84%
3	90	89	1	3	4908	98.88%	99.92%
4	52	47	5	1	4947	90.38%	99.88%
5	86	83	3	9	4905	96.51%	99.76%
6	87	79	8	2	4901	90.80%	99.79%
7	63	50	13	6	4931	79.36%	99.62%
8	94	89	5	0	4906	94.68%	99.9%
9	82	78	4	3	4915	95.12%	99.86%
10	93	93	0	4	4903	100.0%	99.92%
11	106	103	3	1	4893	97.16%	99.92%
12	79	72	7	2	4919	91.13%	99.82%
13	95	94	1	1	4904	98.94%	99.96%
14	49	43	6	1	4950	87.75%	99.86%
15	68	59	9	0	4932	86.76%	99.82%
16	100	99	1	7	4893	99.00%	99.84%
17	100	96	4	3	4897	96.00%	99.86%
Total	**1424**	**1345**	**79**	**51**	**83516**	**94.45%**	**99.84%**

TP: Number of frames with correctly detected eye blinks (true positive)
FN: Number of frames that show eye blinks but the program did not detect (false negative)
FP: Number of frames that are reported as eye blinks but are not (false positive)
TN: Number of frames that are correctly reported as no blinks (true negative).

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TABLE III
COMPARISON OF SOME BLINK DETECTION METHODS WITH PROPOSED ALGORITHM

Method	Overall accuracy (average)	Time (ms) Face/Eye Detection Time (ms)	Time (ms) Blink Analysis Time (ms)	Description
[24]	90.25%	[33.3 – 50]		• with resolution of 320 x 240 and 30 frames per second • program runs in real-time, at approximately 20 - 30 frames per second • Tested on ZJU and "Talking Face Video" databases • Face and eye detection accuracy : 98.4%
[25]	91.8%	Not included	> 5ms (We test template matching for left eye)	• 2.16 GHz Intel Core 2 processor with 2 gigabytes of RAM. • Total of 20 subjects (13 males and 7 females). • 640480 resolution camera • **Eye state classification accuracy:** 96:6% was obtained with the template matching technique
[26]	92.038%	Not included		• 44 images used for training • The model was evaluated using a set of 200 consumer pictures • Average face tracking accuracy of 91.5%
[27]	92.6%	>30 (we use 14.47ms for camshift algorithm)	1.14	• algorithm in C++ by using Bloodshed Dev-C++ 4.9.9.2 as a compiler, and OpenCV • Dell Inspiron notebook with Intel(R) Core(TM)2 Duo CPU T7250 at 2.00 GHz and 2.00 GB RAM • webcam with the resolution at 320×240 (2.0 Megapixel) • overall detection accuracy is 99.6%
[28]	94.2 %	20	15	• Unoptimized C++ program • Intel Core 2 Duo, 2.66 GHz, 2 GB RAM • Tested on some personal video and ZJU database
ours	**94.45%**	**[30-31]**	**<0.074**	• Dell Inspiron 6400 2.0GHz Centrino Dual Core with 2GB RAM. • Webcam:Microsoft LifeCam VX-700 with resolution of 800 * 600 • experiment was performed with a total of 17 participants (14 males and 3 females) and 5000 frames from every subject • overall detection accuracy is 99.84%

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